https://dx.doi.org/10.22161/ijaers.77.31 ISSN: 2349-6495(P) | 2456-1908(O)

Multicriteria model to create and implement an environmental indicator in organizations

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***Abstract*— *Environmental monitoring through indicators is crucial for analyzing the performance of a company and its evolution over time, influencing in the quality of management decision making and in the competitiveness of the company. The aim of the present work is to develop a multicriteria model for prioritizing indicators and obtaining an Environmental Index to simplify the management of environmental indicators of a company as a way of monitoring its efficacy and evolution. To that end, an industry producing petroleum refining inputs, liquid effluents, solid waste, and atmospheric emissions was selected for a case study. The prioritization of criteria and indicators was performed by a team of specialists of the company by means of a combination of two decision-making techniques: the Weighted Sum Method (WSM) and the Analytic Hierarchy Process (AHP). An index is a form of obtaining a systemic view of the results of environmental indicators and guiding the decision-maker in a given direction with the identification of the most relevant points for the company.*

***Keywords*— environment, monitoring, indicator, decision-making, AHP.**

I. INTRODUCTION

Environmental impacts are intrinsic to industrial activities due to their generation of gaseous emissions, liquid effluents, and solid wastes. The great difficulty lies in finding the optimal point between maximizing the production profits and minimizing the environmental risks and impacts. This becomes even more important with the increase in environmental awareness society in general is developing (FIRJAN, 2008). After the occurrence of several accidents in the industry causing impacts to the environment, environmental legislations were created to regulate the sector. This encouraged the industry to invest in environmental management with a preventive focus (DE MARTINI and GUSMÃO, 2009). Innovative companies began to see the environment as an issue that allows for a good insertion in the competitive international market through shareholding, subsidiaries in other countries, or financing with foreign banks (CAMPOS and MELO, 2008; OLIVEIRA, *et al*, 2016). The organizations began to have their own environmental policies and adopt management tools in this area (MAZZI *et al*, 2016). Nowadays, environmental responsibility has become a relevant and multidisciplinary subject that affects environmental policies and markets. Most countries have adopted new regulations and economic instruments, such as trade fees and permits as well as voluntary actions like environmental certifications and reports. Such actions contribute to environmental sustainability (MAZZI *et al*, 2016). Common activities in the business routine - such as merges, incorporations, privatizations, or strategic alliances - also began to consider environmental issues relevant. The 'due diligence process', an audit performed in companies that undergo those procedures, verifies from the very beginning whether there are labor and environment liabilities (ZYLBERSZTAJN *et al*, 2010). Since, according to the statistician and university professor William Edward Deming, "what cannot be measured cannot be managed", the continuous monitoring of indicators is critical for the environment management program to be successful. Based on indicators, it is possible to identify and correct deviations, analyze their causes, and suggest proposals of improvement (CAMPOS and MELO, 2008). However, a very large quantity of indicators can make it difficult to manage the operation. Thus, a joint-evaluation of a set of indicators makes it possible to have a systemic view of the company's performance (RAFAELI and MULLER, 2007). Techniques designed to assist decision-making help in structuring the prioritization of the problem and achieving the best solution in the face of different criteria. In this sense, scientific research has a critical importance for the industry by performing studies that evaluate the adopted indicators and criteria, their prioritization methodologies, and the results of its application to environmental management. Thus, the present work proposes the construction of a model for measuring the efficacy of managing environmental indicators of a company based on the prioritization of criteria and indicators for the construction of an environmental index.

Multicriteria Decision Making (MCDM) Support Methods

The function of MCDMs is to help analysts and decision-makers structure their problems and obtain the best solution in the face of different criteria (FERREIRA *et al*, 2010). There is no favorite method in the business area. The choice of methods, rules, and procedures to solve problems depends on the problem at issue, on the project, and on the aim of a specific research (KUCUKALTAN *et al*, 2016). According to Ferreira *et al* (2010), all MCDMs follow certain steps:

- Identifying the decision-making group,
- Defining problem assessment criteria,
- Identifying alternatives,
- Determining the relative importance of those criteria by attributing them weights,
- Evaluating alternatives regarding the criteria,
- Determining the overall evaluation of each alternative.

The Weighted Sum Method (WSM) belongs to the American school of decision-making. It is applied to multicriteria issues and requires that decision-makers establish a fixed weight for each criterion. With this, the multicriterion problem becomes a single goal problem. Subsequently, values are attributed to each alternative according to each criterion so as to obtain a weighted sum for each alternative (HUANG *et al,* 2014). In its methodology, the objective-functions are aggregated, transforming the vector magnitude into a scalar magnitude. The results of WSM depend heavily on the decision-makers assigning weights to the criteria and on them evaluating each alternative regarding the criteria. It is important to normalize the weights so as to express their importance in relation to the other ones in the same order of magnitude (LOBATO *et al*, 2006). Equation 1 presents the WSM:

$$f(x) = \sum_{i=1}^{n} w_i f_i(x)$$

Equation 1

where $\sum_{i=1}^{n} \quad w_i = 1$

in which:

f(x) is the multi-attribute function for alternative x,

n is the number of criteria, and

wi is the weight of criterion i,

fi(x) is the value attributed to alternative x regarding criterion i.

The method called *Analytic Hierarchy of Processes (AHP)* is one of the most widely known and used methods, and much explored in the literature (LUZ *et al*, 2006; PODGÓRSKI, 2015). This is due to the simplicity of the method, to the availability of support software, and to its wide range of possible practical applications (PODGÓRSKI, 2015). According to HYUN *et al* (2015), AHP follows the concept of the human brain of making decisions hierarchically and with phased analyses.

II. MATERIALS AND METHODS

The selected company is a chemical plant that produces petroleum refining inputs and stands out in its line of business. This industrial plant has an annual production capacity of 34,000 tons. The company was chosen not only for its relevance in the area, but also for its concern with the environment. There are reliable operation data and a historical series that allowed calculating the index for a time interval and evaluating its variations. For reasons of contractual secrecy, the corporate identity of the company, the type of product it offers or any process flowchart will not be disclosed. The steps involved in the development of the environmental indicator are presented in Table 1.

Table 1. Steps involved in the development of an environmental indicator.

Technical visit to the selected company and meeting with the coordinator of the Safety and Environment area for an informal interview, evaluation of the company's environmental strategy, and data collection through documents
Identification of decision-makers

https://dx.doi.org/10.22161/ijaers.77.31 ISSN: 2349-6495(P) | 2456-1908(O)

Identification of criteria and subcriteria, aligned both with the company's environmental policy and the bibliographical review
Identification of environmental indicators adopted in the company and collection of historical data
Prioritization of criteria and subcriteria, using the AHP tool in an electronic spreadsheet
Evaluation of indicators in relation to criteria, using the WSM tool in an electronic spreadsheet
Determination of indexes in an electronic spreadsheet
Evaluating results and proposing improvements

The Environmental Index allows for a synthetic view of the results of 26 environmental indicators of the company. Such indicators were evaluated based on 12 criteria, which belong to four areas of interest (Technical, Socio-environmental, Financial, and Strategic). The criteria with highest priority were: the Effect on Product Quality (26%) and Workers' Health (15%). The most important indicators were those regarding atmospheric emissions (41%). The Environmental Index was stratified into an Environmental Quality Index and an Environmental Performance Index, according to the informational objective of the indicator. Regarding type, the Environmental Index was stratified into liquid effluents, solid waste, and atmospheric emissions. The analysis carried out considered a period of 5 years in which the Environmental Index, which should be minimized, reached an average value of 34.13%, operating within a control range from 45.52% to 22.74%. The minimal value was reached in 2013 (27.57%), and the last result, in 2015, reached 35.80%. In order to assist the manager in monitoring the results and encouraging staff to minimize environmental impacts, an annual target (30.72%) was established based on the statistical analysis of the historical results.

III. RESULTS AND DISCUSSION

Currently, there is a wide range of environmental indicators. They summarize, simplify, illustrate, and communicate sets of more complex data that may be typical or critical for the environment. By including trends and advances over time, they help to provide insights into the state of the environment, thus contributing as a basis for decision-making (EEA, 2014).

In order to obtain a systemic view of the overall performance, the indicators can be integrated according to a methodology that must be adequate to the scenario and to the adopted strategy, forming an index. In the environmental area, an index represents an easier way of communicating data considering that, generally speaking, this is a complex environment due to the large quantity of interconnected variables (LUZ *et al*, 2006). The methodology for creating an index consists of seven stages: developing a theoretical framework, selecting the desired variables, adding missing data, removing variables, normalizing data, data weighting, and data aggregation (GARCÍA-SÁNCHEZ *et al*, 2015).

Identifying decision-makers

The chosen team of decision-makers works directly in the Safety and Environment area of the company under evaluation. They have a compatible technical formation and consist of five members occupying positions as coordinator, engineer, analyst, technician, and trainee. The group is heterogeneous in terms of age, training, and length of professional experience (in the studied company and in their career), allowing for a plurality of opinions that enrich the evaluation.

Although small in size, the team of decision-makers has the appropriate professional competence regarding their technical formation and their knowledge of the process on which they establish judgment. This is evidenced by the low variation in the responses of the team and the consistency in their answers, which proved to be lower than the acceptable limit by the AHP technique (10%) in all judgments.

Questionnaires were used for collecting information – as presented in Annex 1 – based on the AHP and WSM methodologies. Each decision-maker answered the questionnaire individually for a subsequent consolidation of the group responses, as defined by the methodology of each technique. Equal degrees of relevance were adopted for all participants, that is, no judgment was considered more important than the others.

Identifying criteria and subcriteria

According to ABRAMCZUK (2009), the criteria must be uniform and general, that is, all criteria must be adopted for all alternatives in the same way. In addition, they must be chosen previously to defining the alternatives - in the case of the present study, the indicators. One premise adopted to define the criteria and subcriteria was the possibility of decision-making based on the data available

https://dx.doi.org/10.22161/ijaers.77.31 ISSN: 2349-6495(P) | 2456-1908(O)

presently in the company's operation. Thus, the proposed model is a complement of the environmental management carried out by the company, not requiring additional information about the indicators. According to what was recommended by CASTRO *et al* (2005), criteria on the local environmental conditions will not be adopted because they evaluate the area where the operation occurs, and is thus influenced by the entire neighborhood. The company under study is located in an industrial area, influenced by several factories around it, besides the circulation of vehicles, among other factors. Thus, if environmental condition criteria were considered, the evaluation of the company's performance could be influenced by factors that are external to its operation. The evaluation of the environmental condition rests with the governmental agencies, NGAs, and other investigation institutions.

Table 2 shows the criteria and subcriteria adopted in modeling the decision problem. These criteria are general, forming four large groups, whereas the subcriteria are specific.

Table 2. Criteria and subcriteria

Criteria	Subcriteria
Socio-environmental	Effect on Workers' Health
	Effect on the Environment
	Effect on the Local Community
Financial	Investment for Treatment
	Maintenance
	Influence on Production Costs
Strategic	Effect on Company Reputation
	Influence on Legal Requirements
	Influence on Company Transparency
Technical	Effect of Product Quality
	Need for Process Change
	Effect on Process

The team of specialists evaluated the Technical criteria as the most important (36%), followed by the Socio-environmental (31%), the Strategic (20%), and Financial (14%) criteria. Figure 1 presents the results of criteria prioritization with AHP.

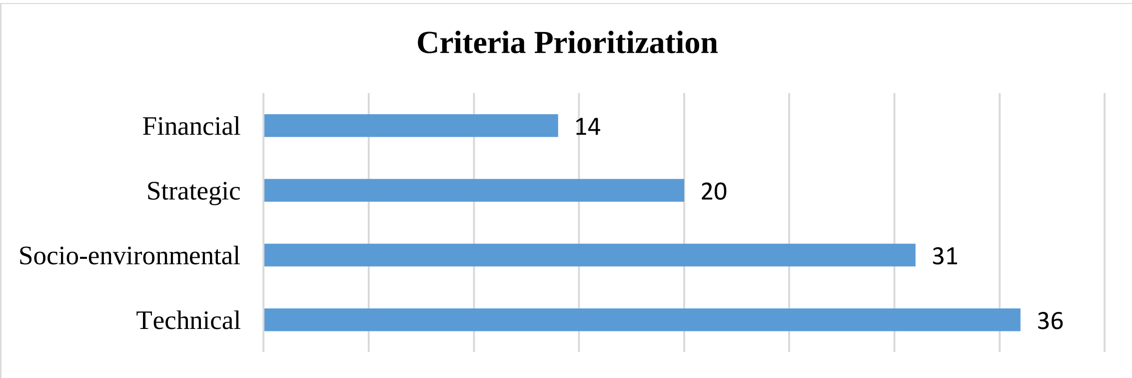

Fig.1: Results of criteria prioritization with AHP.

Source: The authors, 2017.

The importance given to the technical criteria is probably justified on account of the case study having been carried out in a company producing petroleum refining inputs, the major concern of which is product specification, a requirement demanded by the consumer market.

Figure 2 presents the results of technical subcriteria prioritization with AHP.

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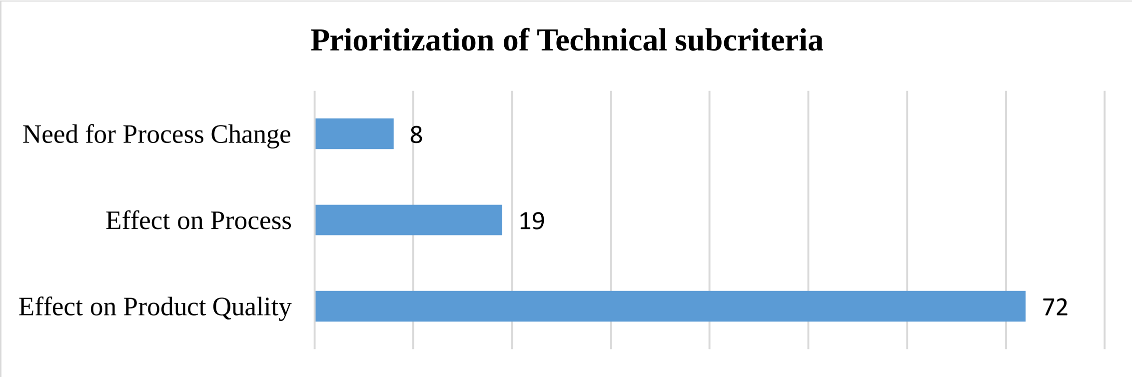

Fig.2: Prioritization of the Technical subcriteria with AHP

Source: Authors, 2017.

Among the technical subcriteria, the Effect on Product Quality obtained a higher percentage in prioritization (72%), emphasizing the concern with meeting the technical specifications of the product. The Effect on the Process (19%) was also considered important, since it is directly related to the quality of the product. But the Need for Process Change (8%) obtained a low degree of prioritization, which is consistent with the high relevance of the technical aspects. Thus, the necessary changes in the process are performed due to their importance.

Prioritization of the Socio-environmental subcriteria with AHP is presented in Figure 3.

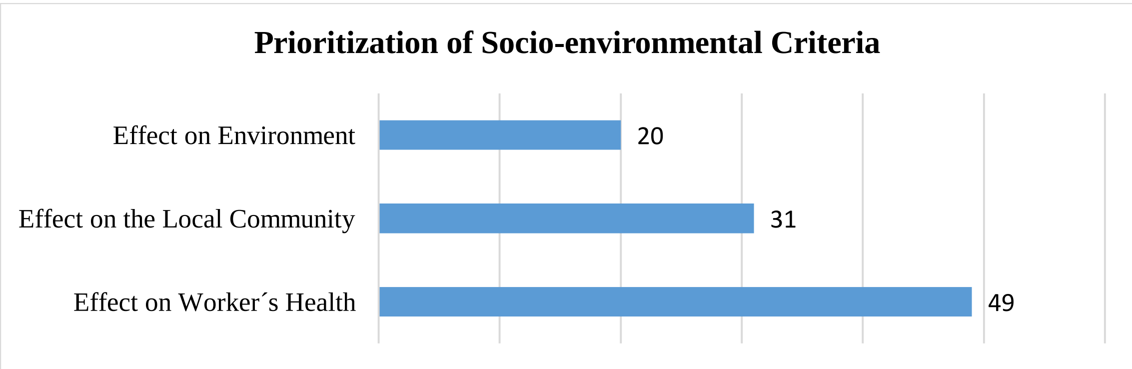

Fig.3: Prioritization of Socio-environmental subcriteria with AHP

Source: The authors, 2017.

The Effect on Workers' Health (49%) was highly representative in the prioritization of the Socio-environmental criteria by the team of specialists, possibly because of the concern the studied company has with its employees. Then, and following the same line of concern with people, appears the Effect on the Local Community subcriterion (31%) and, finally, the Effect on the Environment (20%).

Prioritization of the Strategic subcriteria was the most balanced among the four set of criteria. The greatest importance was given to the Influence on Legal Requirements subcriterion (41%), probably because it is mandatory for the operation of the plant. Then appears the Effect on the Company's Reputation (33%), something intangible and difficult to recover, which was mentioned by research executives of the CNI (2015) as the biggest advantage for the company's engagement in environmentally sustainable practices. As for the Company's Transparency subcriterion (26%), focused on the last review of the ABNT NBR ISO 14.001, it obtained the lowest degree of prioritization among the strategic subcriteria. This happened possibly because the company under evaluation is already transparent regarding its results and is certified by the Environmental Management, Work Health and Safety, and Quality Systems.

https://dx.doi.org/10.22161/ijaers.77.31 ISSN: 2349-6495(P) | 2456-1908(O)

The Influence on the Production Costs (59%) was identified as the most important among the Financial subcriteria, probably because it interferes in the factory's budget in a continuous way. The Investment for Treatment (28%) and Maintenance (13%) subcriteria obtained the lowest prioritization, possibly because they represent occasional costs, not interfering so much in decision-making.

After prioritizing the subcriteria in each group, the obtained global priorities were calculated with AHP considering the individual prioritization of the subcriterion and that of its respective group.

The results are presented in Figure 4, and the calculations are available in Annex 2- 3rd step.

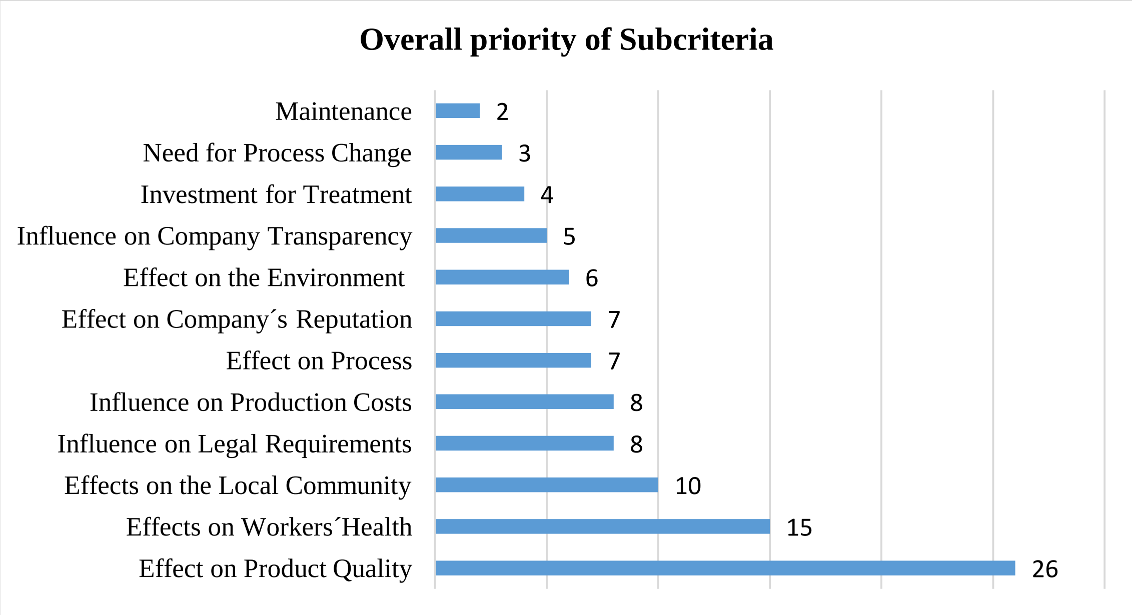

Fig.4: Overall Prioritization of Subcriteria with AHP

Source: The authors, 2017.

The subcriterion with the highest priority in decision-making is the Effect on Product Quality (26%), since it is critical to meet its technical specifications. The Effect on Workers' Health (15%) and the Effect on the Local Community (10%) also stood out as relevant criteria for the team of specialists.

In the next step of applying the AHP technique, the team of decision-makers prioritized the Indexes of Liquid Effluents, Solid Waste, and Atmospheric Emissions two by two in the face of each subcriterion, focusing on obtaining the Environmental Index, according to Table 3.

Table 3. Evaluation of Indexes in each subcriterion index

Subcriteria	**Liquid Effluents**	**Solid Waste**	**Atmospheric Emissions**
Effect on Workers' Health	0.10	0.11	0.79
Effect on the Environment	0.48	0.09	0.42
Effect on the Local Community	0.21	0.13	0.66
Investment for Treatment	0.28	0.07	0.64
Maintenance	0.36	0.08	0.56
Influence on Production Cost	0.40	0.40	0.20
Effect on Company's Reputation	0.25	0.25	0.50

Influence on Legal Requirements	0.33	0.33	0.33
Influence on Company's Transparency	0.33	0.26	0.41
Effect on Product Quality	0.40	0.40	0.20
Need for Process Change	0.40	0.40	0.20
Effect on Process	0.40	0.40	0.20

Source: The authors, 2017.

The Atmospheric Emissions Index showed to be more relevant than the other indexes in a greater number of subcriteria. The considerable importance attributed to the Atmospheric Emissions regarding Workers' Health (79%) is possibly due to the physiological mechanism of exposure. Along 9 working hours, workers were exposed to air with its quality altered due to the operation of the factory. Liquid effluents and solid waste hardly come in contact with the workers.

The prioritization of Atmospheric Emissions regarding the local community (66%) follows the same exposition concept commented on in the effect on workers' health. In addition, visual pollution produced by the emission of water vapor can possibly generate, in the local community, a tendency to think that the factory does not comply with the legal requirements and causes damage to the population.

As for the high prioritization of the Atmospheric Emissions Index regarding the investment for treatment (64%) and maintenance (56%), this is probably justified by the intense operational and maintenance routine of the company to maintain the emission control systems in 11 chimneys. Because it involves greater work, the specialists attributed a higher relevance to emissions even though the costs of treating liquid effluents are more significant for the company. The influence on legal requirements presents the same prioritization (33%) for those three indexes, since all legal obligations must be fulfilled for the plant to operate.

According to ABNT NBR ISO 14 031, it is recommended that an organization select indicators for its environment performance based on significant environmental aspects it can control and influence. Through data obtained from the Health, Safety, and Environment Coordination of the company under study, it was possible to identify the environmental indicators adopted in its environmental management. The company monitors its environmental indicators by means of five groups: liquid effluents, solid waste, atmospheric emissions, energy, and raw materials. The decision to keep the indicators separately in groups was made in order to help in the analysis of each of those areas, observing whether any deviations in the environmental index occurred due to the localized variations. Rafaeli and Muller (2007 do not recommend accumulating 10 or more indicators in the composition of a single index without performing partial branchings at different levels. This is due to the possibility of an indicator to have its performance camouflaged by another in an index composed of many indicators. Thus, an initially trivial problem may be aggravated by the lack of attention regarding small variations when one has a consolidated outcome.

Thus, in order to allow for a differential analysis of environmental indicators, a new division into two groups was proposed: environmental quality indicators and environmental performance indicators, according to Figure 5.

Identification of the indicators

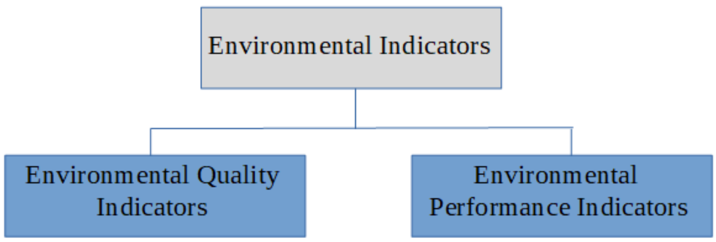

Fig.5: Division of Environmental Indicators

Source: The authors, 2017.

All environmental indicators are relative to the industrial production carried out in the respective period. In order to maintain the same frequency in all indicators, annual values were adopted in the period from 2011 to 2015. This facilitates managerial decision-making and supports the company planning, because it makes historical analyses possible. Table 4 and Table 5 present the indicators used in the case study. The indicators were separated by groups showing their respective calculation formulas and polarity.

Table 4. Environmental Performance Indicators

Environmental Performance Indicator		
Liquid Effluents Indicators		
Indicator	**Calculation formula**	**Polarity**
Inorganic	Volume of inorganic effluent / product mass	-
Organic	Volume of organic effluent / product X mass	-
Sanitary sewage	Volume of sanitary sewage / product mass	-
Solid Waste Indicators		
Indicator	**Calculation formula**	**Polarity**
Industrial	Mass of industrial waste / product mass	-
GSW	Mass of GSW / product mass	-
Recycled	Mass of recycled waste / product mass	+
Atmospheric Emissions Indicators		
Indicator	**Calculation formula**	**Polarity**
Stationary source	Mass of stationary source emission / product mass	-
Fugitive emissions	Mass of fugitive emissions / product mass	-

Source: The authors, 2017.

The organic indicator was calculated regarding product X because liquid effluent is generated only when such product is manufactured. Although the company did not manufacture that specific product in 2014 and 2015, it is important to consider that indicator because there was a large organic load in the effluent. The industrial indicator corresponds to the industrial solid waste sent to a landfill, and to the mud destined to an outsourced company for treatment. The WGS indicator represents the 'general service waste', which comprises the organic waste from the dining hall, common refuse, and construction rubble. In recent years, this indicator has been decreasing because such wastes are being recycled. The Recycled Indicator comprises the recycling of several materials such as: metal, iron, cardboard, plastic, wood, glass, organic refuse from the dining hall, construction rubble, vegetable oil, and mineral oil.

The company evaluated in the present case study conducted its emission inventory in accordance with the *GreenHouse Gas Protocol* (GHG Protocol), in which it identified its stationary and fugitive emission sources.

Table 5. Environmental Quality Indicators

Environmental Quality Indicator		
Liquid Effluents Indicators		
Indicator	**Calculation formula**	**Polarity**
Oils and greases	Mass of oils and greases / product mass	-
Settleable materials	Volume of settleable materials / product mass	-

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Chemical Oxygen Demand	COD mass / product mass	-
Biochemical Oxygen Demand	BOD mass / product mass	-
Total Non-filtered Refuse	TNFR mass / product mass	-
Indicator	**Calculation formula**	**Polarity**
Ammonia	Ammonia mass / product mass	-
Aluminum	Aluminum mass / product mass	-
Chlorine	Chlorine mass / product mass	-
Solid Waste Indicators		
Indicator	**Calculation formula**	**Polarity**
Dangerous	Dangerous wastes mass / product mass	-
Ferrous scrap	Mass of ferrous scrap / product mass	+
Plastic scrap	Mass of plastic scrap / product mass	+
Wood waste	Mass of wood waste / product mass	+
Organic from refectory	Mass of organic refuse from the dining hall / product mass	+
Construction rubble	Mass of construction rubble / product mass	+
Atmospheric Emissions Indicators		
Indicator	**Calculation formula**	**Polarity**
Particulate material	Mass of particulate material / product mass	-
SO_x	SO_x mass / product mass	-
NO_x	NO_x mass / product mass	-
Ammonia	Ammonia mass / product mass	-

Source: The authors, 2017.

All Environmental Quality indicators of the Liquid Effluents group were obtained from laboratory analyses after having passed through the industrial waste treatment plant (IWTP) of the company under study. The Chemical Oxygen Demand (COD) indicator refers to the sum of the COD of the inorganic effluent and the COD of the organic effluent when product 'X' is manufactured. For reasons of simplification, the present case study will consider COD as a whole, since the analysis focus on the impact to the environment. Indicator TNFR refers to the total non-filtered refuse, also known as 'solids in total suspension' (STS).

The Ammonia indicator considers the analysis of NH_3 in atmospheric losses. The Aluminum indicator considers the analysis of Al, and the Chlorine indicator considers the analysis of chloride (Cl^-) and active chlorine (Cl_2) in the liquid effluent.

The Indicator labeled 'Dangerous' refers to different solid wastes of small representativeness, which have been aggregated for the sake of simplification. It considers obsolete asbestos plates that still exist in the factory, health care waste, used mineral oil, mercury lamps, among others.

Ferrous scrap, plastic scrap, wood waste, organic refuse from refectory and civil construction rubble indicators are all recyclable wastes. The plastic scrap indicator includes plastic in general and big bags for storing products. The Organic Refuse from the Dining Hall indicator is recycled by an outsourced company and part of it is used as fertilizer in a vegetable garden grown in the factory.

Determining the relative importance of the criteria and subcriteria

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The relative importance of criteria and subcriteria was obtained by using the AHP tool. The priorities were established by means of a questionnaire (presented in Annex 1), which was filled out by the Security and Environment team. Based on the individual responses of the team of decision-makers, a global preference matrix was obtained (Annex 2) through the geometric mean. All calculations of the AHP methodology were carried out in an electronic spreadsheet in a way that the calculation memory could be provided to the company evaluated in the present case study, and it was possible to make alterations in case there were possible changes.

Evaluation of indicators regarding subcriteria

The evaluation of indicators regarding the subcriteria was carried out through the WSM tool. Since the subcriteria had already been prioritized in the previous step by using the AHP technique, the same weights were adopted in the present step. The evaluation of each indicator varies from 1 to 10 - 1 is adopted when there is no relevance and 10 when there is a great relevance between the indicator and the subcriterion. In this context, relevance can be understood as 'impact' or 'effect'. Thus, a high grade would be considered a bad evaluation and a low grade would be considered a good evaluation. The individual answers were consolidated through the arithmetic mean and later normalized, as presented in Annex 3.

Determining the indexes

The indexes were structured as follows: an environmental index that is divided into Quality and Environmental Performance, each one subdivided into Liquid Effluents, Solid Waste, and Atmospheric Emissions.

Those indexes are calculated based on the sum of products of each indicator with its respective prioritization, calculated with the WSM technique, as presented in Equation 2.

$$Index = x_1 \times Indicator_1 + x_2 \times Indicator_2 + \cdots + x_n \times Indicator_n \quad \text{Equation 2}$$

in which:

$$x_1 + x_2 + \cdots + x_n = 1$$

where:

xi = prioritization of the indicator obtained in WSM

The Quality and Environmental Performance Indexes – presented in Equations 3 and 4, respectively – results from the sum of products obtained by multiplying their respective Indexes of Liquid Effluents, Solid Waste, and Atmospheric Emissions with the prioritization of each index, obtained through the AHP technique.

Index of Environmental Quality = x. (Liquid Effluents Index) + y. (Solid Waste Index) + z. (Atmospheric Emissions Index)

Equation 3

Environmental Performance Index = n. (Liquid Effluents Index) + y. (Solid Waste Index) + z. (Atmospheric Emissions Index)

Equation 4

where:

$$x + y + z = 1$$

and:

x. y. z: prioritization of indexes obtained in AHP

Liquid Effluents Index, Solid Waste Index, Atmospheric Emissions Index: formed by the Environmental Quality indicators

Liquid Effluents Index, Solid Waste Index, Atmospheric Emissions Index: formed by the Environmental Performance indicators

All indexes have a negative polarity, that is, the lower its value, the better the result.

Having defined the prioritization of indicators, it is necessary to define the working range of each indicator in an interval from 0 to 100 in order to keep the indicators equivalent. Table 6 and Table 7 present the unit and the interval considered for each indicator.

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Table 6. Environmental Performance Indicators – Unit and working range

Environmental Performance Indicator		
Liquid Effluents Indicators		
Indicator	**Unit**	**Range**
Inorganic	m^3/t	18.74 - 30.00
Organic	m^3/t X	0.00 - 14.02
Sanitary sewage	m^3/t	0.29 - 0.67
Solid Waste Indicators		
Indicator	**Unit**	**Range**
Industrial	kg/t	69.45 - 140.20
GSW	kg/t	0.00 - 11.28
Recycled	kg/t	8.65 - 22.59
Atmospheric Emissions Indicators		
Indicator	**Unit**	**Range**
Stationary source	tCO2eq/t	1.51 - 1.78
Fugitive emissions	tCO2eq/t	0.00 - 0.05

Source: The authors, 2017.

Table 7. Environmental Quality Indicators – Unit and working range

Indicator of Environmental Quality		
Indicators of Liquid Effluents		
Indicator	**Unit**	**Range**
Oils and greases	kg/t	0.00 - 0.13
Settleable materials	L/t	0.17 - 1.96
COD	kg/t	0.00 - 869.06
BOD	kg/t	0.00 - 0.37
TNFR	kg/t	4.38 - 13.70
Ammonia	kg/t	0.03 - 0.08
Aluminum	kg/t	0.018 - 0.031
Chlorine	kg/t	34.97 - 217.03
Solid Waste Indicators		
Indicator	**Unit**	**Range**
Dangerous	kg/t	0.00 - 4.86
Ferrous scrap	kg/t	2.38 - 3.82
Plastic scrap	kg/t	2.37 - 4.08
Wood waste	kg/t	0.25 - 2.86
Organic from dining hall	kg/t	2.20 - 2.52

https://dx.doi.org/10.22161/ijaers.77.31 ISSN: 2349-6495(P) | 2456-1908(O)

Construction rubble	kg/t	0.00 - 8.85
Atmospheric Emissions Indicators		
Indicator	**Unit**	**Range**
Particulate material	kg/t	0.39 - 1.36
SO_x	kg/t	0.00 - 1.00
NO_x	kg/t	0.00 - 6.90
Ammonia	kg/t	1.97 - 13.50

Source: The authors, 2017.

The normalized values of the indicators that make up the environmental Performance Index are presented in Table 8, along with their respective Liquid Effluents Index, Solid Waste Index, and Atmospheric Emissions Index, for the period between 2011 and 2015. Although the indicators have been based on the annual production, variations are perceived over time.

Table 8. Results: Environmental Performance Indicators

	Normalized Indicators (%)				
	2011	**2012**	**2013**	**2014**	**2015**
Inorganic	30.30	51.83	47.14	44.60	76.12
Organic	37.01	49.49	45.56	0.00	0.00
Sanitary sewage	39.91	53.12	75.90	49.19	31.88
Liquid Effluents Index	**34.45**	**51.70**	**54.96**	**36.42**	**47.40**
Industrial	53.61	36.92	28.74	66.49	64.24
GSW	68.55	37.42	50.87	20.08	24.10
Recycled	42.85	62.84	66.18	25.02	53.11
Solid Waste Index	**41.61**	**19.81**	**19.27**	**36.06**	**31.31**
Stationary Source	67.96	68.46	39.76	36.66	37.16
Fugitive Emissions	24.11	24.12	53.31	59.85	59.90
Atmospheric Emissions Index	**47.70**	**47.98**	**46.02**	**47.37**	**47.66**
Environmental Performance Index	**41.84**	**41.52**	**41.60**	**40.82**	**43.14**

The results of the Liquid Effluents Index, Solid Waste Index, and Atmospheric Emissions Index as well as their consolidation in the Environmental Performance Index are presented in Figure 6 for the same period.

https://dx.doi.org/10.22161/ijaers.77.31 ISSN: 2349-6495(P) | 2456-1908(O)

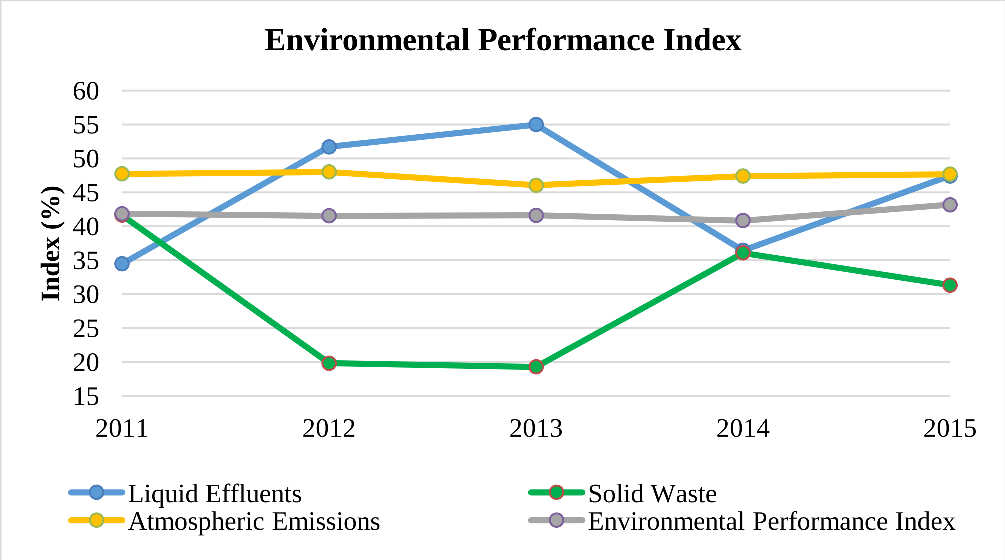

Fig.6: Results: Environmental Performance Index

Source: The authors, 2017.

The variation of the Environmental Performance Index was very small during the analyzed period – below 5% - although the indicators that compose it have had significant variations. This occurs because, from 2012 to 2015, the results of the Liquid Effluents Index and the Solid Waste Index were complementary, that is, when one of the indexes increased, the other decreased, minimizing variations in the Environmental Performance Index.

The same happened regarding the Environmental Emissions Index, which remained roughly constant, with a maximal variation of 4%, whereas its indicators had variations of up to 72% in the Stationary Source indicator and 55% in the Fugitive Emissions indicator. Such variation occurred in the same year – while one indicator increased, the other decreased – and because they had similar prioritizations, the results of the Atmospheric Emissions Index were not impacted.

The indicators that integrate the Environmental Quality Index are presented normalized in Table 9, with their respective Liquid Effluents Index, Solid Waste Index, and Atmospheric Emissions Index, for the period from 2011 to 2015.

Table 9. Results Indicating Environmental Quality

	Normalized Indicators (%)				
	2011	**2012**	**2013**	**2014**	**2015**
Oils and Greases	28.12	62.51	11.01	7.51	44.45
Settleable Materials	62.86	46.18	28.40	42.38	70.17
COD	28.78	61.96	26.19	0.15	0.15
BOD	52.17	37.37	77.14	47.62	35.70
TNFR	41.63	71.94	61.26	45.48	29.69
Ammonia	37.71	35.46	40.66	66.20	69.98
Aluminum	28.13	47.09	57.94	66.84	100.00
Chlorine	39.75	38.97	37.31	58.43	75.54
Liquid Effluents Index	**39.03**	**50.08**	**41.78**	**44.91**	**57.89**
Dangerous	30.48	21.14	11.91	70.46	30.52

Ferrous Scrap (recycled)	46.95	29.64	50.73	46.69	75.99
Plastic Scrap (recycled)	52.30	72.36	54.07	26.24	45.04
Wood Waste (recycled)	74.60	31.87	50.92	37.68	54.93
Organic from Dining Hall (recycled)	0.00	67.33	57.19	28.23	47.25
Construction Rubble (recycled)	46.12	47.19	73.55	26.89	54.27
Solid Waste Index	**-21.37**	**-28.79**	**-36.83**	**-2.47**	**-30.18**
Particulate Material	51.80	55.78	42.53	72.51	27.38
SOx	63.18	41.31	8.55	19.66	44.29
NOx	22.21	40.78	18.74	65.69	52.93
Ammonia	69.58	61.08	28.64	38.08	52.61
Atmospheric Emissions Index	**51.62**	**50.02**	**24.95**	**49.44**	**44.44**
Environmental Quality Index	**27.81**	**28.65**	**13.54**	**33.91**	**28.47**

Source: The authors, 2017.

The results of the Liquid Effluents Index, Solid Waste Index, and Atmospheric Emissions Index as well as their consolidation in the Environmental Quality Index are presented in Figure 7 for the same period.

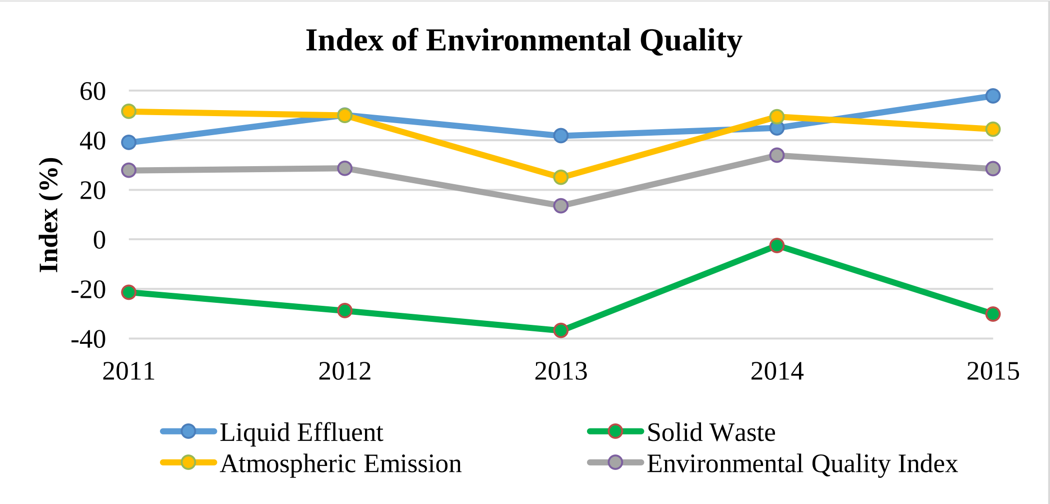

Fig.7: Results: Environmental Quality Index

Source: The authors, 2017.

The Solid Waste Index presents negative values because five out of six indicators that compose it refer to recycled waste and so they have positive instead of negative polarity. The Environmental Quality Index obtained lower values than the Environmental Performance Index because of the Solid Waste Index that, due to the recycling initiative, had its impact decreased. The other indexes - that of Liquid Effluents and that of Atmospheric Emissions - had results similar to those of the Environmental Quality and Environmental Performance Indexes. The Environmental Quality Index showed to be more sensitive to the variations in the results of the indicators that compose it, presenting a variation of up to 112%. Its most stable index is that of Liquid Effluents, with a maximal variation of 20%.

In 2014, the Solid Waste Index presented a result different from that of the improvement trend, concerning the recycling initiative, because its Dangerous Refuses had a significant increase. This happened because of the destination given to the asbestos tiles. That year, the substitutions were more than normal, because corrective maintenances were carried out in the factory. Besides, the Recycled Wastes also presented a decrease in the same year.

As for the Atmospheric Emissions index, which presented an improvement in all its indicators in 2013, had a decrease in its results in the following year, returning to the previous level.

The consolidation of the Performance and Quality Indexes in the Environmental Index is presented in Table 10 and Figure 8.

Table 10. Results: Environment Index

Year	Environmental Index (%)
2011	34.82
2012	35.08
2013	27.57
2014	37.37
2015	35.80

Source: The authors, 2017.

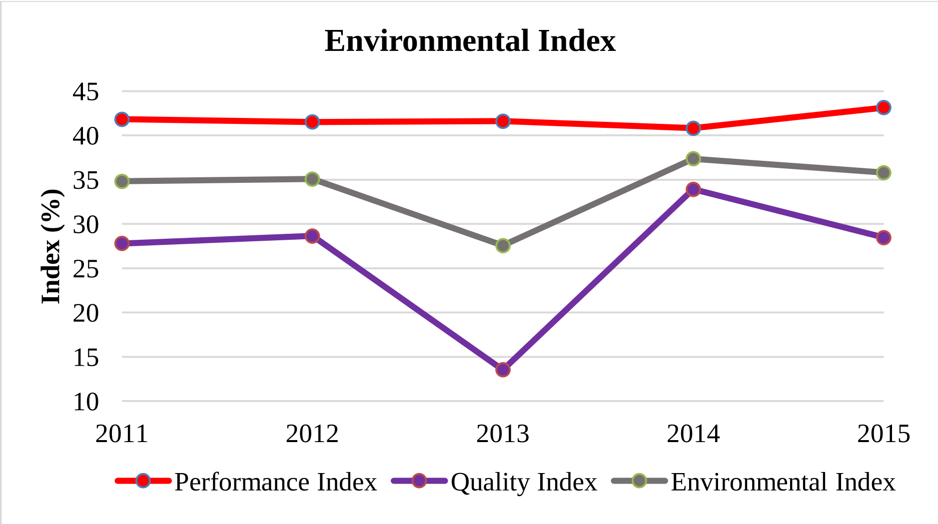

Fig.8: Results: Environmental Index

Source: The authors, 2017.

The Environmental Index presents a similar behavior to that of the Environmental Quality Index, with increases and decreases in the same periods. However, its variations are attenuated, since its result is also influenced by the Environmental Performance Index, which presents small variations. The most significant modification in the Environmental Index occurred in 2013 (-27%) and 2014 (26%), with an initial improvement and a subsequent worsening in the results, followed by an improvement in 2015 (-4%).

IV. CONCLUSIONS

The criteria and indicators identified in the review of literature and through the team of specialists for the construction of the Environmental Index were adequate to represent the management of environmental indicators over time in the company under study. Criteria referring to four different perspectives have been addressed, and the indicators cover a range of information on the environmental aspects of the factory. Regarding the aim of the study which is to obtain an index that characterizes the state of the company in its environmental aspect during the period analyzed, the index, which must be minimized, reached an average value of 34.13%, operating in a control range from 45.52% to 22.74%. The minimal value was reached in 2013 (27.57%), and the last result - in 2015 - reached 35.80%.

The sensitivity of the indexes generated in the present case study is a function of the coefficients obtained by applying the AHP and WSM techniques. The indexes have the interaction of different indicators associated to their respective weights. Thus, the higher the prioritization of an indicator, the more sensitive the index is to its results. But, in general, the indexes obtained in the present work are robust, and are not influenced by small variations in the results of a single indicator.

According to the company evaluated in the case study, the analysis of the impacts that contribute the most to harm the environment becomes possible after prioritizing the criteria and indicators. According to the specialists, the greatest impact refers to the Atmospheric Emissions (41%) justified by the exposure of workers and residents. As far as the latter are concerned, the impact was attributed to the visual pollution, in addition to the possibility of an extensive propagation and by the odor sensation.

The revision of the index may be extended to an evaluation of the criteria and indicators that compose it, so as to verify whether it is necessary to include or discard any measurement or even revise the range of action of any indicator. In the case of the factory under study, there is the production of inputs for petroleum refining. If the plant chooses to produce a new input, using new raw materials that may alter the quality of effluents, residues, or emissions, the insertion of a new indicator must be considered.

The creation of a new model to evaluate the management of environmental indicators of a company, as elaborated in the present work, is not intended to apply a pre-defined equation to different organizations, but to allow for adapting parameters of the model, according to their respective needs.

V. ACKNOWLEDGEMENTS

The authors thank the company that made it possible to carry out the present case study by providing information and resources. The authors also thank the Graduate Program in Chemical Engineering of the State University of Rio de Janeiro (UERJ).

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