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METHODOLOGICAL BENCHMARK FOR ENVIRONMENTAL PERFORMANCE EVALUATION IN METALWORKING COMPANIES

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ABSTRACT

The rise of the environmental variable in business led to the emergence of a new organizational function: Corporate Environmental Management. From this, many industrial companies have adopted administrative and operational practices to achieve positive effects on the environment by reducing or even eliminating damages caused by their activities. Thus, the need for assessing the performance of adopted practices based on environmental indicators that are suitable for the sector in which the company is inserted. Against this background, this research aimed to create a specific methodological benchmark to evaluate the environmental performance of companies belonging to the metalworking sector. As a result, we developed a methodological benchmark consisting of 34 indicators that should be assessed using 19 measurement scales. By way of example, the benchmark was applied to a company that works in this sector, and it has achieved an environmental performance of 92.48%.

Keywords: *environmental management, environmental performance evaluation, environmental indicators, metalworking sector.*

1. INTRODUCTION

In the industrial sector, production operations have reflex in the environment during all process stages, since the search for raw material to waste generation and emissions of potentially polluting agents. Thus, a growing concern over environmental degradation by these activities throughout production processes leads to the creation of a new organizational function, which is called "Corporate Environmental Management" (BARBIERI, 2012).

The Corporate Environmental Management can be defined as administrative and operational policies with activities performed by companies to achieve positive effects on the environment. It has the goal of either reducing or eliminating the damages caused by human action as well as avoiding its appearance. Moreover, the companies act toward minimizing or even eliminating negative effects of their activities (BARBIERI, 2012; ROHRICH and CUNHA, 2004; ROWLAND-JONES et al., 2005).

Industrial businesses conduction ruled in Corporate Environmental Management branch requires the adoption of practices and actions aimed at minimizing the impacts of operations, taking into account the entire lifecycle of products, from raw material acquisition to waste disposal into the environment (SRIVASTAVA and SRIVASTAVA, 2006; EL KORCHI and MILLET, 2011).

In this sense, it is important to elicit and analyze how companies have been conducting the environmental practices. Therefore, many authors such as Rohrich and Cunha (2004), Delmas and Toffel (2004), Hunt and

Auster (1990), Tahir and Darton (2010), and Campos and Melo (2008) have suggested methodologies and tools to assess the environmental performance of companies. This survey allows both evaluating the environmental performance of a company or sector and pointing out for environmental practices that can be adopted by other companies as a way to leverage their environmental management.

On the other hand, there is a distinction of environmental impacts of production operations according to economy sectors. Metalworking sector is among the sectors with operations in the list of most impacting activities against the environment. This is because this sector uses large amount of water in its operations such as for equipment cleaning, hazardous waste production, besides generating oil and grease sediments (DELAVY et al., 2007).

Through this context, it is necessary to conduct sectorial studies whose goals are focused on environmental performance evaluation based on a survey of environmental practices, providing the basis for the development of environmental public policies and being a model for other companies seeking to improve its environmental practices.

Thus, we aimed to develop a methodological benchmark to survey and assess the environmental performance of companies in the metalworking sector.

In this way, this paper is divided into five topics. It starts by an introduction of the subject. The second part deals with methodological issues relevant to this research. The third topic draws a review of the main mechanisms to evaluate the environmental performance found in the literature and a brief description of the operations carried out by metalworking industry and the wastes that are generated. The presentation of the developed methodological benchmark and an application example can be found in the fourth topic. Finally, the fifth topic displays final considerations obtained by the research.

2. METHODOLOGICAL ASPECTS

The proposed methodological benchmark was based on the method developed by Sellitto, Borchardt and Pereira (SBP). It is a model-building mechanism to measure the environmental performance of industrial operations, seeking to capture the complexity of environmental systems through integrated indicators. Therefore, the SBP suggests the development of **constructs** that describe how activities of a given operation affects the environment and the breakdown of these constructs into **indicators** that represent them. Definition and weighting of both constructs as indicators can be variable, and the SBP method suggests its definition by experts aided by researchers (SELLITTO et al., 2010).

Thus, we used the technique of focus groups, which consists of performing forums with a small group of individuals, which are led by a moderator who meet to deliberate on some topic of interest. The procedures of the focused group relied on the steps of achievement proposed by Ribeiro and Newman (2012), namely: planning, conduct of sessions and data analysis (outcomes). Hereinafter, each step for the construction of the proposed referential are set out.

2.1 Planning

At the planning stage, it was defined the group purpose, divided into the following objectives: a) definition and weighting of environmental performance aspects (constructs), which are representative for companies in the metalworking industry; b) definition and weighting for each construct of representative indicators; c) definition of the measurement scale for each defined indicator.

The focus group was composed of six experts in Environmental Management and Metalworking industry. The skills of the experts can be found in Table 1.

Construct definition and subsequent indicator definition were obtained from each member experience, taking into account their relevance and impact on the subject studied (environmental performance analysis). Yet constructs and indicators' environmental impact weighting was made based on the method of *Analytic Hierarchy Process* (AHP).

Methodology consists of mounting a hierarchical structure showing all the relationships, starting by a general goal up to the different alternatives, as shown in Figure 1 (CASTRO et al., 2005).

AHP problem structuring starts by the definition of an intended general goal. From that, criteria are designed in a tree structure, with the main objective located at the roots. As we move away from roots, we meet more

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specific factors, and extremes (the "leaves") represent factors or evaluation criteria. For each group of similar criteria that have the same "father", a matrix of parity comparisons (MPC) with preference levels obtained by comparison between factors must be filled up. AHP principle is to generate a vector of priorities by calculating the largest eigenvector of each MPC (SHIMIZU, 2010). Parity comparisons are obtained by direct questioning of experts that are familiar with the problem (SAATY, 1991).

In AHP method, parity comparisons are made not in an absolute scale due to the nature of components present in a multi-criteria decision taking. Given that often the problem is abstract, it becomes difficult that components would be singly measured, mainly using the same scale. In two by two comparison, when the decision maker express a preference for an "X" attribute, as being much more important than a "Y" one, for example; it is given a weight of "5" for this "X" attribute. However, if the decision maker considers that both criteria have the same importance, it will be assigned a weight "1". Table 2 defines and explains the concept of weights used in the AHP method (Oliveira et al., 2011). It is noteworthy to mention that when using AHP, it is important to assess the consistency ratio (CR) associated with all the assessments. CR values below 10% are considered satisfactory.

Among the decision support *software* based on the AHP, we used the *Make It Rational* (http://makeitrational.com/features), which has an organized and quite friendly graphical interface, as well as allowing the evaluation to be performed by different appraisers, and calculating automatically the consistency ratio (CR).

4.2 Working sessions

Four sessions were held, in which the first one set representative environmental performance constructs for metalworking companies and weighting of the identified constructs. In the second session, environmental performance indicators were defined that represent the deliberate constructs. Finally, third and fourth sessions were carried out to define the range to be used for measuring each of the selected indicators.

4.3 Application (outcomes)

The proposed methodological benchmark was applied to a large company in metalworking to illustrate its use.

3. THEORETICAL FOUNDATION

3.1 Environmental performance evaluation mechanisms

Several authors proposed that business practices aimed at mitigating the environmental impacts of production activities should be measured and evaluated with the objective of directing these actions and to get the knowledge of environmental management evolution in such companies. With this purpose, it is possible to find within the literature of Environmental Management several methodologies and tools to assess the environmental performance of companies.

Among the related researches, we can find a methodology proposed by ODUM (1996) that evaluates the environmental impacts of production operations based on resource use indexes, local environmental services, economic services and economic profitability of the evaluated system.

Studies developed by Campos and Melo (2008) and Jasch (2000), from an extensive literature review, relate indicators that can be used to assess the environmental performance of companies, based on ISO 14000 standard. However, Delmas and Toffel (2004) focused their research on the reasons that lead companies to adopt programs related to environmental issues.

Hunt and Auster (1990), in turn, presented a model of five stages aimed at raising the concern of the companies on environmental issues, environmental management and technological innovation that supported the researches of Rohrich and Cunha (2004). Guinée et al. (1993), Zobel et al. (2002), Günther and Kaulich (2005) adopted product life cycle as a focus point. Ucker et al. (2012), Delai and Takahashi (2011), Tahir and Darton (2010) considered human health in environmental performance evaluation.

It is still possible to check in the literature, reports that focus on certain industry sectors to build evaluation models of environmental performance. As an example, we can cite Rebelato et al. (2013) and Rodrigues et al. (2014), who specifically focused on sugarcane industry. The oil sector appears in Jung et al. (2001) research and the pulp and paper sector are represented by Souza et al. (2004) and Antonov and Sellitto (2011) researches. In addition, Ramalho and Sellitto (2013) and Silva and Amaral (2011) focused their environmental performance evaluation models in aluminum and metal frame manufacturing, respectively. Strezov et al. (2013) developed sustainability indicators for iron and steel productions. In this study, the authors compared the performance indicators in iron and steel industry to the power generation and food production industries.

The analysis of environmental performance evaluation model can still reveal that in most of them, it is possible to identify the use of certain constructs to elaborate the models. Along this line, IChemE (2006) proposed a sustainability measurement design within which it can be found the following environmental indicators: resource use - energy, materials, water and land; emissions, effluents and waste - atmospheric impacts (including impacts on human health); impacts on the water; impacts the soil. Following similar logic, Rao et al. (2006) proposed the use of environmental indicators divided into: input indicators for materials (packaging, hazardous materials and recyclable materials); input indicators for energy (consumption and renewable energy); input indicator for water; output indicators (waste recycling, waste for disposal, hazardous waste and specific residues).

Günther and Kailich (2005) developed an instrument called EPM-KOMPAS. This instrument is based on evaluation of seven impact constructs: human toxicity; eco-toxicity; waste; energy consumption; greenhouse effect; depletion of energy and material resources; and danger of fire and explosions. GRI (2006) proposed a structure to make sustainability reports in which the environmental performance dimension is divided into the constructs: materials; energy; water; biodiversity; emissions, effluents and waste; products and services; compliancy; and transportation. In a multicase study, Sellito et al. (2010) tested a method - called SBP - to generate environmental performance measurement models in manufacturing operations. The choice, organization and implementation of indicators are guided by five constructs established jointly with specialists in air emissions; wastewater; solid waste; resources' use; and management and compliance with applicable legislation.

Joung et al. (2012) carried a review of some indicators to categorize them for industrial applications relying on their similarity, which led them to set five dimensions of sustainability: environmental management; economic growth; social welfare; technological advances; management performance. Strezov et al. (2013) developed sustainability indicators based on the parameters: emissions of greenhouse gases; consumption of drinking water; land use; and air pollution. Shen et al. (2013) presented a structure for sustainable development in which relevant environmental constructs are: loss of biodiversity; atmospheric emissions; energy use; global warming and other environmental impacts; land use; product toxicology; use of resources and their availability; solid waste; water and wastewater usage; noise pollution; underground fires in mines; sedimentation of rivers and flooding in neighborhoods; rainfall rate reduction; closure of large fertile land areas under dump; mercury contamination; and water scarcity.

Thus, from mechanisms able to be used for environmental performance evaluation, it was carried out a categorization of the main aspects (**constructs**) addressed by the above mentioned authors, which are: a) air emissions; b) liquid effluents; c) solid waste; d) use of resources; e) environmental management and compliance with legislation; f) noise pollution; g) influence on vegetation and wildlife; h) influence on microclimate; i) environmental suitability of the products; j) social and human health actions; k) suppliers; l) economic actions; and m) soil contamination. This categorization originated in Table 3, which shows constructs discussed in the literature and the respective authors.

3.2. Metalworking sector operations and generated results

Concerning the environment, metalworking sector is among the economy sector that most pollute the environment. Based on a review of concepts in Dandolini (2001), it was possible to introduce the main operations carried out by the metalworking industry, namely:

i) Modeling (Moldings): mold or container making, commonly known as "male", which has the form of the final workpiece and it will be used liquid metal leakage in melting stage. Molds are usually made of wood, polystyrene and resin;

ii) Casting: dumping or metal casting in liquid state into a mold containing a cavity with the desired geometrical shape for the final piece;

iii) Conformation: changing on material geometry by applying forces with suitable tools that may vary from small matrixes to large cylinders. It can be classified as cold, warm and hot working; which may change according to the need;

iv) Machining: material removal of the main workpiece with the aid of a cutting tool, obtaining the desired shapes and dimensions. The process must produce chips, which are remains removed from the main workpiece;

v) Painting: stage in which workpieces or structures receive one or several paint coats to finish and enhance its conservation. Painting can be made with liquid or powdered ink;

vi) Special Procedures: they have many purposes such as cleaning of workpieces and structures, removal of rust, incrustations and old or defective coatings.

Regarding the waste generated in these steps, we identified: 1) contaminated IPE (Individual Protection Equipment), 2) oakum, 3) used cloth (industrial towel), 4) cardboard, 5) contaminated cardboard, 6) wood, 7) contaminated wood, 8) plastic, 9) contaminated plastic, 10) batteries, 11) grit powder with pieces of cast iron, 12) steel materials, 13) resin waste (dry), 14) supply channel for casting workpieces, 15) particulate material, 16) sleeve filter, 17) mounted stone/ grinding wheel, 18) foundry sand, 19) foundry furnace gases, 20) cans and barrels (empty), 21) contaminated sawdust, 22) used soluble oil 23) used cutting oil (mill), 24) used lubricating oil, 25) oily residue, 26) oxycutting carepa, 27) steel plate shred, 28) electrode waste, welding wire, safety valve, torch and burner nozzles, 29) hoses, 30) contaminated hoses, 31) grindstone, 32) sandpaper, 33) contaminated sands, 34) chips, 35) aerosol spray cans for liquid penetrant testing, 36) cover and nozzle of aerosol tubes, 37) salt and its package, 38) wire, 39) acid / acid water, 40) normalization carepa, 41) paint fumes 42) air filter, 43) protector plastic of the painting booth, 44) floor protective tarps, 45) sweeping waste, 46) floor, machines, equipment and workpieces washing water, 47) lamps, 48) water with oil 49) strap, 50) metal hook and 51) STP sludge.

4. RESULTS

4.1 Methodological benchmark development

As described in the methodology, the SBP method proposes: a) a definition of representative constructs of operations to be investigated b) a definition of indicators for each construct. In addition, assessment scales were set for each o indicator suggested by methodological benchmark. Below, result description for each of the three steps.

4.1.1 Constructs' definition and weighing

It was carried out a first session to define constructs in which weights were also set for each construct using the AHP method. In this session, it was taken as basis the synthesized table of models for the evaluation of environmental performance divided by construct category (Table 3).

The first column of the Table 4 shows the results of this session, independently of constructs and their respective weightings. It is noted that for such results, consistency ratio (CR) was 0.6%, which highlights evaluation consistency.

4.1.2 Definition and weighting of the indicators

In the second session, environmental performance indicators were defined, representing the deliberate constructs. This session was used as beacon document to amount of solid wastes, liquid effluents and gaseous emissions generated in the metalworking processes. Environmental impacts of each waste were taken into account, observing generated volumes and the scope of emissions over industrial processes. Furthermore, the second column of Table 4 illustrates the selected indicators for each of the six features and their relative weighting.

At this stage, CR values for each set of indicators were satisfactory in air emissions - 0.4%; solid waste - 1.7%; wastewater - 1.1%; use of resources - 1.3%; environmental management - 0.7%; environmental compliance - 0.0%.

4.1.3 Evaluation scale definition

Finally, the third and fourth tests were carried out to define the scale to measure the 34 selected indicators. For Luz et al. (2006), indicators can be measured quantitatively (objectives and by direct measurement) or categorically (subjective with performance scale). Aiming to make the benchmark wide-ranging, we opted to use categorical indicators. Therefore, it was defined a performance scale of five levels (0.0, 0.25, 0.50, 0.75, 1.00) for each indicator to detect the company's practices with respect to each assessed parameter. In total, it was prepared 19 assessment scales presented in Appendices A to S. The third column of Table 4 suggests a suitable scale for each indicator.

4.2 Calculation formula and application example

In view of the three steps previously described, general formula for environmental performance calculation is determined of a given company in the sector under study, namely:

$$EP = \sum_{i=1}^{6}\left(w_i \left(\sum_{j=1}^{n_i} I_j k \right)\right)$$

Wherein:

EP : Environmental performance

w_i : construct weighing, $i = 1, \ldots, 6$

I_j : Indicator $j = 1, \ldots, n_i$, n_i number of construct indicators

k : Score of the indicator evaluation, $i = 0.00; 0.25; 0.50; 0.75; 1.00$

For example, the proposed methodological benchmark was applied to a multinational company in the metalworking sector, which produces gearboxes and geared motors. The company has been certified by ISO 14001: 2004 standards for two years, presented an adequate environmental performance, meeting 92.48% of the selected indicators. Table 5 shows the results achieved by this company, wherein scores are detailed and the weighted score achieved by each of the proposed indicators.

5. FINAL CONSIDERATIONS

This paper aims to develop methodological benchmarks to measure environmental performance in companies belonging to metalworking sector. Therefore, we performed an extensive literature review of evaluation mechanisms related to environmental performance and characteristics of production processes and generated waste. Owning this information, a group of six experts systematized, from the AHP method, information from six constructs comprising 34 indicators of environmental performance. Nineteen measurement scales were created, which are suitable to the proposed indicators.

Against the backdrop of developing an script that could allow both business unit evaluation and compare it to peer companies, the developed methodological benchmark is different from these scripts presented in the literature at the following aspects: i) specific character, seeking for suitability to evaluate specific companies in the metalworking industry; ii) environmental performance evaluation in a broad way, covering various aspects involved in environmental management; iii) provide a percentage score for each indicator; iv) provide an overall percentage score for the company in question; v) specific measurement scale for each indicator.

It is noteworthy to mention that depending on the range of considered aspects, this benchmark use requires a multidisciplinary team for its practical application. It reveals the heart of environmental management, which is considered complex and deals with various subjects.

Furthermore, the benchmark is a useful tool to survey company deficiencies with respect to the indicators as demonstrated in practical applications. This tool provides subsidies to support implementation and monitoring of improvement programs of the Corporate Environmental Management.

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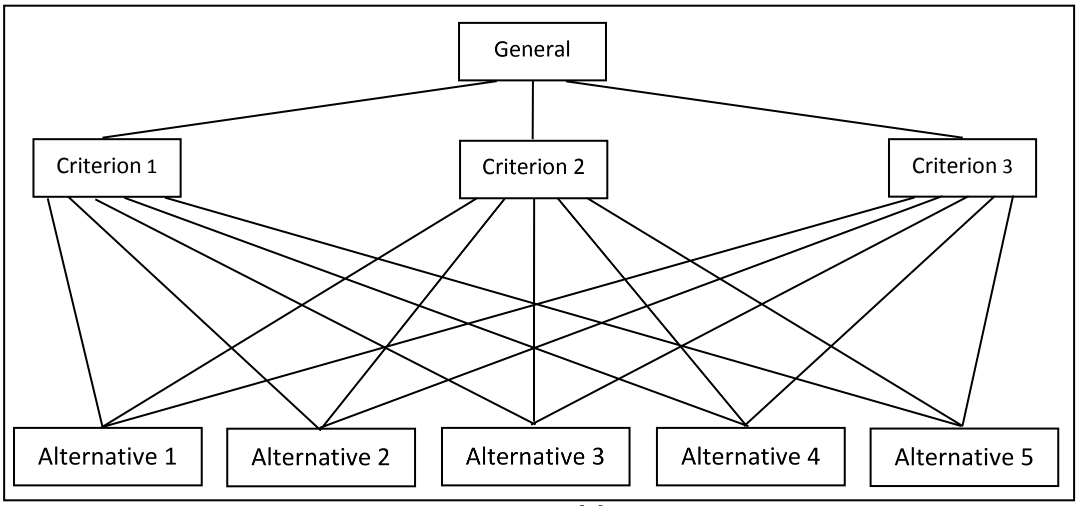
FIGURES AND TABLES



Source: Own elaboration

Expert	College degree	Experience
1	Environmental manager	3 years
2	Production engineer	7 years
3	Mechanical engineer	10 years
4	Environmental manager	12 years
5	Mechanical engineer	7 years
6	Manager	15 years

Table 1 – Skills of the expert team
Source: Own elaboration

Importance level	Weight	Note
1	Same importance	Both attributes contribute to the goal
3	Low importance of one over the other	Experience and judgement favors slightly one attribute in detriment to the other
5	Great importance or essential	Experience and judgement favors strongly one attribute in detriment to the other
7	Very great importance	An attribute is strongly favored in detriment to the other; its importance is shown in the practice
9	Absolute importance	The evidence favors an attribute relative to another with the highest degree of certainty
2, 4, 6, 8	Intermediate values between adjacent values	Seeking for good condition between two definitions

Table 2 - Factors for parity comparisons
Source: Adapted from OLIVEIRA et al. (2011, p.7)

ASPECT (Construct)	REFERENCES
Atmospheric emissions	SELLITTO et al. (2010); LUZ et al. (2006); CASTRO et al. (2005); ANTONOV e SELLITTO (2011); ALMEIDA e SELLITTO (2013); STREZOV et al. (2013); DELAI e TAKAHASHI (2011); UCKER et al. (2012); SOUZA et al. (2004); RODRIGUES et al. (2014); LI e HUI (2001); RAMALHO e SELLITTO (2013); CAMPOS e MELO (2008); GUNTHER e KAULICH (2005); JABBOUR et al. (2014); ZHU et al. (2007); CANTER (1999); GRI (2006); RODRIGUES et al. (2015); JUNG et al. (2001); GUINÉE et al. (1993); ZOBEL et al. (2002); SILVA e AMARAL (2011); REBELATO et al. (2013); JASCH (2000).
Wastewater	SELLITTO et al. (2010); LUZ et al. (2006); CASTRO et al. (2005); ANTONOV e SELLITTO (2011); ALMEIDA e SELLITTO (2013); UCKER et al. (2012); SOUZA et al. (2004); RODRIGUES et al. (2014); LI e HUI (2001); RAMALHO e SELLITTO (2013); CAMPOS e MELO (2008); ZAMBRANO e MARTINS (2007); ZHU et al. (2007); JUNG et al. (2001); VELEVA e ELLENBECKER (2001); IChemE (2006); GRI (2006); RODRIGUES et al. (2015); DELAI e TAKAHASHI (2011); ZOBEL et al. (2002); REBELATO et al. (2013); JASCH (2000).
Solid waste	SELLITTO et al. (2010); LUZ et al. (2006); CASTRO et al. (2005); ANTONOV e SELLITTO (2011); ALMEIDA e SELLITTO (2013); UCKER et al. (2012); RODRIGUES et al. (2014); LI e HUI (2001); RAMALHO e SELLITTO (2013); CAMPOS e MELO (2008); ZAMBRANO e MARTINS (2007); JABBOUR et al. (2014); ZHU et al. (2007); CANTER (1999); JUNG et al. (2001); VELEVA e ELLENBECKER (2001); IChemE (2006); GRI (2006); SHEN et al. (2013); RODRIGUES et al. (2015); DELAI e TAKAHASHI (2011); ZOBEL et al. (2002); SILVA e AMARAL (2011); REBELATO et al. (2013); TAHIR e DARTON (2010); JASCH (2000).
Resource use	SELLITTO et al. (2010); LUZ et al. (2006); CASTRO et al. (2005); ANTONOV e SELLITTO (2011); ALMEIDA e SELLITTO (2013); STREZOV et al. (2013); DELAI e TAKAHASHI (2011); UCKER et al. (2012); SOUZA et al. (2004); RAMALHO e SELLITTO (2013); CAMPOS e MELO (2008); GUNTHER e KAULICH (2005); ZAMBRANO e MARTINS (2007); ZHU et al. (2007);

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	CANTER (1999); JUNG et al. (2001); VELEVA e ELLENBECKER (2001); IChemE (2006); GRI (2006); SHEN et al. (2013); RODRIGUES et al. (2015); GUINÉE et al. (1993); ZOBEL et al. (2002); TAHIR e DARTON (2010); JASCH (2000).
Environmental management and compliance with legislation	SELLITTO et al. (2010); LUZ et al. (2006); CASTRO et al. (2005); ANTONOV e SELLITTO (2011); RODRIGUES et al. (2014); SHEN et al. (2013); RAMALHO e SELLITTO (2013); CAMPOS e MELO (2008); JABBOUR et al. (2014); ZHU et al. (2007); JUNG et al. (2001); RODRIGUES et al. (2015); DELAI e TAKAHASHI (2011); JASCH (2000).
Noise pollution	ALMEIDA e SELLITTO (2013); CAMPOS e MELO (2008); CANTER (1999); SHEN et al. (2013); RODRIGUES et al. (2015); JUNG et al. (2001); GUINÉE et al. (1993); RAMALHO e SELLITTO (2013); JASCH (2000).
Influence on vegetation and wildlife	ALMEIDA e SELLITTO (2013); CANTER (1999); GRI (2006); SHEN et al. (2013); GUINÉE et al. (1993).
Influence on microclimate	ALMEIDA e SELLITTO (2013); GUINÉE et al. (1993); ZOBEL et al. (2002).
Environmental compliance of products	DELAI e TAKAHASHI (2011); CAMPOS e MELO (2008); JABBOUR et al. (2014); ZHU et al. (2007); VELEVA e ELLENBECKER (2001); GRI (2006); RODRIGUES et al. (2015); ZOBEL et al. (2002); TAHIR e DARTON (2010); JASCH (2000).
Social action and human health	UCKER et al. (2012); DELAI e TAKAHASHI (2011); SOUZA et al. (2004); LI e HUI (2001); CAMPOS e MELO (2008); GUNTHER e KAULICH (2005); CANTER (1999); RODRIGUES et al. (2015); JUNG et al. (2001); GUINÉE et al. (1993); ZOBEL et al. (2002); TAHIR e DARTON (2010); JASCH (2000).
Suppliers	DELAI e TAKAHASHI (2011); CAMPOS e MELO (2008); JABBOUR et al. (2014); ZHU et al. (2007); RODRIGUES et al. (2015); JUNG et al. (2001); TAHIR e DARTON (2010); JASCH (2000).
Economic actions	DELAI e TAKAHASHI (2011); CAMPOS e MELO (2008); ZHU et al. (2007); CANTER (1999); RODRIGUES et al. (2015); JUNG et al. (2001); TAHIR e DARTON (2010); JASCH (2000).
Soil contamination	CANTER (1999); SHEN et al. (2013); GUINÉE et al. (1993); ZOBEL et al. (2002).

Table 3 - Key points raised and reference authors
Source: Own elaboration

CONSTRUCTS	INDICATORS	Weighing (%)	Evaluation scale
AIR EMISSIONS 6.28%	Furnace gases	40.78	1
	Particulate material	38.04	1
	Volatile Organic Compounds (VOC)	10.99	1
	Weld Fumes	10.19	1
SOLID WASTE 27.76%	Foundry sand	21.56	2
	Scrapping (metal and non-metallic)	16.18	3
	Several contaminated materials with oils, greases, paints and resins	16.14	4
	Exhaust system filter of the paint booth	10.72	5
	Burned lamps	9.96	6
	Batteries	9.87	6
	Chips (metal and non-metal alloys)	7.10	3
	Carepa welding	3.69	3
	Sweeping waste	2.58	4
	Wood	2.20	7
WASTEWATER 6.28%	Oil emulsions (oil in water)	46.16	8
	Waste oils and greases	27.41	9
	Painting booth system water (water curtain)	15.37	8
	Equipment, workpieces and floor washing water	6.72	8
	Domestic sewage	4.33	8
RESOURCE USE 14.92%	Consumption of metallic and non-metallic alloys	37.07	10
	Power consumption	21.64	10

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	Sand consumption	20.38	10
	Consumption of lubricating and cooling oils	13.23	10
	Water consumption	4.63	11
	Wood consumption	3.06	10
ENVIRONMENTAL MANAGEMENT 29.84%	Environmental Management System	45.76	12
	Environmental strategies	16.55	13
	Environmental structure	15.92	14
	Environmental projects	8.91	15
	Certified suppliers	8.53	16
	Environmental education	4.35	17
ENVIRONMENTAL COMPLIANCE 14.92%	Environmental practices in product designing	45.45	18
	Environmental techniques in process developments	45.45	18
	Reverse Logistic	9.09	19

Table 4 – Constructs, indicators and evaluation scale
Source: Own elaboration

CONSTRUCTS	INDICATORS	Evaluation score	Weighted score
AIR EMISSIONS	Furnace gases	1.0	2.561
	Particulate material	1.0	2.389
	Volatile Organic Compounds (VOC)	1.00	0.690
	Weld Fumes	0.25	0.160
SOLID WASTE	Foundry sand	1.00	5.985
	Scrapping (metal and non-metallic)	1.00	4.492
	Several contaminated materials with oils, greases, paints and resins	1.00	4.480
	Exhaust system filter of the paint booth	1.00	2.976
	Burned lamps	0.75	2.074
	Batteries	0.75	2.055
	Chips (metal and non-metal alloys)	1.00	1.971
	Carepa welding	1.00	1.024
	Sweeping waste	1.00	0.716
	Wood	1.00	0.611
WASTEWATER	Oil emulsions (oil in water)	1.00	2.899
	Waste oils and greases	1.00	1.721
	Painting booth system water (water curtain)	0.00	0.000
	Wash water of floors, equipment and workpieces	1.00	0.422
	Domestic sewage	1.00	0.272
RESOURCE USE	Consumption of metallic and non-metallic alloys	1.00	5.531
	Power consumption	1.00	3.229
	Sand consumption	1.00	3.041
	Consumption of lubricating and cooling oils	1.00	1.974
	Water consumption	1.00	0.691
	Wood consumption	1.00	0.457
ENVIRONMENTAL MANAGEMENT	Environmental Management System	1.00	13.655
	Environmental strategies	1.00	4.939
	Environmental structure	1.00	4.751
	Environmental projects	1.00	2.659
	Certified suppliers	0.75	1.909
	Environmental education	1.00	1.298
ENVIRONMENTAL COMPLIANCE	Environmental practices in product designing	0.75	5.086
	Environmental techniques to develop processes	0.75	5.086
	Reverse Logistic	0.50	0.678
TOTAL			**92.482**

Table 5 – Scores reached by the evaluated company
Source: Own elaboration

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APPENDICES

Appendix A. Evaluation scale 1

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It has control and exhaust systems, but does not make specific monitoring	0.25
3	It has control and exhaust systems, monitors emissions with specific indicators	0.50
4	It has control and exhaust systems, monitors emissions with specific indicators and sets reduction targets	0.75
5	Besides monitoring generation and setting reduction targets, it invests in technologies to reduce generation	1.00

Appendix B. Evaluation scale 2

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It stores waste in the plant building and/ or perform allocation to unlicensed landfill (Class II)	0.25
3	It has waste management and control (proper allocation) and monitors generation using specific indicators	0.50
4	It has waste management and control, monitors generation using specific indicators e set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, invests in technologies to reduce generation	1.00

Appendix C. Evaluation scale 3

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It has a place to store waste, routes waste to recycling, however, it does not perform waste management or control	0.25
3	It has waste management and control (proper allocation) and monitors generation using specific indicators	0.50
4	It has waste management and control, monitors generation using specific indicators e set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, invests in technologies to reduce generation	1.00

Appendix D. Evaluation scale 4

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It routes residue together with the regular trash	0.25
3	It has waste management and control (proper allocation) and monitors generation using specific indicators	0.50
4	It has waste management and control, monitors generation using specific indicators e set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, has awareness campaigns for employees	1.00

Appendix E. Evaluation scale 5

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It routes residue together with the regular trash	0.25
3	It has waste management and control (proper allocation) and monitors generation using specific indicators	0.50
4	It has waste management and control, monitors generation using specific indicators e set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, invests in technologies to reduce generation	1.00

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Appendix F. Evaluation scale 6

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It routes residue together with the regular trash	0.25
3	It routes to the lamp supplier, however, it does not control treatment	0.50
4	It has waste management and control, monitors generation using specific indicators e set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, invests in surrogate technologies or to reduce generation	1.00

Appendix G. Evaluation scale 7

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It burns waste and routes it together with regular trash	0.25
3	It sends waste for incineration, but does not have control over who is going to receive	0.50
4	It has waste management and control, monitors generation using specific indicators e set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, invests in technologies to reduce generation	1.00

Appendix H. Evaluation scale 8

Scale	Description	Value
1	It does not perform specific actions	0.00
2	Residue is launched into public sewage treatment	0.25
3	It has effluent management and control and monitors generation using specific indicators	0.50
4	It has effluent management and control, monitors generation using specific indicators and set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, it has an effluent and Sewage Treatment Station (ESTS) or routes it to an adequate treatment	1.00

Appendix I. Evaluation scale 9

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It has a store, however does not perform destination control	0.25
3	It has effluent management and control (proper allocation and treatment) and monitors generation using specific indicators	0.50
4	It has effluent management and control, monitors generation using specific indicators and set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, invests in technologies to reduce generation	1.00

Appendix J. Evaluation scale 10

Scale	Description	Value
1	It does not perform specific actions	0.00
2	Monitoring is performed singly trough consumption costs	0.25
3	Monitoring is performed with specific indicators	0.50
4	Monitoring is performed with specific indicators and set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, invests in technologies to reduce generation	1.00

Appendix K. Evaluation scale 11

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It has flow and consumption meter; however, it does not perform monitoring	0.25
3	Monitoring is performed with specific indicators	0.50
4	Monitoring is performed with specific indicators and set reduction targets	0.75
5	Besides monitoring generation and set reduction targets, has awareness campaigns for employees	1.00

Appendix L. Evaluation scale 12

Scale	Description	Value
1	It does not have an Environmental Management System (EMS), neither has intention to deploy it	0.00
2	It does not have an EMS but is planning to deploy it	0.25
3	It does not have an EMS but is under implementation process	0.50
4	It has deployed EMS	0.75
5	It has deployed and certified EMS with indicators to show its evolution and continuous improvement	1.00

Appendix M. Evaluation scale 13

Scale	Description	Value
1	It does not have specific environmental strategies	0.00
2	It has informal environmental strategies	0.25
3	It has strategies set by department, including some environmental issues	0.50
4	It has environmental strategies formally defined (documented)	0.75
5	It has environmental strategies formally defined (documented) and integrated with other strategies	1.00

Appendix N. Evaluation scale 14

Scale	Description	Value
1	Lack of a specific area and/ or structure for environmental issues	0.00
2	One employee deals with environmental issues within his/ her assignments	0.25
3	One employee fully dedicated to environmental issues	0.50
4	An specific department takes care of environmental issues	0.75
5	An specific department takes care of environmental issues, which operates in the whole company under defined targets	1.00

Appendix O. Evaluation scale 15

Scale	Description	Value
1	It has no specific environmental projects	0.00
2	It has informal environmental projects	0.25
3	It has environmental projects by department, but in an unstructured way	0.50
4	It has environmental projects formally defined (documented)	0.75
5	It has environmental projects formally defined (documented) and integrated with other company projects	1.00

Appendix P. Evaluation scale 16

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It has suppliers with environmental certification, but does not prioritize certified companies	0.25
3	It has a process of environmental qualification for suppliers, but does not prioritize a	0.50

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	business relationship on the basis of environmental qualification	
4	It has a process of environmental qualification for suppliers and prioritizes a business relationship on the basis of environmental qualification	0.75
5	It only negotiates with suppliers, which has environmental certification	1.00

Appendix Q. Evaluation scale 17

Scale	Description	Value
1	It does not develop specific environmental education actions	0.00
2	The company provides environmental information to employees during their integration	0.25
3	It has a structured process of environmental education for the employees	0.50
4	It has a structured process of environmental education for its own employees and outsourced ones	0.75
5	It has a structured process of environmental education for its own employees, outsourced ones and *stakeholders*	1.00

Appendix R. Evaluation scale 18

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It uses environmentally friendly techniques when required by a customer	0.25
3	It uses environmentally friendly techniques only when there is guaranteed financial return	0.50
4	It uses environmentally friendly techniques in most of its further developments	0.75
5	It uses environmentally friendly techniques in all of its further developments	1.00

Appendix S. Evaluation scale 19

Scale	Description	Value
1	It does not perform specific actions	0.00
2	It has informal environmental practices	0.25
3	It uses reverse logistic, but not constantly and structured way	0.50
4	It uses reverse logistic formally defined (documented)	0.75
5	It uses reverse logistic formally defined (documented) and integrated with other activities in the company	1.00