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Carbon emissions and embodied energy as tools for evaluating environmental aspects of tap water and bottled water in Brazil

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ABSTRACT

This paper has the purpose of evaluating the environmental impact of the consumption of bottled water rather than tap water in the city of Porto Alegre (Brazil) using carbon emission and embodied energy calculations for both possibilities. The calculations took into account the bottled water production, transport, and waste generation. In addition, the quality of tap water was tested in key restaurants to evaluate whether the tap water of the city was drinkable (potable). Six key restaurants were interviewed throughout the city to collect data regarding the water bottle consumption, and to obtain water samples. The results revealed that bottled water is less environmentally friendly since it uses more energy inputs than tap water (respectively, equal to 4,640 and 1.66 MJ/m^3). Results also shown 100% (6 out of 6) of the tested waters were drinkable (potable). The key conclusions are that energy and carbon footprints are important tools to determine sustainability issues, and can be applied by researchers and policy-makers to evaluate environmental aspects of water consumption.

Keywords: Drinking water; Tap water; Bottle water; Carbon footprint; Energy footprint

1. Introduction

In ecological terms, footprint is defined as the quantified impact that human activity has on the environment. A footprint family consists of a number of members (two or more), each of which is a single-dimensional footprint [1]. Among the various existing members, the energy footprint and the carbon footprint were chosen as tools to evaluate the drinking water consumption in Brazil.

The energy footprint is based on the input–output analysis for a process [1]; it maps the flow of the energy supply, demand, and losses. Hermann et al. [2] define energy footprint as “the cumulative fossil and nuclear energy demand in terms of primary, nonrenewable energy use, i.e. the energy content of a material as well as the nonrenewable energy spent on its extraction.” Thus, by measuring the consumption of energy required for a specific process and comparing it to another process, it is possible to evaluate which process requires more energy input.

The carbon footprint is another tool developed to control the environmental impacts of material’s production and consumption. The carbon footprint measures the total amount of GHG emissions that are directly or indirectly caused by an activity or are

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accumulated over the life stages of a product [3]. The measurement of the footprint is often given in terms of carbon dioxide equivalents (CO_2-equivalents) using the mass unit kg; thus, other GHG gasses are taken into account in addition to carbon dioxide.

These two footprints, energy and carbon, will be used to compare the environmental impacts of bottled water and tap water in the city of Porto Alegre (Brazil).

The lack of accessible quality water led to an increase in consumption of bottled water because consumers believe that it is healthy, pure, and has a good taste. These factors lead to a steady increase in sales, even when the increase in price is outrageous compared to tap water [4]. A survey conducted in the USA reports that there is not sufficient scientific evidence to conclude that the taste of bottled water is better than tap water. However, the research indicates that chlorine makes the taste of water worst. Another study reveals that the perception of water quality is directly related to several factors, among them, the taste of water and the trust in water suppliers [5]. The global scenario is contradictory: countries with the healthiest tap water are the ones that consume the most bottled water [6].

Industrialized water consumption has risen worldwide recently and countries like China, Brazil, and Indonesia are the ones with the highest increase from 1999 to 2009. In Brazil, sales of bottled water grew by 500% in the last 19 years, according to (Brazilian Association of Mineral Water Industries (ABINAM) [7]. Brazilian Mineral Resources Research Company (CPRM) states that, between 1996 and 2007, the per capita consumption increased from 11.54 per year to 20.68 L [8]. Fig. 1 illustrates that increase from 1961 to 2008.

The increase in bottled water consumption led to a new challenge, since the environmental problems associated with bottles can be higher than the ones related to tap water. Considering this aspect, different articles and researches have been conducted in order to compare the quality of tap and bottled water [9–15]. These studies concluded that the industrialized water is not always superior in quality than the tap water and that the population's concern about the municipal piped water is not justifiable [10]. Contaminations in bottled water can arrive from packing [11,12,14] or can be derived from the typical water–rock interaction, while in city's water it can be related to corrosion of the pipes [12]. It is difficult to say whether the level of contamination of tap water is higher than bottled water because of variations in definitions and regulations, except in cases where the tap water is known to be contaminated [13].

Considering that the tap water usually has enough quality to be used as drinking water [10], another important aspect to be considered are the environmental issues and the costs associated to the production of tap and bottled water. The costs evaluation can be carried out considering different indicators, as water footprints [16], energy footprints [17], and carbon footprints [18]. Different studies carried out in Italy [16–20] concluded that tap water is usually considered less expensive and environmentally preferred.

Niccolucci et al. [16] conducted a study to identify the total environmental burden required to provide a

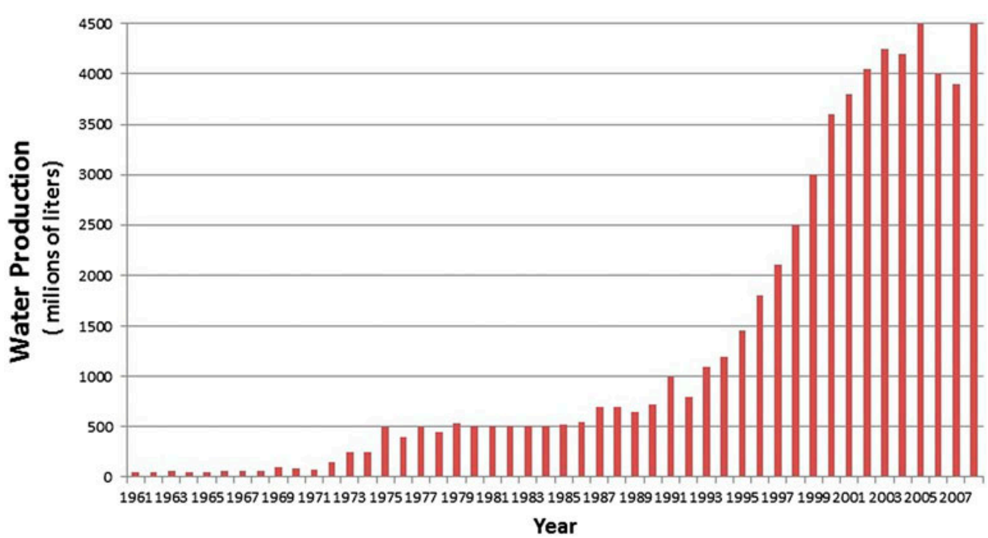

Fig. 1. Evolution of the Brazilian bottled water production from 1961 to 2008 [8].

relative amount of water for consumption, i.e. how many liters of water are effectively used to provide someone 1.5 L of tap water or bottled water. The result was that the tap water has a lower cost when the contribution of cooling water was added to the calculation. The cooling water is required in the production of polymeric materials (such as PET) used in the drinking water industry.

Lagioia et al. [17] showed that the bottled water's quantitative impact is much superior to tap water's impact. In terms of material used, a bottle requires 130–154 kg/m^3, while tap water requires 0.5–1.3 kg/m^3. In terms of energy, a bottle of water uses a 1,000–4,900 MJ/m^3, while tap water uses 2–3 MJ/m^3. The third aspect calculated was waste production; while bottled water produces 130–155 kg/m^3, tap water produces 0.3–0.7 kg/m^3.

Botto et al. [18] showed that a consumption of 1.5 L of tap water would reduce carbon dioxide emissions by 0.34 kg, when compared to industrialized PET water bottles. Nessi et al. [19] also compared the use of bottled water in different scenarios. The conclusion reached when the author compares drinking water of public network versus one-way bottled water is that the first option is environmentally preferred concerning waste generation, energy demand, global warming, consumption of abiotic resources, and eutrophication.

The bottled water in Brazil may contain mineral water or treated tap water; both are commercialized in the country. It has been proven in recent studies that bottled water is not necessarily superior to tap water in terms of quality [21]. People are led to believe that industrialized products have high quality and undergo very strict quality control processes [4]. However, there are studies that show the opposite. Dias [21] evaluated bottled water in Brazil and states that 58% of tested samples were in disagreement with health standards for mineral water and heterotrophic bacteria limits. Among the reasons for such deviation in quality, the author highlights two factors: first, the law allows some mineral waters to be commercialized without any treatment. The second factor is that the quality control is very strict in the departments responsible for water treatment and tap water production. They have high standards that have to be met. This means the quality of bottled water is not dependent on whether it is mineral or tap water, which is later bottled. Thus, tap water ends often exceeding the industrialized water in terms of quality. Also, many of the companies who sell bottled water acquire the water from the tap itself and end up charging the consumer for the cost of the product, the packaging, the transportation, the advertising, and the treatment that is, according to Dias [21], very often, unnecessary. In other words, not only the environment suffers greater impact, but also the consumer ends up paying more for a product that is already available in their homes from the beginning [22].

Considering the growth of bottled water consumption, this paper studied the impact of bottled and tap water production and analyzed the tap water quality in Porto Alegre, Brazil. Using carbon and energy footprints, this study can be compared to the ones published on the literature, especially in Italy, to evaluate if the calculations on the conditions of developed countries would differ from the ones of emerging economies. Using these indicators, a perspective is offered to researchers and policy-makers to provide a picture of costs and environmental issues of water consumption.

2. Materials and method

Although Brazilian bottled water may be mineral or treated tap water, the bottled waters considered in this work were all mineral waters as these represent the majority of the market.

The specific tests and calculations conducted at this study are outlined in Fig. 2.

To calculate the environmental issues of tap water, data of drinking water production were obtained from Municipal Department of Water and Sewers (DMAE),

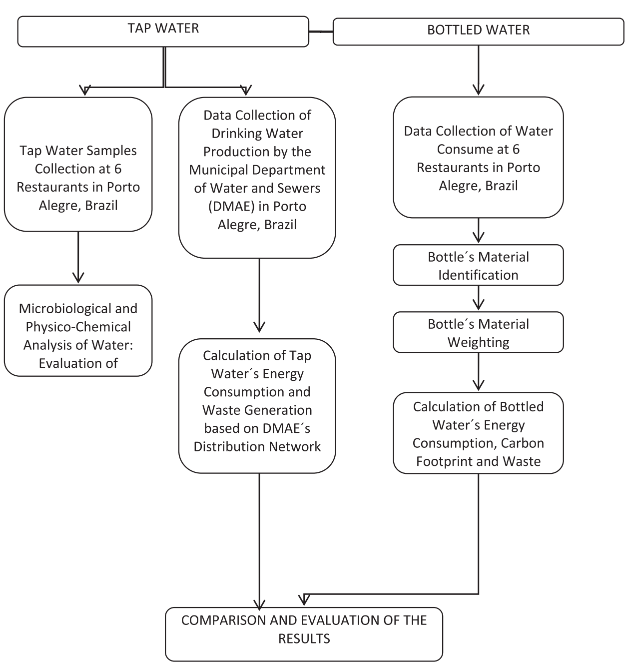

Fig. 2. Flowchart of the experiments and calculations carried out to evaluate the environmental aspects of water consumption in Brazil.

who are responsible for the treatment and regularization of the city's water in Porto Alegre.

Once treated, the water is distributed to the city. At this stage, the water can either go directly to the user's tap or to water tanks (water tanks are a common way to store water in Brazil). Once inside the water tanks, there are high chances of contamination related to corrosion or lack of cleanliness because users do not always have the necessary care with their water tanks. The practice of storing water in tanks makes necessary the use of chlorine or other disinfectants in potable water to avoid contamination according to the Decree of the Ministry of Health number 2914/2011, which sets the standards for drinking water in Brazil [23].

In order to compare bottled and tap water's energy consumption, calculations were made based on the DMAE's distribution network, with the following characteristcs [24–26]

(a) Approximately 17,000 km long;
(b) Serving approximately 1.5 million people;
(c) Approximately 200 million m^3 of water distributed per year;
(d) Seven water treatment plants;
(e) 93 lifting stations along the network;
(f) An average total energy, required to extract, treat, and distribute water in the city's network, of 92.4 GWh/y.

To evaluate the environmental issues of bottled water, data from six restaurants from Porto Alegre that had similar pricing (average of 28 U$ for a complete meal), similar public (middle and upper middle class) and that had been active for at least 10 years were selected. Setting these parameters allowed a representative sample. The middle class represents the majority of the local population [27] and by choosing establishments that have been active for at least 10 years, we make sure that they have the proper business license, proper hygiene standards, and have been inspected by the sanitation department. Contact was made with each restaurant and an interview was conducted. The interview contained the questions presented on Table 1.

After each interview, a water sample from the establishment's tap was collected. A total of six restaurants and six samples were collected. In order to collect the water samples, 5 L PET bottles were used as a recipient. The chosen tap was always the one with better access to the waiters, since they would be the ones filling it up and taking it to the customers. The tap around the orifice was flamed with butane lighter, inside and outside, in order to sterilize it. Water was allowed to run for 1 min prior to collection to remove impurities and accumulated water in the pipe. The bottle was then washed with the running water several times. Finally, approximately 5 L were collected. Container was kept closed until the time of collection. During collection, container was opened, filled, quickly closed, and identified. Samples were kept refrigerated (<10˚C) from the time of collection until the arrival at the laboratory.

Six samples were analyzed according to the Brazilian regulations for drinking water [23] to the following parameters:

(1) Microbiological including heterotrophic bacterial count.
(2) Physicochemical: Aluminum, Chloride, Residual Chlorine, Conductivity, Color, Hardness, Iron, Fluoride, Manganese, Nitrate, pH, Total Dissolved Solids, Temperature, and Turbidity.

The analysis methodology for each parameter is detailed in Table 2.

To identify the material of the polymeric water bottles, a visual inspection was made on the packaging to find the identifying symbols. For all products analyzed, PET was found on the bottle's body and PP on the bottle's cap.

The bottle was separated in three parts: body, cap, and label. These separate components were weighted and the data were used on the CES EduPack software to perform an ecological analysis of the product. The software considers that three main factors contribute to the energy demand and carbon dioxide emission of a material: the embodied energy from the raw materials, the energy associated with the losses during manufacturing and the credit obtained from recovering those losses. The amount of carbon dioxide emitted in the production, transportation, use, and disposal of bottles was calculated, as well as the amount of energy used in these processes. The transport calculations for the caps used the location of a company that produces polypropylene caps in the city of Venancio Aires, Rio Grande do Sul, at a distance of approximately 133 km from Porto Alegre. The transport calculations of the PET used the location of a PET resin supplier that serves Porto Alegre's market. This company has its manufacturing site in Paulina, São Paulo, at approximately 1,240 km from Porto Alegre. The final destination of post-consumer product affected the calculations, so that a recycled product has a better ecological impact over a product sent to a landfill, for instance. It was assumed that 43% of the bottles would be recycled, while the other 57% would go to landfills [29].

Table 1
Questions applied in each selected restaurant

Questions
(a) The establishment runs how many days per week?
(b) Do you serve lunch and dinner every day?
(c) How many clients, on an average, do you receive per month?
(d) What is the material that your bottled water is made out of? Plastic (PET) or glass?
(e) How many bottled water (regular and sparkling) are ordered per month by the restaurant to your supplier?
(f) What is your bottled water's brand?
(g) What is the bottle's destination after use? Regular or recyclable waste?
(h) Does the establishment have a water tank? How often do you clean it?
(i) Hypothetically, if you were to serve tap water to your clients, you would clean the water jars after each use, correct? Would you use water and soap or some other cleaning procedure?

Table 2
Tap water's parameters and analysis methods

Parameters	Methodology
Aluminum	SM 3500 Al
Chloride	SM 4500 Cl- C
Residual chlorine	Iodometric
Conductivity	SM 2510 B
Color	SM 2120 B
Hardness	SM 2340
Iron	SM 3500 Fe
Fluoride	SM 4500 F-D
Manganese	SM 3500 Mn
Nitrate	Salicylate
pH	Potentiometric
Total dissolved solids	Gravimetric
Air temperature	Thermometric
Sample's temperature	Thermometric
Turbidity	SM 2130 B
Heterotrophic plate counting	Plating
Total Coliforms	Multiple-tube
Escherichia coli	Multiple-tube

Note: SM = Standard Methods [28].

3. Results

The establishment's characteristics obtained during the interviews are on Table 3.

The results regarding the bottled water practice and the tap water practice are found on Table 4.

Tables 3 and 4 reveal that the sizes of the restaurants vary significantly. In fact, the customer per month average varies from 1,800 up to 15,000. Based on the answers regarding the cleaning of the jars, it should be noted that soap and water should be taken into account (as an effluent), when one wishes to calculate the environmental impact of the adoption of the tap water practice.

Although one restaurant used glass bottles in addition to PET bottles, only the polymer bottles were used in the calculations. The relationship between bottled waters (Table 4) and clients (Table 3) is not linear. DMAE recommends that water tanks should be cleaned each six months (DMAE, 2013). Thus, it is also noted that all the water tanks are cleaned within recommended interval, reducing the probability of any post-municipal treatment contamination.

Regarding the material wastes generated by bottled and tap water, the following results are presented.

The determination of the weights of the empty bottles was carried out to the five different brands of mineral water used by the restaurants and the results are displayed on Table 5.

Table 5 shows that all brands have similar weights. Thus, the average can be used in the ecological impact calculations. The packaging contribution (i.e. surrounding plastic film, cardboard, and glue) was not taken into account. The label's mass was also disregarded. Since the total amount of bottles was 10,619 (Table 3) and the average bottle weight is 22.81 g (Table 5), the total amount of waste generated in the six restaurants after use is 242 kg month^{-1}. Among the total, 85.74% is the body mass, thus 208 kg month^{-1} of PET polymer are wasted. Concerning the caps, 30 kg month^{-1} of PP polymer should be considered as waste. If each bottle contains 500 mL of water and each bottle weighs 22.81 g, the generated material waste per bottled water cubic meter is 45.6 kg m^{-3}.

Moreover, the main drinking water plant by-product is sludge [17]. The amount of sludge generated by DMAE's plant was estimated by DMAE as 6,413 ton year^{-1}. Considering a 200 million m^3 of water distributed in one year (DMAE, 2014), the total amount of sludge can be calculated as 0.03 kg m^{-3}.

These obtained results agree with Lagioia et al. [17] and show that bottled water generate a much bigger material waste than tap water. It should be

Table 3
Restaurant characteristics obtained from interviews

Restaurant	Operation (days a week)	Lunch and dinner?	Bottle destination after use	Would you be willing to serve tap water?	Cleaning procedure of jars
1	6	Yes	Recyclable/Returnable	Yes	Water + Soap
2	7	Yes	Recyclable	NA	NA
3	7	Yes	Municipal waste with no separation	Yes	Water + Soap
4	7	Yes	Recyclable	Yes	Water + Soap
5	7	Yes	Recyclable	NA	NA
6	7	Yes	Municipal waste with no separation	NA	Sanitized

Note: NA = No Answer.

Table 4
Bottled and tap water characteristics

Restaurant	Bottle's material	Bottles' per month	Do you have a water tank?	Water tank cleaning interval (months)
1	PET and Glass	720 PET and 100 Glass	Yes	6
2	PET	2,400	Yes	6
3	PET	576	No	–
4	PET	3,263	Yes	1
5	PET	3,400	Yes	2
6	PET	260	Yes	2
Total	PET	10,619	–	–

Table 5
Mass percentage per component for five different bottled water brands

Brand	Cap % mass	Body % mass	Label % mass	Total mass (g)
A	10.55%	87.43%	2.02%	25.30
B	11.95%	85.35%	2.70%	24.77
C	12.79%	86.32%	0.89%	21.35
D	14.85%	83.35%	1.80%	20.60
E	12.57%	86.25%	1.18%	22.03
Average	12.54%	85.74%	1.72%	22.81

highlighted that many bottled water companies use tap water as raw material for their product [22]. Thus, in many cases, the actual material waste that should be considered for bottled water is the sum of the tap water sludge generated and the materials used in the bottle's production.

The results concerning the carbon dioxide emission and energy use in the life stages of the PET, calculated by CES EduPack software, are shown in Figs. 3 and 4.

These values refer to the sum of PET bottles used in the six restaurants per month. It is clear that the step involving the greatest environmental impact, both in terms of carbon dioxide emissions and in terms of energy required, is the environmental burden itself. The shipping cost is low because the water was not included in the calculations of transport, since the PET bottle travels empty and is only filled in Porto Alegre, close to its final destination. The distance between the place where the bottles are filled and their final destination is negligible. These assumptions are valid for all brands involved in this study. The "end of life" potential (EoL–End of life potential) assumes negative value because recycling PET emits less CO_2 than processing it from raw materials. The manufacturing site of the PET resin is located approximately 1,200 km (Paulina, SP) away from the city of Porto Alegre.

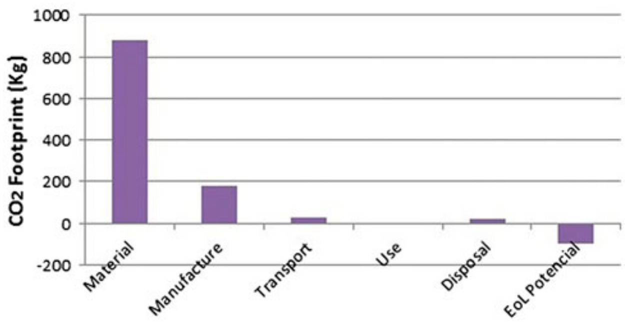

Fig. 3. CO_2 emitted in a PET bottle's body life stages divided by process (EoL = End of Life).

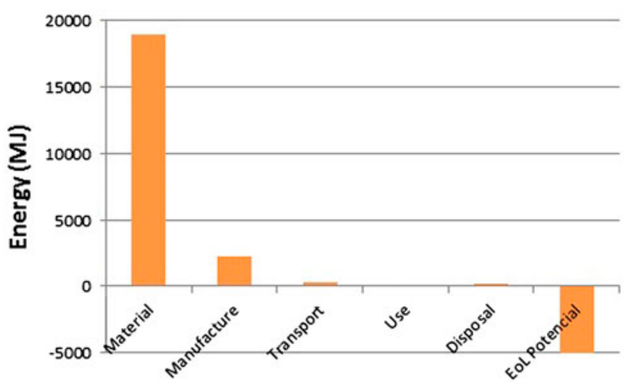

Fig. 4. Energy used in a PET bottle's body life divided by process (EoL = End of Life).

When calculating the CO_2 emission, transportation's CO_2 emission weighs heavily. The recycling does not require the 1,200 km transportation, while the resin manufacturing does.

The results concerning carbon dioxide emission and energy use in the PP's cap life stages obtained through the EduPack CES software are shown in Figs. 5 and 6.

Unlike PET, PP emits a large amount of CO_2 in the manufacture phase. Even so, the environmental impact's greatest share is due to the material itself. It is noteworthy that the "end of life" potential is negative in terms of energy, but positive in terms of CO_2 emissions. In other words, recycling PP emits more carbon dioxide then processing it from raw materials in this case study.

A table of total carbon dioxide emission and energy required for the whole bottle's (body and cap together) discussed life stages regarding all six surveyed restaurants is displayed in Table 6.

According to our results, the consumption of bottled water is approximately two bottles for each seven

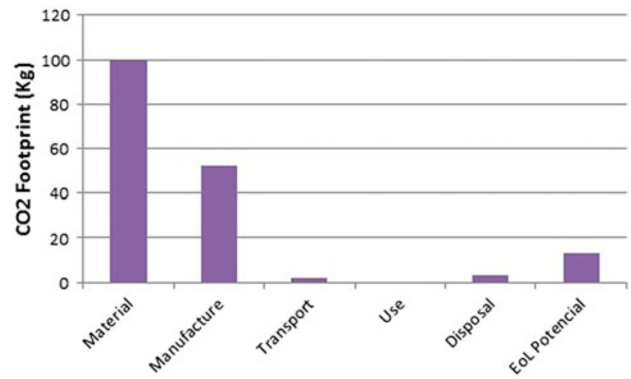

Fig. 5. Carbon dioxide footprint of the PP's cap life stages divided by process.

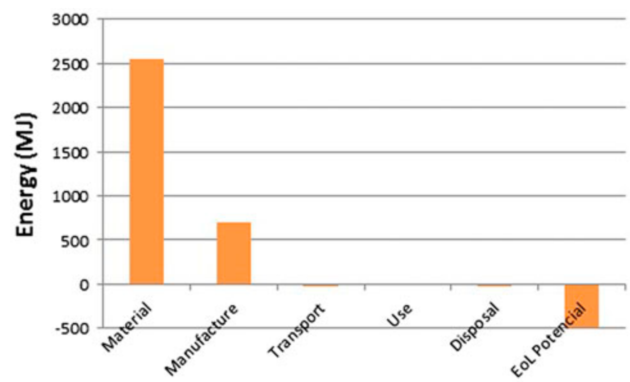

Fig. 6. Energy used in the PP's cap life stages divided by process.

costumers. Moreover, since the total amount of bottles per month was equal to 10,619, the amount of energy per bottled water may be calculated as follows:

$$\frac{24,639.84}{10,619}\left(\frac{\text{MJ}}{\text{bottles}}\right) = 2.32\left(\frac{\text{MJ}}{\text{bottles}}\right) \tag{1}$$

While the carbon footprint per bottle is:

$$\frac{1,210.66}{10,619}\left(\frac{\text{kg}}{\text{bottle}}\right) = 0.114\left(\frac{\text{kg}}{\text{bottle}}\right) \tag{2}$$

If each bottled water contains 500 mL (or 0.0005 m^3):

$$\frac{2.32}{0.0005} = 4,640\left(\frac{\text{MJ}}{\text{m}^3}\right); \quad \text{and} \quad \frac{0.114}{0.0005} = 228\left(\frac{\text{kg}}{\text{m}^3}\right) \tag{3}$$

The amount of energy required for the tap water is calculated using DMAE's [26] values as follows:

Table 6
Quantitative values of the energy and emitted carbon dioxide regarding manufacturing, transportation, raw materials, use, and disposal of bottled water in the six surveyed restaurants

Process phase	Energy (MJ)	Energy (%)	CO_2 (kg)	CO_2 (%)
Material	21,591.845	87.6	983.686	81.3
Manufacturing	2,697.085	10.9	202.168	16.7
Transport	239.631	1.0	17.014	1.4
Use	0.000	0.0	0.000	0.0
Disposal	111.279	0.5	7.790	0.6
Total (for first life cycle)	24,639.840	100.0	1,210.657	100.0
EoL Potential	−5,327.573		−83.395	

Table 7
Microbiological and physical–chemical results of the six collected samples

Parameter	Max. allowed value [a]	Detection limit	Restaurant 1	Restaurant 2	Restaurant 3	Restaurant 4	Restaurant 5	Restaurant 6
Aluminum (mg/L)	0.20	0.001	0.07	0.03	0.03	0.04	0.01	<0.001
Chloride (mg/l)	250	0.5	24	20	26	24	20	26
Residual chorine (mg/L)	0.20–2.0	0.1	0.12	0.13	0.36	0.31	0.29	0.36
Conductivity (μs/cm)	500	0.50	114	116	207	118	114	117
Color (uH)	15	5	<5	<5	<5	<5	<5	<5
Hardness (mg/L)	500	1	20	20	30	30	24	30
Iron (mg/L)	0.30	0.005	0.01	<0.005	<0.005	0.02	0.02	<0.005
Fluoride (mg/L)	1.50	0.05	0.62	0.53	1.27	0.49	1.02	0.91
Manganese (mg/L)	0.10	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Nitrate (mgNO_3/l)	10.0	0.2	3.12	2.16	1.76	3.77	1.64	2.30
pH	6.5–9.5	1	6.80	6.76	8.06	7.18	7.06	7.20
Total dissolved solids (mg/L)	1,000	2	59	58	113	91	58	59
Air Temp. (℃)	–	–	24.2℃	24.2℃	24.2℃	24.2℃	26.0℃	26.0℃
Sample Temp. (℃)	–	–	20.8℃	20.3℃	20.2℃	24.0℃	23.7℃	23.7℃
Turbidity (NTU)	5	1.60	<1.60	<1.60	<1.60	<1.60	<1.60	<1.60
"Viable" Mesophylls Count (CFU/100 ml)	100	1	<1	<1	<1	<1	25	<1
Total coliforms (MPN/100 ml)	Absence	Presence	Absence	Absence	Absence	Absence	Absence	Absence
Escherichia coli (MPN/100 ml)	Absence	Presence	Absence	Absence	Absence	Absence	Absence	Absence

Notes: CFU = colony forming unit, MPN = most probable number, and NTU = nephelometric turbidity units.
[a]Max Allowed Value according to Ref. [23].

$$94.4\left(\frac{\text{Gwh}}{\text{year}}\right) \cong 3.33 \times 10^{8}\left(\frac{\text{MJ}}{\text{year}}\right);\ \text{and}\ \frac{3.33 \times 10^{8}}{200 \times 10^{6}}\left(\frac{\text{MJ}}{\text{m}^3}\right) = 1.66\left(\frac{\text{MJ}}{\text{m}^3}\right) \quad (4)$$

These values (Eq. (4)) represent the energy required to extract, treat, and distribute tap water in the city's premises. The figures also agree with Lagioia et al. [17] and Botto et al. [18] and give strength to the conclusion that the replacement of bottled water by tap water implies in a reduction of the environmental impact as well as a monetary reduction to the costumer.

In order to exchange bottled water to tap water, it is necessary to test the tap water's quality. Thus, the results obtained from the water potability tests of the six tap water samples are shown on Table 7.

Table 7 shows that among the six samples, two (samples 1 and 2) revealed residual chlorine content below the minimum allowed value. DMAE [26] clarifies that instead of using chlorine, they use alternative disinfecting agents such as chlorine dioxide and hydrogen peroxide in their water treatment. Fig. 7 exhibits the residual chlorine concentration for several samples analyzed since 2012.

Figure 7 reveals that most samples have chlorine concentration below the minimum allowed value. The lack

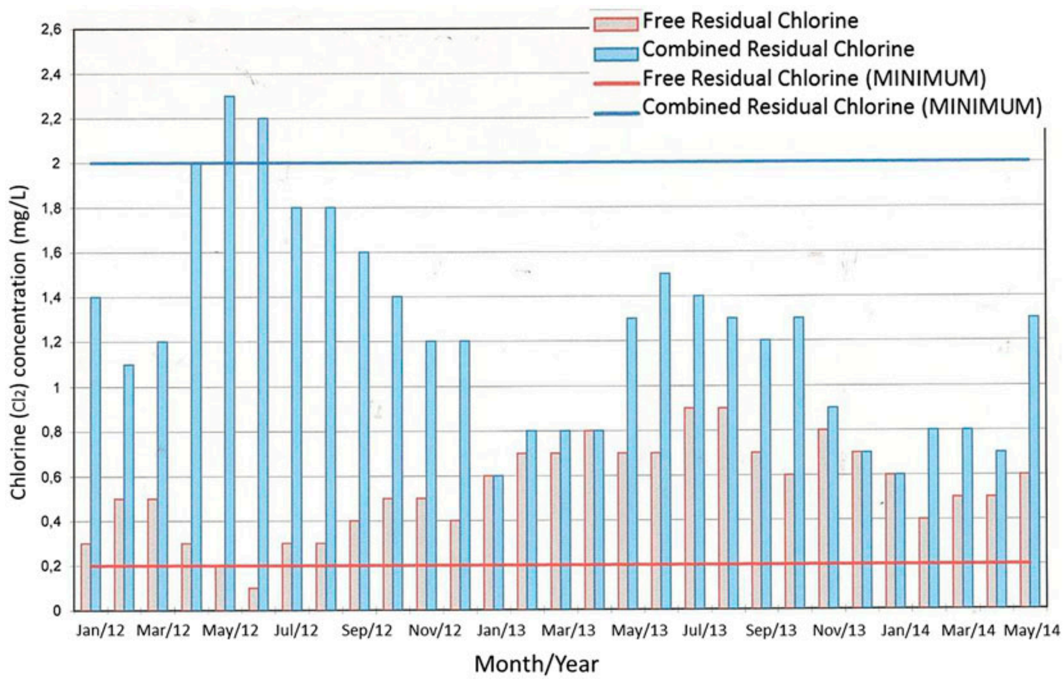

Fig. 7. Monthly average of general distribution system for the city of Porto Alegre from January 2012 to May 2014 [26].

of chlorine is offset by the alternative disinfecting agents mentioned previously. The substitution of these agents is allowed according to the Brazilian legislation and the lack of total coliforms in all tested samples proves the efficiency of these agents, according to DMAE [26]. However, despite this nonconformity, all six samples presented in Table 7 are considered potable.

4. Conclusion

Firstly, when directly comparing energy requirement for bottled water versus tap water, bottled water requires approximately 2,800 times more energy inputs (4,640 MJ/m^3) than tap water (1.66 MJ/m^3). From the observed results, tap water from the selected restaurants could be consumed by humans without damaging their health. Therefore, all the participating restaurants could serve tap water to customers. Furthermore, it is concluded that if this were to become a habit to the regulars of these establishments, approximately 1.2 tons of carbon dioxide emission could be avoided per month and approximately 24.6 GJ of energy could be reduced per month. Regarding the residue generated in this case study; the bottled water involves a bigger waste generation (4.56 kg/m^3) than tap water (0.03 kg/m^3), the bottled water residue being PET (approx. 85%) and PP (approx. 12%), and tap water residue being sludge generated in the water treatment process. The tap water, if served, would require water and soap in order to clean the water jars. A more detailed study on the environmental impact of the cleaning product's effluents is recommended as a future study.

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