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ECOLOGICAL COSTS OF A MICROBREWERY IN THE BRAZILIAN NORTHEAST

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ABSTRACT

Objective: The aim of this study is to investigate the environmental and economic impacts of craft beer production in the Brazilian Northeast, to evidence the main hotspots and propose mitigation alternatives.

Theoretical Framework: Life Cycle Thinking proposes a way of thinking that aggregates systems and preserves their interrelationships, to understand the whole of production systems and identify critical points in their subsystems, processes and flows. Here, environmental analysis was carried out through Life Cycle Assessment and economic analysis through Life Cycle Cost Assessment and Ecological Costs.

Method: The methodology adopted for this research includes the use of Life Cycle Assessment to quantify environmental emissions, and Life Cycle Cost Assessment and Ecological Costs to quantify economic impacts in a microbrewery located in the Northeast of Brazil. Data was collected through interviews and questionnaires with those responsible for specific sectors of the brewery.

Results and Discussion: The results showed that the main environmental hotspot was the local and regional distribution of beer using a gasoline-powered light commercial vehicle. In terms of economics, beer packaged in stainless steel kegs had the lowest cost and beer in aluminum cans had the highest manufacturing cost. When environmental costs were taken into account, beer packaged in a PET growler obtained the best result and beer packaged in a stainless-steel keg obtained the worst economic result. With the implementation of electric vehicle distribution, in addition to the environmental benefits, there were also economic benefits, especially in terms of environmental costs (ecocosts).

Research Implications: The practical implications of this research have shown that the use of electric vehicles to distribute the final product (beer) can mitigate environmental emissions, bringing environmental and economic benefits to the company studied.

Originality/Value: This study contributes to the literature by being the first Brazilian study to quantify the environmental and economic impacts of craft beer production and distribution. The relevance and value of this research is evidenced by the fact that it proposes tangible solutions to the hotspots identified.

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Keywords: Life Cycle Assessment, LCA, Life Cycle Costing, LCC, Ecocosts, Electric Mobility

CUSTOS ECOLÓGICOS EM UMA MICROCERVEJARIA NO NORDESTE BRASILEIRO

RESUMO

Objetivo: O objetivo deste estudo é investigar os impactos ambientais e econômicos da produção de cerveja artesanal no Nordeste brasileiro, com o intuito de demonstrar os principais *hotspots* e propor alternativas de mitigação.

Referencial Teórico: O Pensamento do Ciclo de Vida propõe uma forma de pensar que agrega os sistemas e preserva as suas inter-relações, de maneira a compreender o todo dos sistemas produtivos e identificar os pontos críticos em seus subsistemas, processos e fluxos. Amienyo et al. (2016) analisaram os impactos ambientais e econômicos em cervejarias do Reino Unido através da avaliação de dois cenários: a nível de consumidor e nacional, utilizando a Avaliação de Ciclo de Vida e seguindo as normativas NBR 14040 e 14044.

Método: A metodologia adotada para esta pesquisa compreende a utilização da Avaliação do Ciclo de Vida para quantificação das emissões ambientais, e da Avaliação do Custo do Ciclo de Vida e os Custos Ecológicos para mensuração dos impactos econômicos em uma microcervejaria instalada no Nordeste brasileiro. A coleta de dados foi realizada por meio de entrevistas e questionários com os responsáveis por setores específicos da cervejaria.

Resultados e Discussão: Os resultados obtidos revelaram que o principal *hotspot* ambiental foi a distribuição local e regional da cerveja pelo uso de veículo comercial leve movido a gasolina. Na questão econômica a cerveja embalada em barril de aço inox obteve o menor custo e a cerveja em latas de alumínio o maior custo de fabricação. Quando atrelados os custos ambientais, a cerveja embalada em *growler* de PET obteve o melhor resultado e a cerveja embalada em barril de aço inox o pior resultado econômico. Com a implementação da distribuição com veículo elétrico, além dos benefícios ambientais, foram constatados benefícios econômicos, principalmente nos custos ambientais (*ecocosts).*

Implicações da Pesquisa: A implicação prática dessa pesquisa demonstrou que a utilização de veículos elétricos para distribuição do produto final (cerveja) consegue mitigar emissões ambientais, incrementando benefícios ambientais e econômicos para a empresa estudada.

Originalidade/Valor: Este estudo contribui para a literatura ao ser o primeiro estudo brasileiro que quantifica os impactos ambientais e econômicos da produção e distribuição de cerveja artesanal. A relevância e o valor desta pesquisa são evidenciados por propor soluções tangíveis para os *hotspots* identificados.

Palavras-chave: Avaliação de Ciclo de Vida, ACV, Avaliação dos Custos do Ciclo de Vida, ACCV, Ecocosts, Mobilidade Elétrica.

COSTES ECOLÓGICOS EN UNA MICROCERVECERÍA EN EL NORDESTE BRASILEÑO

RESUMEN

Objetivo: El objetivo de este estudio es investigar los impactos ambientales y económicos de la producción de cerveza artesana en el Noreste brasileño, con la finalidad de demostrar los principales *hotspots* y proponer alternativas para mitigarlos.

Marco Teórico: El Pensamiento de Ciclo de Vida propone una forma de pensar que agrega los sistemas y preserva sus interrelaciones, de modo a comprender el todo de los sistemas productivos e identificar los puntos críticos en sus subsistemas, procesos y flujos. Amienyo et al. (2016) analizaron los impactos ambientales y económicos en cervecerías del Reino Unido a través de la evaluación de dos escenarios: a nivel de consumidor y nacional, empleando el Análisis de Ciclo de Vida con estándares NBR 14040 y 14044.

Método: La metodología adoptada para este estudio comprende la utilización de la Evaluación del Ciclo de Vida para la cuantificación de las emisiones ambientales, y de la Evaluación del Coste del Ciclo de Vida y los Costes Ecológicos para mensuración de los impactos económicos en una microcervecería instalada en el Noreste brasileño. La recolección de datos fue realizada por medio de entrevistas y cuestionarios con los responsables de los sectores específicos de la cervecería.

Resultados y Discusión: Los resultados obtenidos revelaron que el principal *hotspot* ambiental fue la distribución local y regional de la cerveza por el uso de vehículo comercial ligero propulsado a gasolina. En la cuestión económica la cerveza envasada en barril de acero inoxidable obtuvo el menor coste y la cerveza en latas de aluminio el mayor coste de fabricación. Cuando agregados los costes ambientales, la cerveza envasada en *growler* de PET obtuvo el mejor resultado y la cerveza envasada en barril de acero inoxidable el peor resultado económico. Con la implementación de la distribución con vehículo eléctrico, además de los beneficios ambientales, fueron constatados beneficios económicos, principalmente en los costes ambientales (*ecocosts).*

Implicaciones de la investigación: La implicación práctica de ese estudio demuestra que la utilización de vehículos eléctricos para la distribución del producto final (cerveza) consigue mitigar emisiones ambientales, incrementando beneficios ambientales y económicos para la empresa estudiada.

Originalidad/Valor: Este estudio contribuye a la literatura al ser el primer estudio brasileño que cuantifica los impactos ambientales y económicos de la producción y distribución de cerveza artesana. La relevancia y el valor de este estudio son evidenciados por proponer soluciones tangibles para los *hotspots* identificados.

Palabras clave: Análisis de Ciclo de Vida, ACV, Evaluación del Coste del Ciclo de Vida, ECCV, Ecocosts, Movilidad eléctrica.

1 INTRODUCTION

Global beer consumption is on an upward trend and Brazil is one of the largest producers, with a production of 14.74 billion liters in 2022 (BARTHHASS, 2023). This puts Brazil in third place in the world, behind China with 36.04 billion liters, and the United States with 19.41 billion liters brewed (BARTHHASS, 2023). This production volume is associated with environmental and economic impacts that must be quantified. After quantification, mitigation solutions can be elaborated and evaluated to minimize damage and adverse effects.

In the case of Brazil, the national beer market has been growing for the last 20 years, with an increase of 11.6% compared to 2021/2022, with 1,729 breweries registered in the country at the end of 2022 (BRASIL, 2023). This growth is driven by craft breweries, especially nano-breweries, which have a production capacity of up to 60,000 liters per year, and micro-breweries, which produce up to 600,000 liters yearly (BRASIL, 2023).

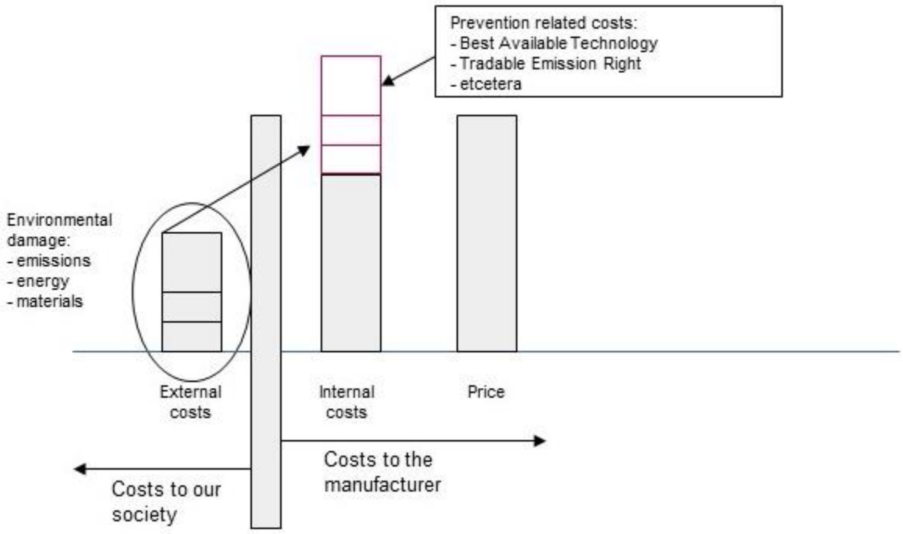
The Life Cycle Assessment (LCA) is a powerful tool for quantifying the environmental impacts associated with the production of consumer goods. It considers the product's entire life cycle, from the extraction of raw materials to its final destination, attributing the impacts at each stage, thus facilitating decision-making to mitigate these impacts (GUINEE, 2001; GUINEE, 2002). Life Cycle Costing (LCC) takes an economic approach and estimates the monetary costs at the different stages of the product's life cycle (AMIENYO et al., 2016). LCC shows the costs throughout a product's life cycle, from acquiring raw materials to managing waste. Ecological costs (from now on referred to as *ecocosts*) express the environmental burden of a product based on the avoidance of this burden. Ecocosts must be incurred to reduce environmental pollution and the depletion of materials: for example, to offset the emission of 1 t CO_2, it would be necessary to invest €116 in offshore wind farms (VOGTLÄNDER et al., 2023).

Companies could already start accounting for the environmental costs of the life cycle of their products – this means the emissions caused by manufacturing a specific product should be added to the manufacturer's internal costs. However, there is currently a mentality that "pollution is free" and manufacturing costs do not cover the environmental damage caused by production. Some practices employed to reduce the consumption of fossil fuels (and associated carbon emissions) include the implementation of solar collectors, especially in Brazil during water crises that limit the production of hydroelectricity (Santos et al., 2017). The use of renewables, besides reducing environmental impacts (Grilo et al., 2018) and even monetary costs and productivity (Perlin et al., 2022), has also motivated research that adapts solutions employed in spatial settings to electronics systems in general (Santos et al., 2020), with clear benefits regarding the costs and emissions of energy systems.

Figure 1 illustrates that companies can prevent or mitigate pollution-related costs by using the best available technology and using less environmentally aggressive alternatives in some of their processes throughout their product's life cycle.

Figure 1

The environmental burden gradually transforming into internal costs for the manufacturer (Adapted from VOGTLÄNDER, 2023)



2 THEORETICAL FRAMEWORK

Although there is research on environmental impacts in breweries, only one study relates environmental and economic impacts in breweries. Amienyo et al. (2016) studied two scenarios in the UK. The first scenario estimated environmental impacts and costs at a consumer level, to provide information about beer consumption by the population. The functional unit adopted was the production and consumption of 1 liter of beer at home. The second scenario considered the environmental impacts and costs of annual beer consumption across the UK. The second scenario aimed to inform the brewing industry and policymakers about beer's environmental impacts and contribution to the economy. In this analysis, the functional unit was beer production and annual consumption in the UK. The results indicated that the production of raw materials was the main critical point, followed by the production of packaging. Amienyo et al. (2016) concluded that beer packaged in steel cans presented the lowest environmental impacts compared to aluminum cans and glass bottles.

Considering that there are no Brazilian studies relating environmental and economic impacts in breweries, the objectives of this study are: i) to quantify environmental impacts by applying the Life Cycle Assessment methodology to a microbrewery; ii) to estimate the Life Cycle Costs for the same microbrewery; and iii) to quantify ecological costs (ecocosts), assigning a financial value to the environmental impact of beer production at the microbrewery.

3 MATERIAL AND METHODS

The environmental impacts of producing one liter of beer were estimated using Life Cycle Assessment (LCA), following standards NBR 14040 and 14044 (ABNT, 2014a; ABNT 2014b). An attributional LCA is developed, with an expansion of the frontier to consider using malt residue as animal feed by local farmers.

Simapro v.9 software was used (PRÉ SUSTAINABILITY, 2023) with the Ecoinvent database version 3.8 (ECOINVENT, 2023). For the Climate Change category, the IPCC 2021 GWP100y method was used (IPCC, 2021), quantifying greenhouse gas emissions in terms of CO_2-eq. For the Ecological Systems category, the Environmental Footprint EF 3.0 (EUROPEAN COMMISSION, 2024) was used to find the Acidification (mol H+ eq.) and Eutrophication (kg P eq) values. UseTox 2 (USETOX, 2024) was also used for Ecotoxicity, represented in CTUe (Comparative Toxic Unit for human toxicity impacts). In the Human Health category, the ReciPe 2011 Midpoint (RIVM, 2024) method was used for the Formation of Photochemical Oxidants (in terms of NOx eq.) and for Particulate Matter (in terms of PM 2.5 eq.), and UseTox 2 (USETOX, 2024) for Human Toxicity, with carcinogenic and non-carcinogenic effects, expressed in CTUe (Comparative Toxic Unit for aquatic ecotoxicity impacts).

Data was obtained on-site at a microbrewery in northeast Brazil, with an annual production capacity of 180,000 liters of pure malt beer of different styles. Beer production is divided into 60% stainless steel kegs (50 liters), 15% PET growlers (1 liter), 15% glass bottles (0.50 liters), and 10% aluminum cans (0.35 liters).

The processes considered (Figure 2) start with barley cultivation and its transportation to the malting plant. The malting process encompasses the consumption of thermal energy, electricity, and water. The transportation of malt to the brewery, both domestic and imported, was also considered. The hops are grown and transported to the processing plant, undergoing drying and pelletizing processes. Transportation to the brewery was included. The readers are directed to Diniz and Carvalho (2024) for more details.

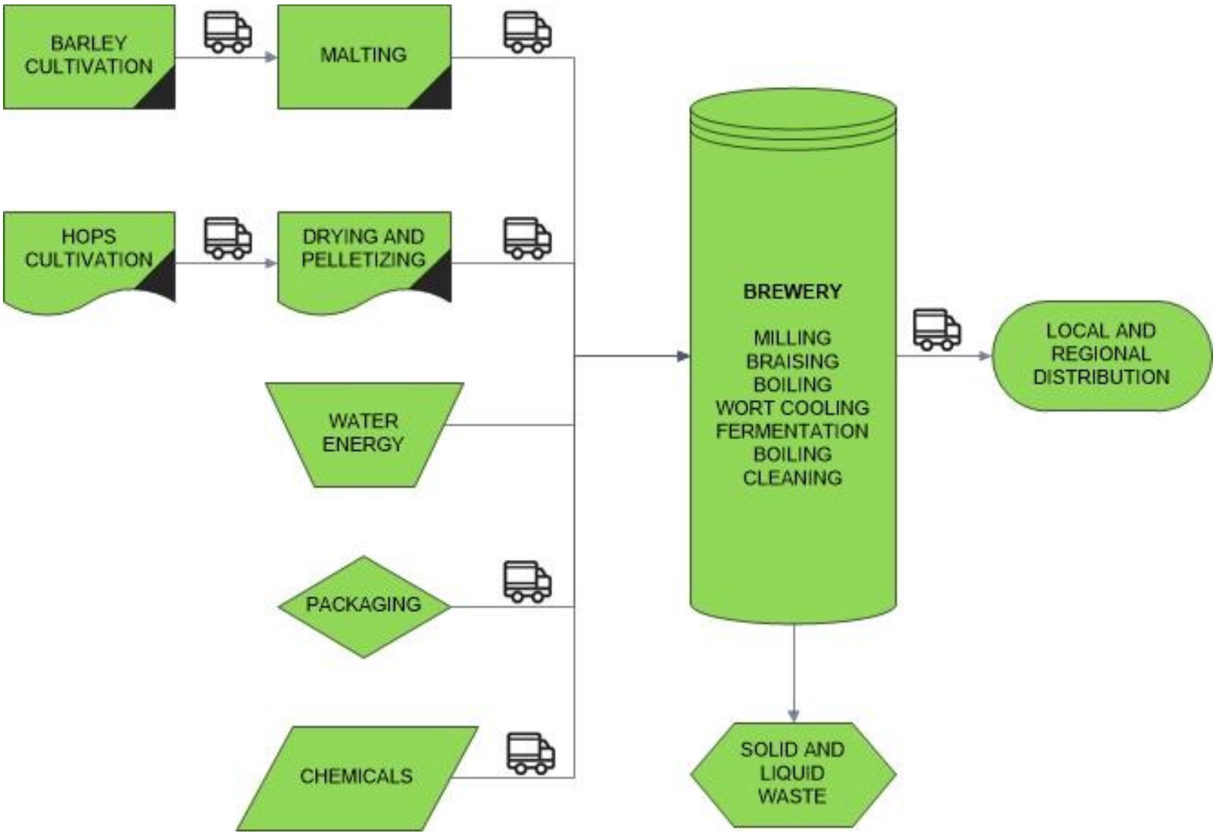
Within the brewery, the consumptions of thermal energy, electricity and water were recorded for: milling the malt, mashing, boiling and cooling the wort, fermentation, filling of the different packaging formats, and final cleaning of the equipment.

For solid waste, it was considered that the filtering residue is used by local farmers for animal feed (replacing the purchase of barley and soybeans). The farmer is responsible for collecting the filtering residue at the brewery. Liquid waste is treated by the local water and sewage company.

For packaging and chemical products, the transportation of these products from the distributors to the brewery was also considered. Finally, the local and regional distribution of beer to points of sale was registered.

Figure 2

Processes and materials considered in the environmental and economic impact studies.



Life cycle costing (LCC) was used to assess the total cost of the product throughout its life cycle. In the case of beer, involves the acquisition of raw materials, brewing, packaging, distribution, and waste management. In the case of the brewery studied, the cost of managing liquid waste is linked to the cost of the water consumed. The cost of solid waste is either associated with taxes or does not generate costs, as in the case of malt waste, where a farmer collects the waste and uses it as animal feed. Following Amienyo et al. (2016), the LCC was then adapted by replacing the waste management costs with the brewery's management costs, as shown in Equation 1. All costs are considered in reais (R$).

$LCC_{BEER} = C_{RM} + C_{PR} + C_{PA} + C_{TR} + C_{MA}$ (1)

In which:

LCC_{BEER} = Life cycle cost of producing 1 liter of beer;
C_{RM} = Raw material costs;
C_{PR} = Production costs (water, energy, chemicals);
C_{PA} = Packaging costs;
C_{TR} = Transport costs (fuel, maintenance);
C_{MA} = Brewery management costs (staff, taxes and marketing).

Raw material costs (C_{RM}) include the annual purchase of domestic and imported malts, hops, and yeast. Production costs (C_{PR}) included chemical products, water, electricity, and heat. For packaging costs (C_{PA}), the purchase of each type of packaging was taken into account: stainless steel kegs, glass bottles, PET (polyethylene terephthalate) growlers, and aluminum cans. Transportation costs (C_{TR}) include fuel costs and vehicle maintenance. Management costs (C_{MA}) include marketing costs, salaries, and state and federal taxes.

These parameters were obtained from technical visits to the brewery, with data provided by the accounting department. All values refer to year 2022. For the calculation of ecocosts, data shown in Table 1 were used (TUDelft, 2023).

Table 1

Environmental cost values (ecocosts) for different impact categories.

Midpoint	**Category**	***Ecocosts* (2022) ***	**Method**
Climate Change	Global Warming	0.116 €/kg CO_2-eq	IPCC 2021 GWP100y
Ecological Systems	Acidification	8.75 €/kg SO_2-eq (= 6.68 €/mol H+-eq.)	EF 3.0
Ecological Systems	Eutrophication	4.70 €/kg PO_4-eq (= 14.40 €/kg P-eq)	EF 3.0
Ecological Systems	Ecotoxicity	0.00289 €/CTUe	UseTox 2
Human Health	Formation of photochemical oxidants	5.35 €/kg NOx-eq	ReciPe 2016 Midpoint
Human Health	Particulate matter	35.00 €/kg PM2.5-eq	ReciPe 2016 Midpoint
Human Health	Human toxicity (cancer effects)	920,000.00 €/CTUh	UseTox 2
Human Health	Human toxicity (non-cancer effects)	216,000.00 €/CTUh	UseTox 2

* 1€ = R$5.36 (31/12/2023 - BCB, 2023).
Source: The concept, structure, and midpoint tables of the eco-costs for LCA, TUDelft, 2023.

4 RESULTS AND DISCUSSIONS

Using data collected at the brewery, it was possible to establish the cost parameter values for each packaging type, shown in Table 2.

Table 2

Cost parameters for Life Cycle Cost calculations.

Packaging	C_{MP} R$	C_{PR} R$	C_{EM} R$	C_{TR} R$	C_{GE} R$
STEEL KEG	272,640	133,440	4,500	38,160	471,600
BOTTLE	68,160	33,360	11,320.32	9,540	117,900
GROWLER	68,160	33,360	3,300	9,540	117,900
ALUMINUM CAN	45,440	22,240	20,106.24	6,360	78,600

By inserting the values of the cost parameters into Equation 1, the life cycle costs of beer production (CCV_{BEER}) are obtained for each type of packaging (Table 3).

Table 3

Life cycle costs of beer production, total and per liter.

Packaging	CCV Total/Year R$/year	CCV Total/Liter R$/L
STEEL KEG	920,340.00	8.52
BOTTLE	240,280.32	8.90
GROWLER	232,260.00	8.60
ALUMINUM CAN	172,746.24	9.60

Table 3 shows that beer packaged in stainless steel kegs presented the lowest life cycle cost when looking at the cost per liter produced (R$8.52/L). This occurs because the kegs are reused up to 120 times before the keg is sent to recycling (water consumption for washing the keg between uses has been accounted for). Aluminum cans presented the highest LCC (R$9.60/L) because of the amount required for packaging: for each liter of beer, almost three 350 ml cans are needed. The high cost of packaging is evident in the value of the C_{PA} for aluminum cans (R$20,106.24, nearly double the second-highest value, for bottles). Table 4 shows the results of the LCA for the different packaging formats.

Table 4

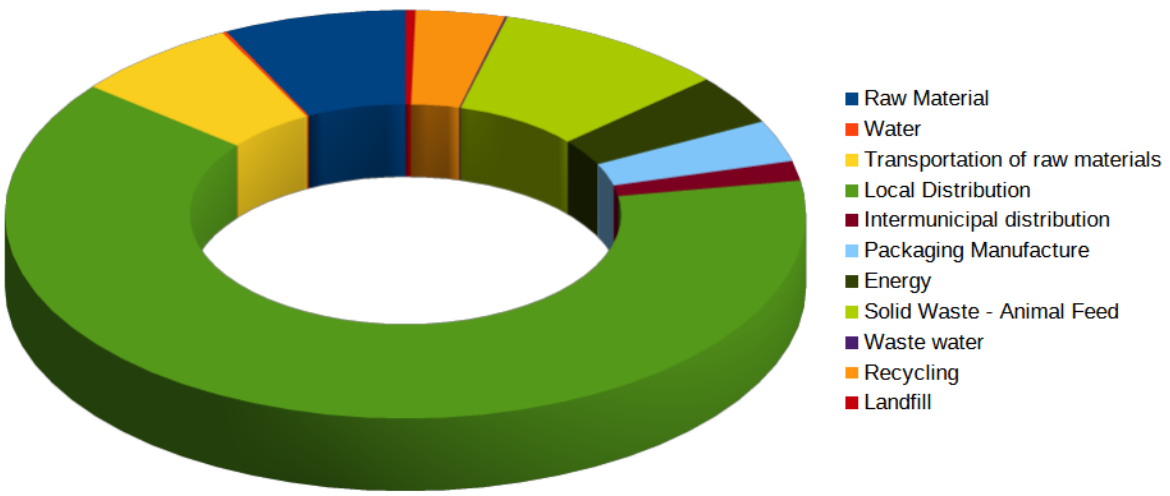
Environmental impacts per liter of beer packaged in different formats.

Impact Category	**Method**	**Environmental Impact / L beer**
Global Warming	IPCC 2021, GWP100y	2.56 kg CO_2-eq
Acidification	EF 3.0	0.0153 mol H+-eq
Eutrophication	EF 3.0	0.000275 kg P-eq
Formation of photochemical oxidants	UseTox 2	0.0111 kg NOx-eq
Particulate matter	ReciPe 2016 Midpoint	0.00388 kg PM2.5-eq
Ecotoxicity	ReciPe 2016 Midpoint	0.592 CTUe
Human toxicity (carcinogenic effects)	UseTox 2	2.47×10^{-7} CTUh
Human toxicity (noncarcinogenic effects)	UseTox 2	1.05×10^{-6} CTUh

Analyzing the results of the LCA, the beer distribution stage was the most significant in all eight categories studied. Using the Global Warming impact category as an example, Figure 2 shows that around 80% of the emissions (dark green section) are associated with the current distribution mode, using a gasoline-powered light vehicle.

Figure 2

Breakdown of current Global Warming Potential of the brewery.



Environmental burdens were converted to monetary values and were incorporated within the internal costs of the brewery for a more detailed analysis. The values of the environmental impacts of the current operating model are shown in Table 5.

Table 5

Ecocosts for the current distribution model.

Impact Category	Impact value per liter	Monetary Value	Ecological Cost per liter	Ecological cost per year
Global Warming (kg CO_2-eq)	2.56	R$ 0.62	R$ 1.59	R$ 286,507.01
Acidification (mol H+ eq)	0.0153	R$ 35.80	R$ 0.55	R$ 98,606.42
Eutrophication (kg P eq)	0.000275	R$ 77.18	R$ 0.02	R$ 3,820.61
Formation of photochemical oxidants (kg NOx eq)	0.0111	R$ 28.68	R$ 0.32	R$ 57,201.74
Particulate matter (kg PM2.5 eq)	0.00388	R$ 187.60	R$ 0.73	R$ 130,918.54
Ecotoxicity (CTUe)	0.592	R$ 0.02	R$ 0.92	R$ 165,093.59
Human toxicity (carcinogenic effects) (CTUh)	$2.47x10^{-7}$	R$ 4,931,200.00	R$ 1.22	R$ 219,241.15
Human toxicity (noncarcinogenic effects) (CTUh)	$1.05x10^{-6}$	R$ 1,157,760.00	R$ 1.22	R$ 218,816.64
			R$ 6.56	**R$ 1,180,205.69**

Diniz and Carvalho (2024) suggested the use of an electric vehicle for deliveries - specifically for the sake of reducing emissions, as Rovai et al. (2023) highlighted that the adoption of electric vehicles can be challenging. Table 6 demonstrates that the ecocosts associated with this change are positive. Diniz and Carvalho (2024) compared the use of a regular Brazilian gasoline-fueled light commercial vehicle with an electric vehicle that consumed electricity from the regional electric grid (27% hydro, 17% wind, 9% mineral coal, 16% natural gas, 12% oil, 6% sugarcane bagasse, and 13% imports from other regional subsystems). By changing the light commercial vehicle used in the local market to an electric vehicle, the ecocosts of producing and distributing beer are reduced by 60%, from around R$1.2 million to less than R$500,000 annually.

Table 6

Ecocosts associated with the adoption of electric vehicles for distribution.

Impact Category	Impact value per liter	Monetary Value	Ecological Cost per Liter	Ecological cost per year
Global Warming (kg CO_2-eq)	0.744	R$ 0.62	R$ 0.46	R$ 83,033.45
Acidification (mol H+-eq)	0.00527	R$ 35.80	R$ 0.19	R$ 33,949.08

Eutrophication (kg P-eq)	1.05×10^{-4}	R$ 77.18	R$ 0.01	R$ 1,462.30
Formation of photochemical oxidants (kg NOx-eq)	0.00269	R$ 26.68	R$ 0.07	R$ 12,931.30
Particulate matter (kg PM2.5-eq)	0.00128	R$ 187.60	R$ 0.24	R$ 43,071.20
Ecotoxicity (CTUe)	33.4	R$ 0.02	R$ 0.67	R$ 120,109.62
Human toxicity (carcinogenic effects) (CTUh)	8.95×10^{-8}	R$ 4,931,200.00	R$ 0.44	R$ 79,417.65
Human toxicity (noncarcinogenic effects) (CTUh)	4.83×10^{-7}	R$ 1,157,760.00	R$ 0.56	R$ 100,688.62
Total			**R$ 2.64**	**R$ 474,663.23**

Looking at the different packaging formats and comparing the current mode of distribution with the adoption of electric vehicles, the most significant impact on ecocosts was for beer packaged in aluminum cans. There was a reduction of around 75% in the value of environmental impacts when electric mobility was adopted: the cost decreased from R$5.45 to R$1.38 per liter of packaged beer. In the case of glass bottles, the reduction was approximately 45%, with the cost decreasing from R$8.90 to R$4.83 per liter. Table 7 summarizes the results of both scenarios: (A) business as usual, and (E) electric vehicle distribution.

Table 7

Ecocosts, in R$, for different types of packaging

Impact Category	**Bottle (A)***	**Bottle (E)****	**Growler (A)**	**Growler (E)**	**Keg (A)**	**Keg (E)**	**Can (A)**	**Can (E)**
Global Warming (kg CO_2-eq)	2.08	0.95	1.48	0.35	1.46	0.33	1.32	0.19
Acidification (mol H+ eq)	0.71	0.36	0.51	0.15	0.51	0.15	0.44	0.08
Eutrophication (kg P eq)	0.04	0.02	0.02	0.01	0.02	0.01	0.02	0.00
Formation of photochemical oxidants (kg NOx eq)	0.41	0.16	0.29	0.05	0.29	0.04	0.28	0.04
Particulate matter (kg PM2.5 eq)	0.97	0.48	0.68	0.19	0.67	0.18	0.59	0.10
Ecotoxicity (CTUe)	1.28	0.88	0.85	0.45	0.84	0.44	0.88	0.48
Human toxicity (carcinogenic effects) (CTUh)	1.73	0.96	1.17	0.39	0.16	0.38	0.77	-0.01
Human toxicity (noncarcinogenic effects) (CTUh)	1.67	1.02	1.13	0.47	0.12	0.46	1.15	0.50
TOTAL	**8.9**	**4.83**	**6.13**	**2.07**	**6.06**	**1.99**	**5.45**	**1.38**

*(A) current business model; ** (E) adoption of electric vehicle for local distribution.

When the ecocosts are entirely assumed by the microbrewery, there is a significant impact on its revenue. This is shown in Table 8, evidencing drastic reduction in the profit margin (column 6) and even resulting in a loss, as in the case of the sale of beer in stainless steel kegs. This loss of around R$0.42 per liter of beer corresponds to an annual loss of around R$45,000, as this packaging accounts for around 60% of the microbrewery's sales.

Table 8

Quantification of profits/losses from the internalization of ecocosts by the microbrewery.

	Current Cost (LCC)	**Actual ecocost**	**Total Costs** (LCC+ ecocosts)	**Average Sale Price**	**Sale Price – LCC**	**Sale Price – Total Costs**
Keg	R$ 8.52	R$ 8.90	R$ 17.42	R$ 17.00	R$ 8.48	-R$ 0.42
Bottle	R$ 8.90	R$ 6.13	R$ 15.03	R$ 18.60	R$ 9.70	R$ 3.57
Growler	R$ 8.60	R$ 6.06	R$ 14.66	R$ 22.00	R$ 13.40	R$ 7.34
Can	R$ 9.60	R$ 5.45	R$ 15.05	R$ 19.00	R$ 9.40	R$ 3.95

In the (unlikely) case that it begins to be mandatory to assume all ecocosts throughout the production chain, it would be imperative for the microbrewery to adopt local distribution with electric vehicles or operate with economic losses. Table 9 compares the current profit with the profit with the internalization of ecocosts after adopting electric mobility.

Table 9

Quantification of profits/losses from the internalization of ecocosts by the microbrewery when electric mobility is adopted for local distribution.

	Current Cost (LCC)	**New ecocosts***	**Total Costs** (LCC+ ecocost)	**Average Sale Price**	**Sale Price – LCC**	**Sale Price – Total Costs**
Keg	R$ 8.52	R$ 4.83	R$ 13.35	R$ 17.00	R$ 8.48	R$ 3.65
Bottle	R$ 8.90	R$ 2.07	R$ 10.97	R$ 18.60	R$ 9.70	R$ 7.63
Growler	R$ 8.60	R$ 1.99	R$ 10.59	R$ 22.00	R$ 13.40	R$ 11.41
Can	R$ 9.60	R$ 1.38	R$ 10.98	R$ 19.00	R$ 9.40	R$ 8.02

* New ecocosts refer to the scenario with electric vehicle distribution.

Therefore, in the event of a mandatory internalization of ecocosts, the microbrewery would operate with losses of around R$45,000 in the sale of kegs, but the adoption of electric vehicles for distribution can change the numbers to an annual profit of approximately R$394,200.00. These results demonstrate that adopting electric mobility for local deliveries is environmentally and economically viable for the microbrewery.

Finally, ecocosts can be interpreted as necessary costs to reduce the corresponding environmental pollution and can be considered as “hidden obligations” (when regulations are enforced). The importance of these ecocosts is associated with the financial risk of not complying with (future) regulations. In the European Union, for example, some regulations require businesses to quantify and report their environmental impacts, and the consideration of ecocosts can help comply with these regulations (and avoid penalties or fines). Although still not a reality in Brazil, business owners can get ahead competition by proactively reducing their ecocosts.

5 CONCLUSION

Concerning all environmental impacts, the local beer distribution stage was the most significant, contributing to approximately 80% of environmental loads associated with manufacturing and distributing 1 liter of craft beer packaged in different formats. Identifying this hotspot enabled the proposition and analysis of incorporating electric vehicles for beer distribution with positive results.

When life cycle costs were analyzed, beer packaged in stainless steel kegs (50 L) presented the lowest costs (R$8.52/L) and beer packaged in aluminum cans (0.35 L) presented the highest costs (R$9.60/L). This is due to the larger capacity of the barrels and their reusability, while the aluminum cans are single-use and almost three cans are needed to package 1 liter of beer.

An average value of R$6.56 per liter of beer brewed and distributed was found for ecological costs. If the brewery maintained its current business model, it would have to pay around R$1.2 million per year to compensate for the environmental impacts associated with the life cycle of its beer production. With the option of adopting electric mobility for local distribution, the ecological costs would drop to less than R$500,000 a year.

When analyzing the incorporation of ecocosts into the final costs of the different packaging options, beer packaged in a 1-liter PET growler obtained the best economic result per liter of beer sold, with a profit of R$7.34 without the adoption of electric mobility and R$11.41 with electric mobility. In this analysis, the stainless-steel keg ended up with the worst result, generating a loss in the current model of R$0.42 per liter. However, if electric mobility was adopted, a profit of R$3.65 per liter of beer could be realized.

Once a monetary value has been assigned to environmental emissions, it becomes clear that the pollution caused by the life cycle of a product presents high costs. It has been demonstrated herein that adopting electric vehicle distribution presents environmental and economic benefits. A suggestion for future studies includes an in-depth analysis of packaging formats with the possibility of narrowing the packaging options to realize further benefits.

Finally, the internalization of ecocosts can significantly impact a company's finances. In the case presented herein, the microbrewery assumed all the emissions costs, some of which could have been the responsibility of its suppliers. Suggestions for future work include defining or adapting ecological cost values for the Brazilian reality.

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