Environmental performance evaluation – A new tool for the industry

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Abstract

Several tools are available in the literature to evaluate environmental performance. However, there is a lack of scientifically addressed analytical tools focusing industrial processes. Thus, based on a literature review, this study aimed to construct and test a new analytical tool for environmental performance evaluation specifically in the industry. This tool named EPIP (Environmental Performance of Industrial Processes) has as main function to identify environmental aspects with worst performance and to drive decision-making toward environmental improvements. In order to assess the effectiveness of EPIP, this tool was applied in a manufacturing industry packaging yogurt cup. The analysis of the results showed that the environmental aspects with worst performance were related to the thermoforming activities, such as energy consumption, solid waste generation and air pollution emissions. Altogether, the outcomes of this study showed that EPIP is a significant contribution to the industry, mainly those with low level of environmental management maturity, which are starting to move toward the environmental sustainability.

Keywords: Environmental Performance Evaluation; Environmental Sustainability; Industrial Processes; Environmental Impact Assessment

1. Introduction

Industrial activities consume large amounts of natural resources and release several types of effluents, solid wastes and greenhouse gases, that badly affect the environment (Sen et al., 2015). It has been a matter of concern in the whole word, leading the local governments and society to pressure the industrial sector to reduce and control the environmental impacts of its processes and products (Matos et al., 2015). Thus, research has been undertaken to develop tools and strategies to ensure that industrial activities move in a sustainable direction, based on the current policy makers, environmental laws and international standards (Herva and Roca, 2013; Carvalho et al., 2014).

According to the literature, environmental management strategies based on voluntary administrative instruments are the key to overcome this challenge. Several researchers describe these instruments as "Environmental Systems Analysis Tools", which may be classified into procedural and analytical tools (Ahlroth et al., 2011). Procedural tools explore procedures for decision-making, (e.g. Environmental Management Systems, Environmental Impacts Assessment, Environmental Performance Evaluation and Life Cycle Analysis), whereas analytical tools aim to analyze technical aspects and quantify them (e.g. Life Cycle Impact Assessment and Environmental Risk Analysis) (Wrisberg et al., 2002).

Analytical tools play an important role in the analysis of the industrial environmental performance, once they help identify the most significant environmental impacts, driving the management actions toward the most critical environmental aspects, saving time, work and financial resources (Perotto et al., 2008). Several analytical tools are available to evaluate environmental performance such as: Material Flow Cost Accounting - MFCA (Schmidt, 2013), Life Cycle Impact Assessment - LCIA (Elduque et al., 2015), Ecological Footprint (EF) (Herva and Roca, 2013) and Environmental – Failure Mode and Effects Analysis (E-FMEA) (Kania et al., 2014). However, such tools were not created with a specific focus on the assessment of the industry object, and therefore are not able to meet its needs mainly regarding the comprehensiveness in the analysis, which lead to the reliability and objectivity of the results. Tools with very subjective analysis may drive the management actions to environmental aspects less significant, resulting in a great effort and small improvements.

Another issue about the available analytical tools is the absence of standardization. Global Reporting Initiative Guidelines and the ISO 14031 standard consider some specific criteria for environmental performance evaluation, such as: materials and energy use, atmospheric emissions, risks of incidents, cost of pollution prevention, among others. On the other hand, in the literature several authors present analysis based on the Environmental Impact Assessment, (Elduque et al., 2015; Herva and Roca, 2013) or Environmental Risk Analysis (Kania et al., 2014), and alternatively, some studies consider Environmental Costs as the main criteria to evaluate environmental performance in industries (da Silva and Amaral, 2009; Ong et al., 2012).

Thus, due to the wide variety of analytical tools available in the literature, most of them use different approaches and different parameters to evaluate the environmental performance, and therefore, there is no a consensus among regulatory agencies, international organizations, and researchers about the criteria to be used for a suitable analytical tool to evaluate the environmental performance of industrial processes (Silva and Amaral, 2009). It is mean that, even with a large amount of different tools available, when the object is the industry, there are no specific analytical tools that efficiently assist in the decision-making to environmental improvements.

In this context, this study aimed to build and test a new analytical tool to efficiently evaluate environmental performance of industrial processes, mainly those with low environmental maturity. This analytical tool was named EPIP (Environmental Performance of Industrial Processes).

2. Methodology

The process to construct EPIP tool consisted in the definition of criteria, variables and equations. Based on a large literature survey were defined the criteria for EPIP. Standards, guidelines regarding environmental performance, and the most important studies in the literature that report analytical tools applied to evaluate environmental performance of industrial processes (even that these studies were not developed for the industry object), were assessed to define the EPIP´s criteria.

The criteria were selected in an attempt to obtain a tool that considers a broader range of environmental aspects and information, but easily applicable and with focus in the low environmental maturity industries. This concept of a "useful and efficient tool" was endorsed by Angelakoglou and Gaidajis, (2015) and Schmidt, (2013), throughout three observations: 1) Tools with higher number of information are extremely needed because provide more reliable results, in shorter time and with lower implementation cost, 2) Tools that consider a broader range of criteria tend to produce more objective and meaningful results, and 3) Tool based on data from environmental accounting tend to be more easily applicable due the ease in obtaining and controlling information, mainly in low environmental maturity industries.

In order to quantify and assess the selected criteria, a set of variables and equations was defined to be used in the EPIP tool. Some important factors of the industrial process were considered in the variable definition, such as: the amounts and types of materials and waste, the amount of energy used, environmental costs of inputs/outputs of the manufacturing process, and environmental impact categories indicators (midpoint indicators) and damage categories indicators (endpoint indicators). These factors of midpoint and endpoint indicators were based on the LCIA methods (Life Cycle Impact Assessment), mainly the IMPACT2002+ method for midpoint indicators and Eco-indicator 99 method for endpoint indicators.

According to the literature, economic and environmental integration helps decision-makers to understand changes in environmental impacts and their associated costs. Moreover, the integration of economic and environmental aspects is considered an issue of growing importance today (Silva and Amaral, 2009). For this reason, economic analysis was included in this study.

Thus the variables set in EPIP tool were divided into two groups: economic analysis group and environmental analysis group. Two groups of variables were employed because the group of economic variables uses a different unit of measure (monetary unit) than the group of environmental variables (dimensionless). The mathematical operation used to relate these two groups was multiplication because it allows the interrelation of different units, while minimizing differences in order of magnitude of the result in the environmental and economic analyses. The variables of the economic analysis group were based on the analytical tools MFCA (Schmidt, 2013), MAICAPI (Silva and Amaral, 2009) and LCC (Ong et al., 2012).

In order to assess environmental aspects according to its environmental performance, a main equation was developed (Eq. 1). The equations used to obtain the variables that make up the main equation were formulated based on the equations reported in MFCA and LCIA tools.

After the tool was built, in order to assess the effectiveness of EPIP tool to evaluate environmental performance, it was applied in a manufacturing industry packaging yogurt cup. This industry is a multinational producer of plastic packaging for food. It is located in the Metropolitan Region of Curitiba, Parana - Brazil. Its manufacturing process involves the production of packaging yogurt cup with a volume of 150 mL, white color, and raw material based on polypropylene (PP). The stages of EPIP application in this industry drew in: Mapping process; lifting of mass, energy and operating costs; lifting of management costs; LCIA application with use of weighting factors. Through these stages it was possible to measure the environmental performance of the environmental aspects raised for the studied industrial process.

3. Results and discussion

3.1 Selection of EPIP's criteria

As a result of the literature survey, eight criteria were defined to be evaluated in the EPIP tool. How early mentioned (section 2), the most important sources used to define the criteria were the Global Reporting Initiative Guidelines, the ISO 14031 standard and key papers often cited in this study, which present the use of analytical tools for industrial evaluation. The focus to select the criteria was to construct a tool with a wide applicability (large number of criteria) and that produce reliable results.

Among the literature assessed, MFCA and LCIA were the tools more used to base the criteria definition in this study, due their high scientific contribution for the environmental evaluation of the industry object, in the last years. Also, is important to mention that the selected criteria were used at least once in the literature regarding analytical tools applied to environmental evaluation in the industry. The eight selected criteria were: I. amount of inputs-outputs materials (Material Balance); II. consumption/production of Energy (Energy Balance); III. solid, liquid and gaseous emissions, and final destination of solid waste; IV. environmental Impact Assessment; V. environmental Costs (material, energy and emissions); VI. legal compliance and stakeholder requirements; VII. surrounding environment condition; and VIII. applied measures to prevent pollution (investment costs and/or adoption of procedural tools to reduce environmental impact).

In addition, some authors consider the externalities costs in the environmental performance evaluation (da Silva and Amaral, 2009; Jasch, 2003). However, a significant uncertainty is assigned to this criterion (da Silva and Amaral, 2009) and hence, this criterion was not selected for the EPIP tool.

3.2 Definition of EPIP´s variables and equations

The EPIP tool has one main equation (Eq. 1) used to analyze and classify environmental aspects according to environmental performance. This equation calculates equivalent Cost of each n Environmental Aspect (CEA(n)), which is detailed in the sequence of this study. The input data for EPIP Equation 1 as well as for the other equations of it were discretized as environmental aspects according to ISO 14001 (ISO 14001, 2004).

$$CEA(n) = [MLC(n)+CEC(n)+MDC(n)+EMC(n)].[IM(n)+IE(n)] = EcG(n).EnG(n) \quad (1)$$

In this Eq. 1, were defined the variables Material Loss Cost (MLC(n)), Consumed Energy Cost (CEC(n)), Material Destination Cost (MDC(n)) and Environmental Management Cost (EMC(n)), which composes the economic analysis group, and the variables Impacts of consumption and emission Materials (IM(n)) and Impacts of Energy consumption (IE(n)), which composes the environmental analysis group. Furthermore, EcG(n) represents the sum of the variables of the economic analysis group while EnG(n) represents the sum of the variables of the environmental analysis group.

All cost variables in Eq. 1 are in local currency (in $), whereas the environmental variables are dimensionless. Thus the measuring unit designed for variable CEA(n) is $Eq (in Equivalent Currency Unit). This unit was created because the equivalent cost value of the environmental aspect does not correspond to an actual monetary outcome, once that monetary values for each cost variable were transformed by multiplying them with environmental impact values.

3.2.1 Economic analysis group

The variable components of this group are Material Loss Cost, Consumed Energy Cost, Material Destination Cost and Environmental Management Cost. Each of these variables has a particular equation for the calculation, which are described throughout this section.

MLC(n) represents quantification of the costs of material loss for each environmental aspect n (in $). Eq. 2 calculates MLC(n) where ML1 x m(n) is row matrix of mass quantity for each loss material as waste m (in kg) in the environmental aspect n and MCm x 1(n) is the unit cost column matrix of each material m in the waste (in $/kg). Note that mass sum of each material loss that makes up the n environmental aspect results in the total mass output (in kg) of this environmental aspect (MOUT(n)).

$$MLC(n) = ML1 \times m(n).\ MCm \times 1(n) \quad (2)$$

CEC(n) is an energy usage cost balance in processing the environmental aspect n. For this variable, the environmental aspect can be product or waste. In Eq. 3, CE(n) is the consumption energy for processing environmental aspect n (in kWh), EUC(n) is energy unit cost (in $/kWh) and PE(n) is the ratio (in %) between output mass (MOUT(n)) of environmental aspect n (in kg) and input mass (MIN(n)) of raw material (in kg).

$$CEC(n) = CE(n).EUC(n).PE(n) = CE(n).EUC(n).MOUT(n)/MIN(n) \quad (3)$$

MDC(n) is the material balance of destination costs in the environmental aspect n. The waste destination forms that were considered to calculate MDC(n) were obtained according to waste hierarchy reported by Crittenden and Kolaczkowski, (1995) (from prevention to waste disposal), which consider the follow material destination: Reuse in the source, Reuse inside of industry, Recycle inside of industry, Reuse in other industry, Recycle in other industry, Waste treatment inside of industry with internal disposal, Waste treatment inside of industry with external disposal, Transport, treatment, and external disposal, Transport and external disposal without treatment and Unsuitable disposal (does not comply with legal requirements). Thus, Eq. 4 was built considering MDC(n) a material destination cost (in $), while MOUT(n) is the total quantity of material to be destined in environmental aspect n (in kg), which corresponds to the output mass of this aspect, D%1 x d(n) is a row matrix of material total quantity in percentage to destination d, WDd x d is a principal diagonal matrix of destination weights (dimensionless), which can be obtained using AHP method, and DCd x 1(n) is the column matrix of material destination unit cost for each destination d in the environmental aspect n (in $.kg-1). If the destination of environmental aspect is d=10, this aspect is already considered as a priority in the analysis, because it is not in compliance with law.

$$MDC(n) = MOUT(n).[D\%1 \times d(n).WDd \times d].DCd \times 1(n) \quad (4)$$

EMC(n) corresponds to a collection of investments/expenses made by the industry in the period of time between environmental performance assessment by EPIP tool. These investments/expenses are to simplify actions to reach improved environmental performance of one or a group of environmental aspects. These actions can be divided into simple actions such as: training, communication and awareness, machinery maintenance and investment in control equipment, or more complex actions such as redesign of products, design of new products for replacement, exchange of machines with more modern equipment or reformulation and/or reduction of production steps. In this context, Eq. 5 calculates the environmental management cost in which TCE represents the sum of the Total Costs with Environmental management (in $) involving a specific number of environmental aspects, where MEA is the sum (in kg) of Mass output Environmental Aspects and MOUT(n) is the output mass of environmental aspect n (in kg).

$$EMC(n) = TCE.MOUT(n)/MEA \quad (5)$$

3.2.2 Environmental analysis group

LCIA was introduced in the EPIP tool to adjust the economic value in order to obtain a better economic and environmental balance. In this context, the environmental analysis group of EPIP tool seeks to consider a balance between cost and environmental impacts. For this, it is employed environmental analysis methods for life cycle impact assessment (LCIA), because of its greater objectivity and reliability analysis.

The environmental analysis group was organized for variable of Impacts of consumption and emission Materials IM(n) and variable of Impacts of Energy consumption IE(n) by impact categories, obtained by adapting four methods of LCIA: IMPACT 2002+ vQ2.22 (Humbert et al., 2015; Jolliet et al., 2003), EDIP 2003 (Danish Environmental Protection Agency, 2005),Water footprint (Pfister et al., 2009) and Cumulative Energy Demand (CED) (Frischknecht et al., 2007). These methods were selected according to the following analysis: I. According to Carvalho et al. (2014) the most widely used methods of LCIA between the years 2005 and 2011 were the Eco-indicator 99, IMPACT 2002+, CML, and EDIP; II. IMPACT 2002+ method is a combination of the IMPACT 2002, Eco-indicator 99, CML and IPCC methods (Jolliet et al., 2003); III. EDIP method has waste impact categories not present in other methods; IV. Water and energy use are environmentally critical factors for industries and should be dealt with more fully in LCIA. Thus, two specific methods for these analyzes were selected: Water Footprint and Cumulative Energy Demand. These methods are considered suitable to evaluate the consumption of these resources in an industrial processes (Angelakoglou and Gaidajis, 2015).

IMPACT 2002+ was used as the reference method because it encompasses the methods of CML and Eco-Indicator 99 and as a whole, comprises the group of the three methods most used in LCA (Carvalho et al., 2014). In addition, the IMPACT2002+ contains impact categories that include the main potential environmental impacts of industrial activity when putting the system limit as the industry itself.

The variable IM(n) (Eq. 6) calculates the environmental impacts of materials for each environmental aspect n. Their variables are as follows: MOUT(n) is the output mass of each environmental aspect (in kg), Wj (dimensionless) is the Weighting factor of the Impact Category j, ICj(n) (in kgeq(category). kg-1) is the value of impact category j in the environmental aspect n, Nj (in kgeq(category)/person/year) is the Normalization factor of the impact category j, and k is the total number of impact categories considered by EPIP tool. The impact categories considered by IM(n) are shown in Tab. 1, except impact categories Non-renewable energy and Renewable energy which are used by the IE(n).

$$IM(n)=MOUT(n).[\ \textstyle\sum Wj.ICj(n)/Nj]\ \text{, to } j=1 \text{ until } k \quad (6)$$

The variable IE(n) (Eq. 7) calculates the environmental impacts for each environmental aspect n regarding the energy consumed in processing this environmental aspect. In the Eq. 7, CE(n) (in kW.h) and PE(n) (in %) are variables already shown in Eq. 3, and Wj, ICj(n) and Nj are variables already shown in Eq. 6.

$$IE(n) = EC(n).PE(n).[\sum Wj.ICj(n)/Nj] \text{ , to } j=1 \text{ until } k \tag{7}$$

Tab. 1. Impact categories considered in the environmental analysis group by EPIP.

Impact category	Reference methods for impact category	Normalization factor	Normalization Reference
Human toxicity	IMPACT2002+	219 kg chloroethylene into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Respiratory effects	IMPACT2002+	8.80 kg $PM_{2.5}$ into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Ionizing radiation	IMPACT2002+	5.33E05 Bq Carbon-14 into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Ozone layer depletion	IMPACT2002+	0.204 kg CFC-11 into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Photochemical oxidation	IMPACT2002+	12.4 kg ethylene into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Global warming	IMPACT2002+	11.600 kg CO_2 into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Aquatic ecotoxicity	IMPACT2002+	1.36E06 kg triethylene glycol into water$_{-eq}$/pers.y	(Jolliet et al., 2003)
Terrestrial ecotoxicity	IMPACT2002+	1.20E06 kg triethylene glycol into soil$_{-eq}$/pers.y	(Jolliet et al., 2003)
Aquatic acidification	IMPACT2002+	66.20 kg SO_2 into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Aquatic eutrophication	IMPACT2002+	14.30 kg $PO^{4}{}_{3-}$ into water$_{-eq}$/pers.y	(Jolliet et al., 2003)
Terrestrial acidification / nutrification	IMPACT2002+	315 kg SO_2 into air$_{-eq}$/pers.y	(Jolliet et al., 2003)
Bulk waste	EDIP 2003	1726 kg bulk waste$_{-eq}$ /pers.y	(Eurostat, 2015)
Hazardous waste	EDIP 2003	180 kg hazardous waste$_{-eq}$/pers.y	(Eurostat, 2015)
Water scarcity index (WSI)	Water footprint	365000 kg water withdrawal$_{-eq}$/pers.y	(Jolliet et al., 2003)
Non-renewable energy	Cumulative Energy Demand	3320 kg crude oil$_{-eq}$/pers.y or 152000 MJ/pers.y	(Jolliet et al., 2003)
Renewable energy	Cumulative Energy Demand	152000 MJ/pers.y	(Jolliet et al., 2003)
Mineral extraction	IMPACT2002+	5730 kg iron (in ore)$_{-eq}$/pers.y	(Jolliet et al., 2003)

Note that although the method for assessing environmental impacts by EPIP tool has been drawn up by the composition of impact categories of different methods of LCIA and their respective characterization factors, the normalization factors used were obtained from a unique method, IMPACT2002+. The exception is the normalization factor of the impact categories of waste generated, which does not exist in IMPACT2002+. Therefore, it has been used the per capita production of hazardous and bulk waste from the European Union for the 2004 (reference year) as a normalization factor (Eurostat, 2015), once it is equivalent to the normalization standard used in the IMPACT2002+.

The weighting factors of impact categories can be obtained in two ways: I. selection of the weighting factors already present in the Eco-Indicator 99, if there is unsuitable knowledge of the quality of the industry surrounding environment to perform its own weight; II. selection to obtain the damage weighting factors, by applying the Analytical Hierarchy Process (AHP), which is a multi-criteria method that compares and ranks impact categories by levels of importance.

After the development of mathematical modeling of EPIP tool, the registration of these equations in Microsoft Excel® software was performed for the simulation of the results.

3.3 Stages of EPIP tool application in the general industrial processes

Broadly speaking, the proposed methodology for application of EPIP tool comprises six stages: (1) mapping processes; (2) lifting of mass, energy and operation costs; (3) survey of management costs;

(4) performing of LCIA adapted; (5) LCIA weighting; and (6) analysis of results. Stages (2), (3), (4) and (5) consist in the quantification of environmental performance in the industrial process.

3.3.1 Mapping processes

In the stage 1 occur the steps linked to gathering information on the production process, requiring the lifting of the process, the preparation of the process flow diagram, and identification of environmental aspects related to raw materials, inputs and waste. This stage is characterized by mapping the industrial process to be analyzed, and the representation of this process as environmental aspects.

3.3.2 Mass, energy and operation costs

The stage 2 involves the quantification of raw materials, inputs consumed and waste generated for each identified environmental aspects, the quantification of unit costs of each material used in the process, survey of powers and time of machine use and the quantification of destinations types adopted for each environmental aspect. Note that the quantification of the data should consider a time defined such as day, week, month, or year.

3.3.3 Management costs

The stage 3 consists in the withdrawal of environmental management costs such as training, equipment calibration, installation of devices to reduce production errors, research and development costs related to investments for alteration of the product, and new product development or change process with more efficient machinery. There are also global management costs, covering the entire industry such as the cost of Environmental Management System implementation (EMS) and certification, and costs of environmental audit, among others.

3.3.4 LCIA adapted

The stage 4 involves the identification of categories of environmental impacts by consumption and emission of materials and energy that are related to each environmental aspect, followed by the identification of compounds and energy types present in the impact categories related to this environmental aspect. It is noteworthy, once this impact of consumption and emission of materials and energy is limited to industry boundaries. Therefore, the impacts examined by EPIP tool are related to the consumption of materials, water and energy and the release of solid, liquid and gaseous emissions are restricted to the area of the industry. For each environmental aspect, all impact categories are analyzed by the EPIP tool user, selecting the characterization factors in their corresponding impact categories, according to the materials and energy in this environmental aspect.

3.3.5 LCIA weighting

The stage 5 involves the definition of values of weighting the impact categories or categories of damage. At this stage occurs the selection of the method of weighted analysis. The weighting may occur through the AHP method by the comparative analysis between damage categories. The weighting also may occur using the damage weighting factors of the Eco-indicator method. It is recommended to use the AHP method for weighting when the surrounding environmental conditions are known.

3.3.6 Analysis of results

Finally, stage 6 provides the analytical results achieved by the implementation of EPIP tool using the Relative Equivalent Cost as the value for ranking the environmental aspects assisting in the identification of items of interest to decision-making in pursuing environmental improvements.

4. Application of EPIP tool in a yogurt packaging cup industry

In order to test the efficiency of EPIP tool to evaluate environmental performance of industries, it was applied in a yogurt packaging cup industry. Firstly, it made the mapping process of the industry. Briefly, the manufacturing process begins with the receipt and storage of raw material to be used in the production of polypropylene (PP). This PP is transported from the storage area to the mixing area using forklifts. Then mixer silos are used to homogenize the PP to be processed. Next, the PP is transported by treadmill to the extrusion process, which melts the polymer under average temperature of 230 °C and transforms the PP to plastic sheets. Then baths and water sprays are employed to cool the plastic before coiling. Plate waste is packed in big bags and then sent to the shredder to produce PP beads, which return to the production process.

The next process involves coiling. Coils are forwarded to the thermoforming machine. In this process the coil is inserted into the machine to unroll and then transported by treadmill to a heating section, under temperature of 180°C, and a molding metal block, for forming the plastic packaging cups. The cups are cooled by air and the waste of the molding, named grid is also packed in big bags for subsequent grinding. The final step of PP cups processing is performed by using of printing machines dry offset. The printing is divided into three stages: printing setting, printing, and quality control.

As from the mapping of the process production, the environmental aspects of the stages of production were identified, resulting in a total of 45 environmental aspects divided as follows: 1 in the receipt of stocks, 3 in the mixer silo, 4 in the extrusion, 1 in the water cooling, 4 in the Thermoforming, 1 in grind, 6 in the dry offset print setting, 7 in dry offset printing, 4 in cleaning, 6 in general purpose, 2 in kitchen, 3 in office, 1 in maintenance machines, and 2 in internal transportation.

After the calculations using the data collected, the results of equivalent costs for each environmental aspect were obtained and the five environmental aspects that have the greatest equivalent costs are showed in the Fig. 1. These five environmental aspects were: 1) the grid Thermoforming (A11), 2) the plastic cups produced in Thermoforming (A10), 3) VOCs printing (A27), 4) steam (A08), and 5) the plastic cups contaminated with the oil of Thermoforming (A13), which corresponds to 99 % of the total equivalent relative cost in the case of the yogurt packaging cup industry.

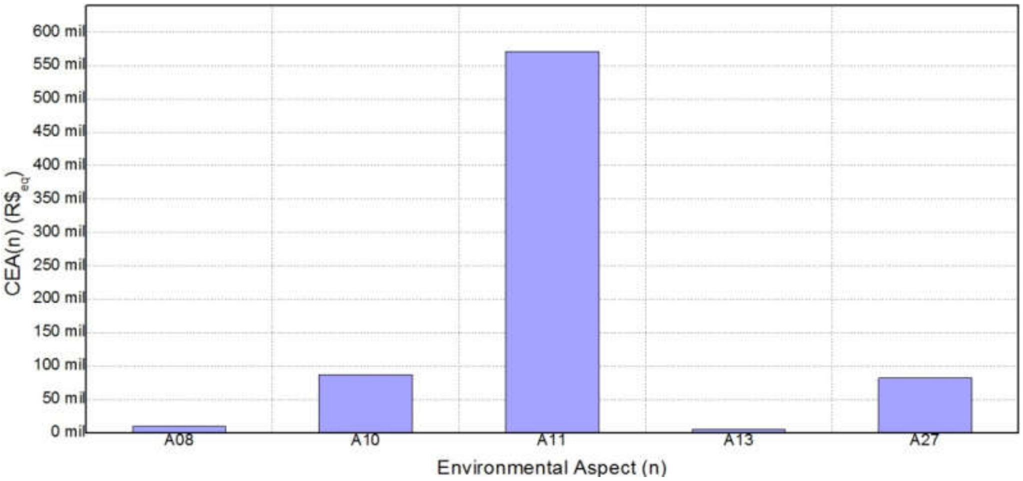

Fig. 1. Results obtained for the five environmental aspects larger equivalent costs by EPIP tool.

In order to better understand and interpret the results of equivalent costs of each environmental aspect presented in the Fig. 1, the most relevant results for economic and environmental analysis were analyzed. The results of the economic analysis group found that the environmental aspects that had the highest costs were the plastic cups produced in Thermoforming (A10), the grid Thermoforming (A11), and steam (A08), corresponding the relative cost of 78% of total expenditure on environmental aspects. It is possible to observe that these three aspects were of greater economic impact because they use a lot of energy, both PP processing and reprocessing. Regarding the environmental analysis group, the environmental aspects that had the highest impacts were VOCs printing (A27), grid Thermoforming (A11), and the plastic cups contaminated with the oil of Thermoforming (A13), corresponding to the relative cost of 84 % of the total impact on environmental aspects. The underlying reason for the result of VOCs Printing is possible due to photochemical oxidation. For the environmental aspects of grid Thermoforming and plastic cups contaminated with the oil of Thermoforming, the largest contributions of their impacts were the bulk waste generation in large quantities and the use of energy.

When comparing the results of the ranking of environmental aspects of economic analysis group, environmental analysis group and aggregated analysis (total equivalent cost), it is possible to observe differences in the sequence of environmental aspects priority to be improved in the environmental performance. Therefore, the ranking of environmental aspects provided by the EPIP tool in an industrial process possibly indicate, as priority environmental aspects, those with the highest costs, which are directly related to the inefficiency of material and energy, and/or those that present the greatest environmental impacts, which are related to the quantity and level of impact severity.

5. Conclusions

The EPIP tool has as main contribution to the state of art provides a decision-making support tool to evaluate environmental performance having a different approach than other existing analytical tools. The efficient process of selection of criteria, definition of variables and formulation of equations performed in this study resulted in a tool that efficiently fills a literature gap regarding analytical tools available to evaluate environmental performance to industries.

The tool built in this study has an environmental and economic analysis integrated enabling the industry to analyze aggregated data of materials, energy, costs and environmental impacts, providing a result through a single score (Equivalent cost of environmental aspect, CEA(n), which facilitates the interpretation by decision-makers. This more comprehensive approach makes EPIP tool gets more reliable results targeting the action taken for environmental improvements.

Furthermore, an important point is that the EPIP tool prioritizes the use of data with ease of control and collection by industries. It is known that a minimally organized industry has at least a structured and controlled accounting area. Therefore, a tool that prioritizes the use of such information facilitates its adoption. It is further observed that the broader scope gives greater applicability to EPIP tool, making it safer for the evaluation of environmental performance and guidance to decision-makers of the most critical environmental aspects to be improved by the industry.

The application of EPIP tool in a yogurt packaging cup industry demonstrated that it is a useful tool to aid in decision-making. Nevertheless, it is necessary to conduct more studies with different industrial typologies to check the outcomes from the EPIP tool for different situations. It is also important a review of normalization factors defined for aggregation of the impact categories, because there are different references between the normalization factors of waste generated impact categories, and the other impact categories selected to compose the environmental analysis performed using the EPIP tool.

In this context, it becomes necessary to carry out studies for developing normalization factors based on the same reference time and space in order to reduce errors in the result to be obtained by EPIP tool. Finally, it is necessary to carry out studies that explore the cost of externalities and the system boundary expansion beyond the industry, in order to make it more comprehensive and suitable.

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