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COST ASSESSMENT OF THE BRAZILIAN CONSTRUCTION AND DEMOLITION WASTE RECYCLING PLANT: A CASE STUDY OF PORTO ALEGRE

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Abstract

The construction activities generate representative amount of Construction and Demolition Waste (CDW) around the world. Brazilian City Halls collected about 45 million tons/year. CDW recycling plants needs to be economically viable. The characteristics of recycling plants and future expectations vary around the world. Thus, the cost analysis needs to be adapted to the local reality and future scenarios should be evaluated. In this context, the objective of this paper is to evaluate the CDW recycling plant costs in Brazil. Two scenarios are tested, actual Scenario (1) and future Scenario (2), with air jig. Four steps are performed: literature review, inventory of the inputs, economic indicators analysis, and sensitivity analysis of alternative solutions. The results suggest that both scenarios do not reach positive economic indicators (IRR, NPV and Payback). The Fixed Costs are the main influence on the results, mainly due to the acquisition of Equipment. The Variable Costs represent, in Scenario 1 and 2, 18% and 10% of their Total Fixed Costs, respectively. Scenario 1, however, has possible conversion into positive IRR easier than for Scenario 2, once the Air Jig influence significantly in the increment of costs. A Government subsidy tested would not make the CDW Recycling Scenarios economically attractive. Only Scenario 1 can achieve positive results, however without the acquisition costs of Land, Equipment and Vehicles. Counterparts with the City Hall, in exchange for the supply of these inputs, would not influence the positive results. The use of new technologies maybe will be possible after the recycled aggregate market is consolidated in Brazil.

Keywords: *cost analysis, CDW recycling plant, brazilian construction and demolition waste, waste management.*

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Introduction

The construction activities are responsible for one of the most representative waste around the world, the Construction and Demolition Waste (CDW). Brazilian municipalities collected about 45 million tons of CDW discarded by the population in 2017 (ABRELPE, 2018). This is more than 25 of the 28 European Commission members, which generate less than 10 million tons per year (European Commission, 2017). As can be seen, make CDW recycling economically attractive and technically feasible reuse in Brazil is an urgent need.

The implementation of CDW recycling plants in many countries is a reality, result mainly from environmental public policies, however, economic viability is a key factor for the interest in this kind of project. Martinez-Sanchez *et al.* (2015) describes a lack of clear methodology with cost calculation principles, detailed assessment focus and transparency for subsequent applicability. The divergence in methodology applied in the costs of CDW recycling induces the diversity of inputs that represent the most critical points of this activity. For Huang *et al.* (2002), Chaves (2015), Duran *et al.* (2006), Galán *et al.* (2013) and Wang et al (2004), Equipment costs are the most significant. In other works, with the same objective, Land Acquisition and Civil Construction costs are among the most significant (Corrêa et. al, 2009, Fonseca and Ribeiro Junior, 2018, and Kuhn et. al, 2017). Mah *et al.* (2018), however, highlights transport-related costs, which is more latent in scenarios where reuse of the recycled aggregate is predicted to produce recycled concrete aggregate (RCA).

The limits of cost evaluation, however, must be previously defined. A consensus has been defined in recent years, that the cost evaluation needed to evolve from the traditional linear approach, from the beginning to the end of the process, extending the boundaries of this system, being treated similarly to Life Cycle Assessment (LCA). The application of Life Cycle Cost does not have specific norms, such as the environmental analysis, however, can be expanded to the boundaries of the LCA. Hackenhaar *et al.* (2019) proposed the boundary of the system for the LCA of the production of Brazilian recycled aggregate. The border of this study adopted limits the transporting evaluation of the aggregate generation site, operation, and the transportation to place of use.

The characteristics of recycling plants vary around the world, a result of local reality, availability and demand, characteristic of the original CDW. These different characteristics directly influence the productive capacity of the recycling plant, emphasized by Liu *et al.* (2019) as of fundamental importance in economic analysis. The Brazilian National Sanitation Information System (SNIS) shows that only 9% of recycling plants with a production capacity upper than 10,000 m^3/month. These data allow inferring about the probable failure of recycling plants if projected for productions over that capacity.

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Overall, the extensive literature analysis showed the most widely used Life Cycle Cost (LCC) equation was NPV, IRR, and Payback (Miah et. al 2018). In this sense, some authors agree with the following results, as Payback time between 3 and 11.2 years (Huang *et al.*, 2002, Di Maria *et al.*, 2018, and Neto *et al.*, 2017) and the Minimum Attractive Rate of Return (MARR) of CDW recycling projects, that according to Petter (2015) and Doan (2016) the value considered should be about 12%.

This low production capacity of most CDW recycling plants suggests a market still unstable for recycled aggregates in Brazil, maybe result of stagnant technology applied just identified in 2009 for Miranda *et al.* (2009): loader or backhoe, vibrator feeder, conveyor belt, jaw crusher or impact, permanent magnetic separator or electromagnet, and vibrating screen.

The improvement of the quality of the aggregate, by the concentration of the CDW concrete fraction, and consequent expansion of its reuse possibilities could help in its affirmation as a product. Cazacliu *et al.* (2014), Sampaio et al (2016) and Ambrós *et al.* (2016) has increased efforts to the use of mining equipment in improving quality of CDW aggregates. The use of air jig, for example, favors the concentration of the concrete fraction of CDW and consequently allows to elaborate concrete with better results of resistance to compression when compared to the production with mixed aggregates.

In this sense, the objective of this paper is to evaluate the CDW recycling plant costs in Brazil. Two scenarios are tested, actual Scenario (1) and a future Scenario (2) applying Air Jig to achieve better quality recycled aggregates. In the end, it is intended to identify alternative ways to achieve more economically attractive results, according to the availability of resources, technology and tools applied in Brazil.

Research methodology

To achieve the objective of this paper, it is necessary to perform 4 steps, as follows: identification of studies related to cost analysis on CDW recycling, inventory of the inputs for the cost analysis, definition of economic indicators to be applied, and the realization of sensitivity analysis of some inputs and/or alternative solutions to make more attractive the CDW Brazilian recycling plants.

Identification of studies

In order to obtain the most current literature on the cost approach in CDW recycling plant and identify the main inputs that make up this, the following procedure was performed:

- Initially, a systematic review is realized. The identification of studies in scientific journals was undertaken by a systematic search in Science Direct and Springer platforms. The general word source on title, abstract or author-specified keywords were ‘‘cost", “construction”, “demolition”, "waste" and "management". A

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screening of the literature was made evaluating if the cost analysis were applied and if CDW were the reference on the study,
- In this systematic review, only literature reported in English was included in the review scope and only Research Articles were selected,
- In a complementary manner, a non-systematic search was applied to identify additional studies. In this sense, PhD thesis and papers that address costs on CDW Brazilian have been considered. This literature corresponds to scientific studies available on the worldwide internet search network,
- The non-systematic search adopts as search words the same ones used in systematic review, however being applied in the Portuguese language. The non-systematic review is considered finished when the inputs identified for each article evaluated do not differ more from the previous ones.

Inventory inputs to the cost analysis
The first source of inputs to be applied in the cost analysis comes from systematic and non-systematic reviews. Inputs are also obtained from the recycling plant of CDW in the city of Porto Alegre, Brazil (Figure 1), object of the case study of this paper.

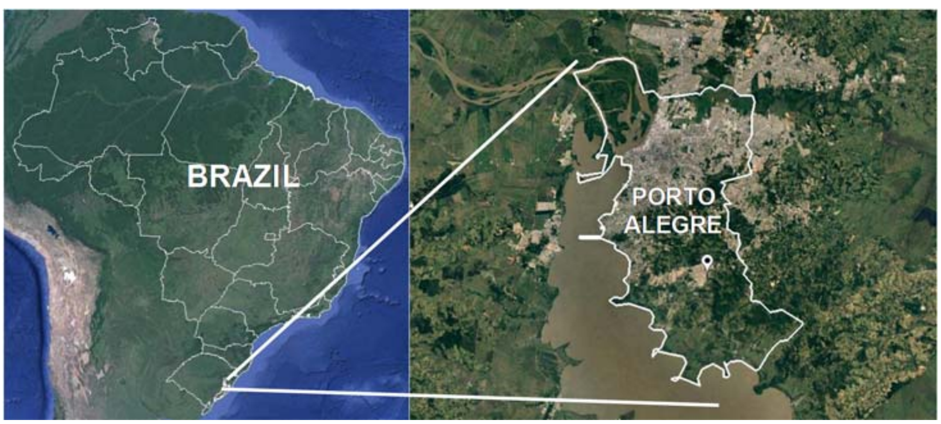

Figure 1. Location of the city of Porto Alegre, object of the case study of this paper.

The values adopted for each input are defined based on the information provided by the recycling plant and, in its unavailability, data obtained in the literature. Data consulted in the literature with divergent results among authors undergo selection criteria, with prioritized data with the following assumptions:
- Measured data are preferable to estimates,
- Data from an average of recycling plants are comparable to data obtained from only one plant,

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- More recent data are adopted rather than data obtained over a longer period of time,
- Data from Brazil are preferable to data obtained in other countries,
- Data of technology equal to that adopted are preferable to the technology analogous or different from that available at the study site.

Still, for the evaluation of costs, it is necessary to define some premises. These assumptions relate, for example, to the number of employees, transportation distances and the number of vehicles, equipment to be adopted in the recycling plant, among others. Some of the data adopted in this work were obtained from a local recycling plant. Data not provided by the enterprise were arbitrated based on the characteristics of the enterprise and the other Brazilian recycling pants equivalents. The assumptions adopted are presented in Table 1.

Table 1. The assumptions adopted for data not provided.

Infrastructure:	Recycling plant:
0.5 ha total area,	10,085 ton/month,
450 m² civil construction,	6 waste skips,
20-year lifespan of project.	1 crusher,
Employees:	1 vibration screen,
2 plant operations,	3 conveyor belts *(plus 1 conveyor belt on Scenario 2)*,
1 manager,	1 magnetic separator,
1 sale,	1 Air Jig *(only on Scenario 2)*,
2 truckers.	20 years lifespan.
Transport:	Production:
Generator to recycling plant: 30 km,	58.5% coarse aggregates *(only on Scenario 1)*,
Recycling plant to site:15 km,	39% coarse aggregates *(only on Scenario 2)*,
Recycling plant to landfill (refuse): 12.5 km.	19.5% Coarse concrete concentrate *(only on Scenario 2)*,
Vehicles:	41% fine aggregates,
2 trucks,	0.49% other recyclable waste,
1 backhoe	0.01% refuse.
10 years lifespan.	

Methods of cost analysis

Financial analysis is, typically, used to analyze whether a project is stable, solvent, liquid or profitable enough to warrant a monetary investment. For this, it is necessary to apply methods to identify the cash flows as Net Present Value (NPV), one of the most frequently used dynamic method. NPV is a method of bringing all cash flows from an investment project to the date zero and adding them to the value of the initial investment, using as a discount rate the company's Minimum Attractive Rate of Return (MARR). The definition of the NPV is performed according to the following equation:

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$$NPV = \sum_{0}^{n} \frac{NCF_t}{(1+i)^t}$$

With:
NPV – Net Present Value,
NCFt – Net cash flow at time t (i.e. cash inflow-cash outflow),
t- Time of the cash flow,
i – Discount rate,
N- Number of periods (years).

In order to have positive NPV it is necessary that the Internal Rate of Return (IRR) is higher than the MARR of the project. In this sense, the IRR analysis is performed, supporting later identifications of possible alternative solutions in the search for more satisfactory results of the financial indicators. The IRR analysis is performed according to the following Equation 1:

$$IRR = \sum_{t-1}^{t} NPV = \frac{NCF_t}{(1+i)^t} - C_0 = 0$$

Equation (1)

With:
Co – Total Initial investment

The Payback period is the length of time required to recover the cost of the investment. Payback is a risk assessment criterion, in this sense its period analysis is particularly useful in sector where investments depreciate quickly, and where a full return of the initial investment is a serious concern (Neto et. al, 2017). Thus, more attractive projects with recovery of capital invested in less time. The Payback analysis is performed according to the following Equation 2:

$$Payback = (last\ year\ with\ negative\ NCF) + \left(\frac{Absolute\ Value\ of\ NCF\ in\ that\ year}{Total\ cash\ flow\ in\ the\ following\ year}\right)$$

Equation (2)

<u>Assessment of sensitivity and alternative solutions to cost analysis inputs</u>

Carried out the cost analysis of current scenarios and using the Air Jig alternative solutions for some of the inputs are tested, verifying the sensitivity of the results to these changes. The analysis of these alternative solutions is preceded by the presentation of new results on economic indicators and discussion of application potential feasibility in Brazil.

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Results

Literature review

Initially, 144 research articles were identified on the Elsevier platform and 167 articles on the Springer platform. Of this total 19 refer to research articles on CDW has as one focus the evaluation of costs in the recycling process or management. Only 12 articles were able to provide input data: Huang et al (2002), Zhao *et al.* (2004), Wang et al (2004), Duran *et al.* (2006), Coronado *et al.* (2011), Galán *et al.* (2013), Abdelhmid (2014), Dahlbo *et al.* (2015), Di Maria *et al.* (2018), Liu *et al.* (2019), Mah *et al.* (2018) and Queheille *et al.* (2019).

About the main inputs identified the transportation of the residues should be highlighted, whether from the origin to recycling plant or from plant to site of use, and the costs related to disposal of waste in the landfill. The costs of maintenance machines and equipment, in addition to costs related to the workers of the recycling plant, are also highlighted in some works identified by literature review.

Additional literature consulted by non-systematic review suggest more inputs. Nine new literature on CDW management were identified, which are specific to Brazil. The non-systematic research was considered finished when the identification of new inputs in the composition of the cost evaluation was considered exhausted.
Figure 2 illustrates the contribution of systematic and non-systematic reviews to the identification of inputs from cost evaluation. The graph demonstrates the increase in inputs considered in papers on costs analysis of CDW recycling in Brazil. The order of graphic presentation follows the number of new activities identified for each job. The stability of the graph suggests that the inputs proposed in available scientific papers on the subject have been exhausted.

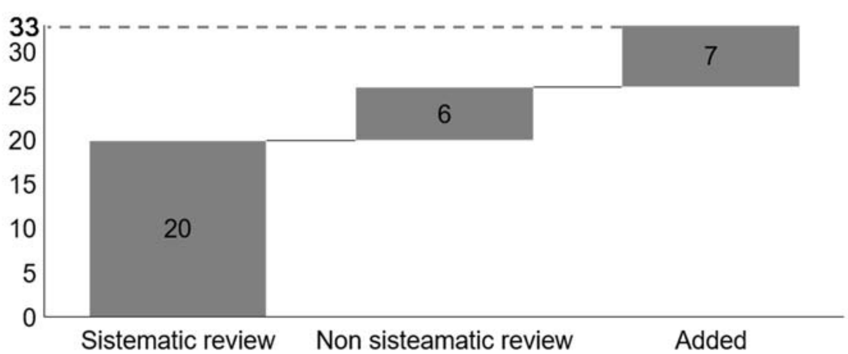

Figure 2. Contribution of additional literature consulted in a non-systematic way.

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The non-systematic review identifies another eight (8) papers: Jandovski and Masuero (2004), Paiva *et al.* (2012), Manfrinato *et al.* (2008), Corrêa *et al.* (2009), Chaves (2015), Gomes *et al.* (2015), Kuhn *et al.* (2017) and Fonseca e Ribeiro Júnior (2018). These authors contribute to an increase in the number inputs to be used in the cost evaluation of CDW recycling, such as the Contingency forecast and the Rates, previously unidentified.

The greater registration by the authors from non-systematic review of the inputs Energy, Equipment Acquisition and Construction. In this way, it is possible to infer that these are the most critical items in evaluation of costs in the Brazilian CDW management. The costs associated with Maintenance are highlighted in studies from other countries, and thus also considered a critical input. Figure 3 illustrates the inputs defined from each literature accessed.

Authors Inputs	Abdelhmid (2014)	Begum et. al (2006)	Chaves (2015)	Coronado et. al (2011)	Corrêa et. al (2009)	Cursino et. al (2009)	Dahlbo et. al (2015)	Di Maria et. al (2018)	Duran et. al (2006)	Fonseca e Ribeiro Júnior (2018)	Galan et. al (2013)	Gan and Cheng (2015)	Gomes et. al (2015)	He et. al (2018)	Huang et. al (2002)	Jandovski and masuero (2004)	Kuhn et. al (2017)	Liu et. al (2019a)	Liu et. al (2019b)	Mah et. al (2018)	Manfrinato et. al (2008)	Marzouk and Azab (2014)	Paiva et. al (2012)	Petter (2015)	Queheille et. al (2019)	Sobotka e Sagan (2016)	Wang et. al (2004)	Yuan et. al (2011)	Zhao et. al (2011)
Administration	X									X			X			X					X								
Civil Construction			X			X				X					X	X	X				X			X					
Company regullation						X																							
Contingency																	X												
Depreciation			X										X																
Diesel								X		X													X						
Electricity						X		X	X	X			X		X	X	X				X		X						
Environmental regulation	X																X												
Equipment (plant)	X		X			X			X	X			X		X	X	X				X			X			X		
Governmental subsidy															X														
Land acquisition			X			X			X	X						X	X												
Landscaping										X						X	X							X					
Maintenance of equipment			X			X			X	X					X	X					X		X						
Maintenance of vehicles			X			X			X	X					X	X					X		X						
Maintenance of infrastructure																X													
Payment/ Labors	X							X	X						X					X					X		X		
Plant Installation											X													X	X				
Project																	X												
Sale recyclable waste							X								X														
Taxes																X													
Tipping fee (landfill)				X					X		X				X												X		X
Training	X																												
Transport to landfill (refuse)	X			X				X	X		X							X							X		X		
Transport to utilization site	X			X				X	X		X							X							X		X		
Transport waste from deconstruction	X			X				X	X		X							X							X		X		
Vehicles						X										X	X												

Figure 3. List of inputs inventoried to the manufacturer of systematic and non-systematic literature on the cost evaluation of CDW recycling. In gray color the authors contributed with each input, highlighted in black.

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Two entries were created, with the nomenclature of "CDW reception, segregate" and "CDW reception, mix", to be able to differentiate the cost charged in Brazil by recycling plants to receive the CDW from the generator. "Marketing" was also added to the inputs identified in the literature. The recycled aggregates available for sale are divided into "Corse Aggregate", "Fine Aggregate" and “CDW concrete concentrated”.

Some data had split, such as the Taxes, suggested by Jadovski and Masuero (2004) which was divided into "Tax on revenue" and "Taxes social contribution". In the same way, Environmental Regulation was divided between the initial cost, "1st Environmental Regulation", and the maintenance costs of the environmental authorization in Brazil. The "Environmental regulation, maintenance" should be carried out, on average, every 4 years according to the characteristics of the project under study.

Cost of recycling CDW in the Brazilian scenario

Cost analysis requires the separation of inputs between Fixed Costs and Variable Costs. The Fixed Costs have their values inventoried for the entire useful life of the recycling plant, in this work estimated in 20 years. Variable costs have their inventoried values based on 1 month. The source of the data adopted in the cost evaluation of this paper is illustrated in Table 2.

Table 2. Inputs and source of the values adapted to the case study.

Input	Adopted from
Civil Construction	Kuhn *et al.* (2017), Jadovski and Masuero (2004) and Corrêa et. al (2009)
Equipments and Vehicles	Manufacters
Administration, Depreciation, Payment labors, Landscaping. Maintenance of Equipment and Vehicles, Maintenance of Infrastructure	Jadovski and Masuero (2004)
Land Acquisition	Market price
Installation plant	Galán *et al.* (2013)
1st Environmental Regulation and its maintenance	Local Environmental Protection Agency
Regulation of Company	Corrêa *et al.* (2009)
Contingency and Project	Kuhn *et al.* (2017)
Electricity (by equipment)	Di Maria *et al.* (2018)
US$/kwh	Regional supply company
Marketing, Social Contribution Taxes, Training labors, Fine aggregate* and CDW concrete concentrated*	Estimated
CDW reception mix, CDW reception, segregate, Other recyclable waste, Diesel, Tipping fee,	Data collected
Tax on revenue	According to activity
Transport from the source of the waste and Transport to the landfill	Petter (2015) and data collected

**estimated by preview studies*

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Fixed Costs are related to Construction, Equipment, Acquisition of land, Landscaping, Plant Installation, Vehicles, Regularization of the Company, Contingency, Project, and Depreciation. The values associated with the inputs of Scenarios 1 and 2 are shown in Table 3.

The Civil Construction, for Scenario 2, where the inclusion of Air Jig is foreseen, it is considered a 5%. The costs of the Equipment and Vehicles have a Depreciation estimated at 10%. The Land Acquisition is obtained from consultation of lands for sale, between 0.5 and 1 hectares in the same region of the local power plant where some inputs were obtained. Landscaping services have an estimated value corresponding to 5% of civil works. The installation of the plant increase by 5% in Scenario 2. The additional equipment provided for Scenario 2, Air Jig and Conveyor Belt, has their production capacities, energy consumption and costs obtained in Di Maria *et al.* (2018), according to Table 2.

Kuhn et. al (2017) suggests a Contingency value be kept as a reserve for eventual unforeseen and/or emergency situations. The initial design of the recycling plant is also obtained from Kuhn et. (2017) and for this, it is considered that the entry of Air Jig does not influence the project values, and the value already considered in Scenario 1 is maintained in Scenario 2.

Table 3. Values applied to Fixed Costs of Scenarios 1 and 2.

	Fixed Cost					
	Civil Construction[1]	Equipment[1]	Land Aquisition[1]	Landscaping[1]	Plant Installation[1]	Vehicles[1]
Scenario 1	88,082.90	244,082.90	129,533.68	4,404.15	68,000	156,151.81
Scenario 2	92,487.05	993,982.84	129,533.68	4,624.35	71,400	156,151.81
	1st Environmental regulation[1]	Company Regulation[1]	Contingency[1]	Project[1]	Depreciation[1]	
Scenario 1	1,266.00	518.13	6,735.75	10,362.69	40,023.47	
Scenario 2	1,266.00	518.13	6,735.75	10,362.69	115,013.47	

** Paid each 4 years, 1 – Inbound logistic, 2 – Operations, 3 – Outbound logistic, 4 – Marketing and sales, 5 – Service, 6 – Infrastructure, 7 – Human resource, 8 – Technology development, 9 – Procurement.*

Variable Costs consist a greater quantity of inputs (Table 4). The values related to “Environmental Regularization, Maintenance” were obtained from local environmental agency and paid each 4 years. The input of Government Subsidy is considered in the cost analysis, however currently in Brazil no value regulation is provided for this waste. The Social Contribution Taxes are obtained from average discount data in Brazil, of approximately 23% (reference June 2019) of workers costs. Training labors values were estimated on 0.5% of revenue. Similarly, no suggested input was available for Marketing activity. 0.5% of the revenues was adopted.

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"CDW reception mix" correspond 25% (2,713 ton/month). This material has a refuse fraction (0.01%, equal to 1.09 ton/month) that needs be sent to landfill. That being said are considered two Inputs, Tipping fee and the Transport to the landfill. The destination cost was obtained from the local inert landfill (US$ 2.81/ton). The transport to landfill considers the cost suggested by Petter (2015), of US$ 0.15/ton/km, and the transport distance of 12.5 km.

Table 4. Values applied to Variable Costs of Scenarios 1 and 2.

	Variable Cost (US$/mês)				
	Administration[6]	Environmental regulation, maintenance[6]	Governmental subsidy[5]	Marketing[4]	Payment labors[7]
Scenario 1	148.45	308.60*	0	859.68	7,596.40
Scenario 2	148.45	308.60*	0	897.56	7,596.40
	Training labors[7]	Tax on revenue[9]	Taxes social contribution[7]	Tipping fee[5]	Transport to landfill[3]
Scenario 1	859.68	44,015.69	1,747.17	3.05	2.04
Scenario 2	897.56	45,955.09	1,747.17	3.05	2.04
	Diesel[2]	Electricity[2]	Maintenance of equipments[2]	Maintenance of vehicles[2]	Maintenance of infrastructure[6]
Scenario 1	800.00	538.35	6,102.07	23.85	880.83
Scenario 2	800.00	1,018.29	24,849.57	23.85	924.87
	Transport aggregate to utilization site[3]	Transport waste from construction[1]	CDW reception mix[9]	CDW reception segregate[9]	Other recyclable waste[9]
Scenario 1	24,294.92	48,834.00	43,706.43	48,589.83	4.79
Scenario 2	24,294.92	48,834.00	43,706.43	48,589.83	4.79
	Coarse Aggregate[9]	CDW concrete concentraded[9]	Fine Agregate[9]		
Scenario 1	53,072.79	-	26,562.44		
Scenario 2	35,381.86	25,266.71	26,562.44		

** Paid each 4 years, 1 – Inbound logistic, 2 – Operations, 3 – Outbound logistic, 4 – Marketing and sales, 5 – Service, 6 – Infrastructure, 7 – Human resource, 8 – Technology development, 9 – Procurement.*

Data of diesel consumption was collected, corresponding to 800 l/month for the backhoe. The cost of diesel in Brazil considered in the study (reference, June 2019) is approximately US$ 1.00 per liter. The diesel costs of the trucks are considered in the inputs classified as "Transport ...". The electricity consumption considers 0.424kwh/ton, in Scenario 1, and 0,802 kwh/h, in Scenario 2. The kwh value of the regional supply company (reference, June 2019) is approximately US$ 0.117/kwh.

The Maintenance of the Equipment has the estimated cost of 2.5% of the capital invested in them. The Maintenance of Vehicles is equivalent to 0.0018 US$/km/vehicle. Considering the amount of 10,852 ton/month, 52 tons per trip, 2 vehicles and a plus 5% of this referring to the backhoe in

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the recycling plant. Costs of Maintenance of Infrastructure are estimated in 1% of the civil construction.

Monthly waste transportation from the generation site (10,852 tons) to the recycling plant considers an average distance of 30 km. The transport of recycled aggregate to site utilization refers the percentages of fine aggregate, coarse aggregate and concentrated in concrete aggregate. The latter only in Scenario 2, equivalent to 10,797.74 tons/month as an average distance of 15 km. Both transportations highlighted in this paragraph chosen the distance cost suggested by Petter (2015) of US$ 0.15/t/km.

Inputs related to the framework as acquisition are mostly composed of inputs created from the market, products and by-products exploited by local recycling plants. The values corresponding the payment of generator to allocate the CDW to the recycling plan were divided into 2 inputs, "CDW reception, mix" and "CDW reception, segregate".

The "CDW reception, mix" corresponds 25% (2.713 ton/month). The revenue from receiving this type of waste in the recycling plant US$ 16.11/ton. The "CDW reception, segregate" corresponds to the previously sorted waste and corresponds to 75% (8,139 tons). The revenue from receiving this type of waste is US$ 5.97/ton. Part of the material that characterizes the waste as mixed is sold by the recycling plant as "Other recyclable waste". As input collected, it corresponds to less than 0.5% (53.17 tons/month). Revenue from the sale of "Other recyclable waste" is US$ 0.09/ton.

After the CDW beneficiation, there is a production of Fine Aggregates and Coarse Aggregates, also with commercial value. The Fine Aggregate corresponds 41% (4,449.32 ton/month), in both scenarios, and is sold at US$ 5.97/ton. The Coarse Aggregate corresponds 58.5% (6,348.42 ton/month), in Scenario 1. In Scenario 2, 2/3 (4,232.28 ton/month) of the Coarse Aggregate benefited in Air Jig maintains characteristics of inferior quality, however, 1/3 (2,216.14 ton/month) presents better quality, denominated "CDW Concrete Concentrated".

The Coarse Aggregate has a market price of US$ 8.36/ton. The "CDW Concrete Concentrated", has an estimated revenue of US$ 11.94/ton, considered to be still competitive with the natural aggregate cost, based on SINAPI (Jun.19) of US$ 13.72/ ton. Revenue has discounted rates, defined as "Tax on revenue". The amount considered corresponds to the sum of PIS / COFINS 7.6% and IPI / ICMS (18%), with reference to June 2019.

Economic indicators analysis

Both scenarios evaluated do not reach positive IRR values. IRR values are close to -1%, in Scenario 1, and -10%, in Scenario 2. These results are next to obtained by Petter (2015), which found negative IRR scenarios, even though their data sources have not been filtered by the same

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selection criteria adopted in this paper. Likewise, the divergence between NPV and Payback values is significant. Compared to other studies Payback found (21.3 years) is much higher than the range suggested by Huang *et al.* (2002), Di Maria et. al (2018) and Neto *et al.* (2017), between 3 and 11.2 years. However, it is important to note that obtained results are from recycling plants in European and Asian countries.

Scenario 1 has a value closer to zero, which suggests a possibility of conversion into positive IRR easier than Scenario 2. Similarly, Payback, close to the expected economic life of the project, suggests that changes in input values may result in more attractive economic indicators. The economic indicators identified for the two Scenarios are presented in Table 5. The Fixed Costs are the main influence on the results and, as can be seen in Figure 4, they diverge significantly between Scenario 1 and Scenario 2.

Table 5. Economic indicators of the current Scenarios (1) and Future Scenario (2) CDW recycling.

Scenario	NPV (1.000 US$)	IRR (%)	Payback (years)
Scenario 1	- 486	- 0.59	21.30
Scenario 2	- 1.422	- 10.13	73.73

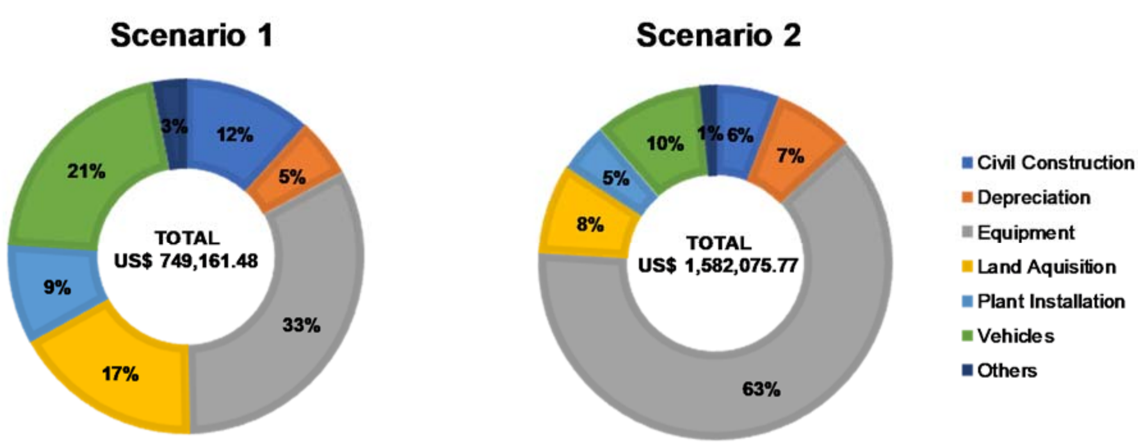

Figure 4. Participation of the main inputs in the analysis of Fixed Costs of CDW recycling under study.

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Important factor refers to the greater representativeness of costs to be related in equipment, corroborating with Huang *et al.* (2002), Chaves (2015), Duran *et al.* (2006), Galán *et al.* (2013) e Wang *et al.* (2004). The economic impact of the Equipment is evidenced when compared to the Fixed Costs of Scenario 1 and Scenario 2. Equipment costs in Scenario 1 represent slightly more than 32%, and in Scenario 2 it's almost 63%. The results corroborate with Neto *et al.* (2017), which has in the increase of productive capacity to reduce the participation of the costs with infrastructure.

The Air Jig, included in Scenario 2, is the main responsible for the improve of costs. The high costs of its acquisition mask even the participation of other inputs, such as the acquisition of Land, Vehicles and Civil Construction, which in Scenario 1 represent 17%, 21% and 12%, respectively. The total value of fixed costs has an increase in Scenario 2, compared to Scenario 1, has its value doubled, achieve about 53%.

The Variable Costs represent, in Scenario 1 and 2, 18% and 10% of their Total Fixed Costs, respectively. This superiority in Scenario 1 evidences the significant influence of the Air Jig acquisition on the Fixed Cost of Scenario 2 and, at the same time, a small influence on the Variable Costs.

Even so, the increase in Variable Costs, in Scenario 2, is just over 15%, in relation to Scenario 1. The Maintenance of the Equipment to represent 16% of the variable costs, 12% more than in Scenario 1. Thus, the transportation of CDW, one of the critical points in recycling according to Miah et. al (2018), to the recycling plant and from it to the reuse site has its contributions in Scenario 1 (of 36% and 18%) reduced in Scenario 2 (to 31% and 15%).

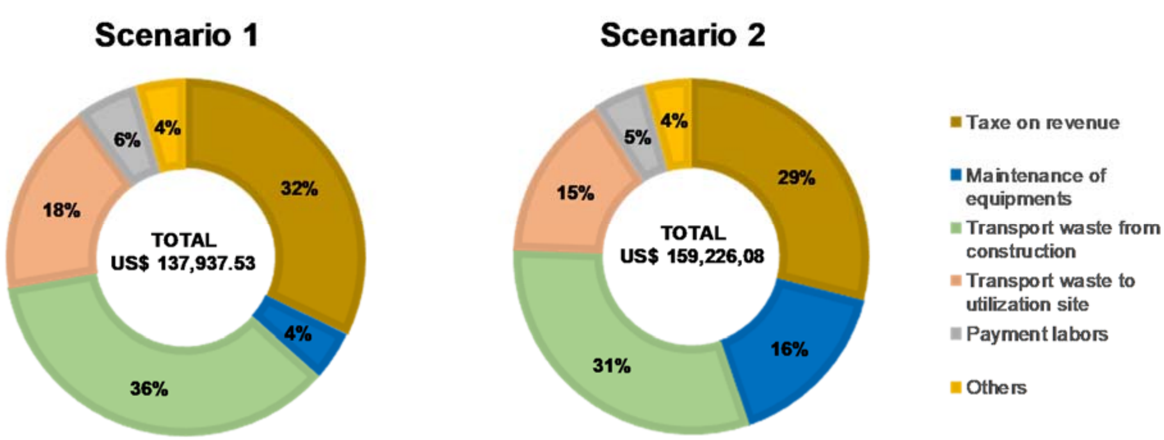

Figure 5. Participation of the main inputs in the analysis of Variable Costs of CDW recycling under study

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Alternative solutions to the feasibility of CDW recycling

The first two attempts to reach economic attractiveness of the project focuses on the amount charged for the receipt of the CDW and on the amount charged to sale recycled aggregates. The sensitivity of these values is tested, which are increased by 25%, 50%, 75% and 100%. The same percentages are applied on the rate of tax revenue, however, related to the reduction of "Tax on revenue" proportional to the percentages applied. The economic indicator adopted in this sensitivity analysis is the IRR. Graphs are shown in Figure 6 illustrates the IRR behavior from these percent variations.

The results suggest that only Scenario 1 would reach positive IRR values from the increased costs of receiving CDW and selling recycled aggregate or reducing rates of Tax revenue. However, in order to reach values close to the MARR suggested for this type of business (12%), reposting costs to customers could make recycled aggregates unattractive. Similarly, lower rates of Tax revenue should tend to zero to achieve better IRR results. Given the current lack of policy for this type of waste in Brazil, the emergence of regulation predicting such a significant amount of tax reduction would be very unlikely.

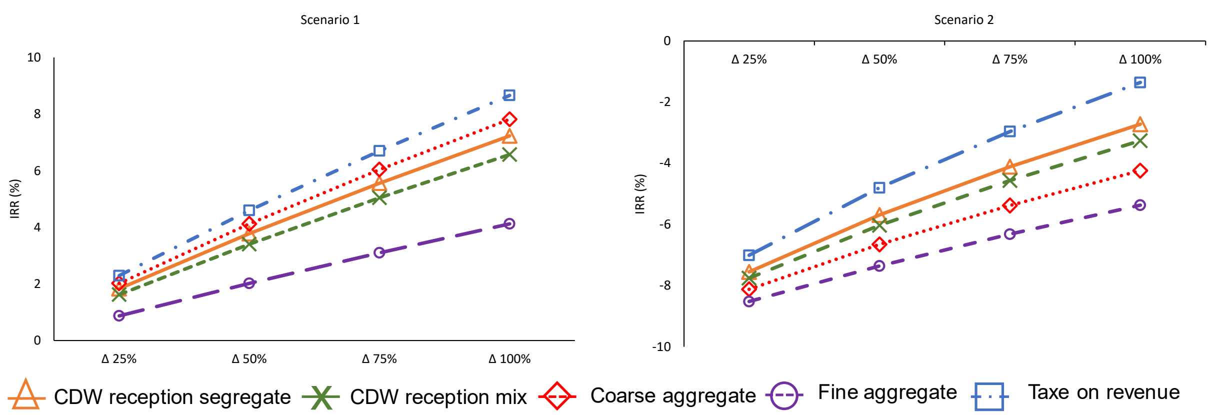

Figure 6. Sensitivity of the amounts charged for the receipt of CDW, sale of recycled aggregates and reduction of the interest rate on sales in Scenarios 1 and 2.

Thus, new efforts are made on others Variable Costs. Governmental subsidy and Energy consumption are evaluated, initially, in order to achieve results that present attractive financial indicators on the project. Other alternative solutions maybe can be found on Fixed Costs. These, however, basically refer to inputs without which there is no way to carry out the CDW recycling process, such as Equipment, Vehicles and Civil Construction. In this sense, it is difficult to reduce the associated costs or the number of Equipment, Vehicles or Civil Construction since these are the results of the expected production demand. Table 6 presents some possible alternative

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solutions for Scenarios 1 and 2. The use of Government Subsidy is evaluated, from the monetary receipt per ton received. The results suggest, however, that even considering a US$1/ton value for the estimated monthly total (10,852 tons) the economic indicators suggest a low attractiveness of the project, where only Scenario 1 reaching a positive IRR value (2.24%). This value, however, may not justify the investment, since the risk associated with CDW recycling activity requires a higher MARR. At the same time, this Scenario would have its Payback only from the 15th year, on a considered economic life horizon of 20 years considered.

Table 6. Evaluation of the sensitivity of economic indicators to alternative solutions in the cost analysis inputs of CDW recycling

Alternative solutions	VPL (1,000 US$)		IRR (%)		Payback (years)	
	Sc. 1	Sc. 2	Sc. 1	Sc. 2	Sc. 1	Sc. 2
Gov. Subsidy per ton. received (1 US$/ton.)	-399	-1334	2.24	-7.14	15.98	47.64
Exemption of energy consumption	-476	-1407	-0.23	-9.57	20.49	67.68
Exemption of acquisition of equipment	-236	-421	3.65	-2.48	14.02	26.31
Exemption of acquisition of vehicles	-323	-1259	1.93	-9.17	16.46	63.78
Exemption of acquisition of land	-346	-1280	1.55	-9.27	17.08	64.77
Exemption of acquisition of equipment, vehicles and land	87	-22	19.54	9.99	4.98	8.52
Exemption of acquisition of equipment, vehicles and land (with counterpart 25%)	27	-83	14.44	3.90	6.46	13.71
Exemption of acquisition of equipment, vehicles and land (with counterpart 50%)	-32	-144	8.89	-4.85	9.20	35.15

Sc. = Scenario

A second alternative solution is the exemption of energy consumption. This solution could result from the implementation of alternative energy source solution (without this being considered in fixed costs) or by the payment of the energy consumed by the recycling plant by the City Hall. This solution presents even fewer promising results, with IRR equal -0.23%, even in Scenario 1.

The following alternative solutions refer to Public-Private Partnerships (PPPs), a method that can be applied in Brazil, where, for example, the City Hall provides the infrastructure and the private initiative executes the service. These solutions are presented in a gradual way with the exemption of the acquisition of Equipment, Vehicles, Earth (including earthmoving), and the sum of these.
This analysis then includes a counterpart of the private initiative, being a compulsory part of the material received monthly originating from the City Hall. Thus, this fraction that represents the counterpart is destined to the recycling plant without cost.

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The results suggest that IRR values are attractive for both Scenarios only, from the availability of the Equipment, Vehicles and Land, even if Scenario 2 has IRR (9.99%) below the Minimum Attractive Rate of Return suggested for recycling of CDW (12%). Scenario 1 also maintains its attractiveness with the counterpart, restricting itself to a little more than 25% (IRR = 14.44%), as can be seen in Table 6. The counterpart of receipt 50% of the material coming from the City Hall, without costs, however, conducts the IRR value from business to just under 9%, with Payback of 9.2 years.

Final remarks

According to results, a Government subsidy, without other contributions on Fixed Costs, would not make the CDW Recycling Scenarios economically attractive.

The main critical points identified in the cost analysis show the maintenance of a common problem, even with studies in other countries, regarding the high costs of acquiring Vehicles and Equipment for the operation of the recycling plant.

Scenario 1 is more attractive, however requiring the availability of Equipment, Vehicles and Land. The use of a counterpart with the reception of CDW of the city hall without associated cost has, according to the MARR initially foreseen, attractiveness up to just over 25%. However, assuming the risks of the investment, the 50% counterpart could also be accepted.

Although the new technology, introduced in Scenario 2, increase concrete concentration in the recycled aggregate, in this way improving its quality and allow to produce concrete of greater resistance to compression, economically the process becomes impracticable.

The use of new technologies, like air jigue, only will be possible after the recycled aggregate market is consolidated in Brazil. Thus, there may be greater demand for higher quality recycled aggregates for more noble uses.

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