# A LEAN AND CLEANER PRODUCTION BENCHMARKING METHOD FOR SUSTAINABILITY ASSESSMENT: A STUDY OF MANUFACTURING COMPANIES IN BRAZIL

Aline Ribeiro Ramos[1], alinerr83@gmail.com
João Carlos Espíndola Ferreira[1], j.c.ferreira@ufsc.br
Vikas Kumar[2], vikas.kumar@uwe.ac.uk
Jose Arturo Garza-Reyes[3], j.reyes@derby.ac.uk
Anass Cherrafi[4], anass.charrafi@ced.uca.ma
[1] Universidade Federal de Santa Catarina, Mechanical Engineering Department, Florianópolis, SC, 88040-900, Brazil
[2] Bristol Business School, University of the West of England, Bristol, BS16 1QY, United Kingdom
[3] Centre for Supply Chain Improvement, The University of Derby, Campus, Derby, DE22 1GB, United Kingdom
[4]Cadi Ayyad University, Av. Abdelkrim Khattabi, B.P. 511 – 40000, Marrakech, Morocco

**Abstract:** A constant evolution in the efficiency of production systems and government policies has enabled the control of the environmental impact of production activities and encouraged companies to develop strategies to achieve more sustainable operations. Despite this, more needs to be done to reduce the risks of globalised production activities. In this context, evidence suggests that Lean Manufacturing (LM) and Cleaner Production (CP) make a positive contribution to the environmental performance of organisations. However, very little has been reported in the scholarly literature regarding the convergence and divergence of these two approaches. This work therefore attempts to take advantage of the synergies of LM and CP by proposing a Lean Cleaner Production Benchmarking (LCPB) method to assess the practices and culture regarding the application of CP in companies. The method considers the management aspects of people, information, products, suppliers and customers, management and processes, as well as the LM practices that contribute to a more eco-efficient production. LCPB uses a methodology based on benchmarking that was applied to 16 Brazilian manufacturing companies in order to assess their practices and performances regarding CP. The method seeks to provide a diagnosis to verify whether CP is effectively carried out by the companies, and what their performances are regarding actions beneficial to the environment. The application of LM practices that contribute to CP was also evaluated through the proposed LCPB method. The paper contributes to the theory by proving further evidence of the compatibility and synergies of LM and CP. In addition, it proposes a novel method that enables the analysis of companies' practices and performances related to CP, assesses their actions associated with sustainability, and contributes to identifying points where there is a lack and difficulty regarding CP. The proposed method helps to relate LM and CP activities, indicating that companies that seek to apply LM concepts are those that present high CP practices and performance.

**Keywords:** Cleaner Production, Lean Manufacturing, Benchmarking, Indicators, Sustainable Manufacturing.

## 1. INTRODUCTION

Over the years, rapid industrialization around the globe has, on one hand, improved quality of life, whereas on the other hand, it has had a significant negative effect on our environment (Georgiadis et al., 2006). Considering the perception of the negative impacts generated, many organizations have started to invest in re-designing processes and products to make them more sustainable. Currently, companies are considering, within the scope of their operations, the establishment of goals which consider and address environmental concerns. This has been mainly influenced by customers' behavior, changing environmental regulations, and the need to seek alternatives to reduce costs and improve quality (Garza-Reyes, 2015a; Nishitani, 2011). Customers are increasingly demanding with regard to the cost and quality of products, and more recently, the environmental impact generated by such products and their production processes. This has represented a significant change in the production business models seen over the last decades, which have now been enhanced through the adoption of various environmentally friendly practices to make products and processes more sustainable (Mont, 2002; Simpson et al., 2004). Among the most significant sustainability practices that have been integrated into the value chain of companies is Cleaner Production (CP) (UNEP, 2012). CP refers to the continuous application of an integrated economic, environmental, and technological strategy to products and processes in order to increase efficiency in the use of raw materials, water, and energy through the non-generation, minimization or recycling of waste in all production sectors (Mantovani et al. 2017; UNEP, 2001). Therefore, CP seeks to provide preventive actions aiming to minimize the impact to the environment, and avoid actions carried out only at the exit of the production system.

On the other hand, another set of practices that have contributed to sustainability are those of Lean Manufacturing (LM) (Garza-Reyes, 2015a). In this line, recent studies have demonstrated that LM can be a significant contributor to address current sustainability issues (Cherrafi et al., 2017a; Nadeem et al., 2017; Cherrafi et al., 2016; Garza-Reyes et al., 2016; Chiarini, 2014; Jabbour et al., 2013). Consequently, Lean and Green initiatives have been merged to deploy operational strategies that aim at not only helping organizations to achieve their economic objectives but also improve their sustainability performance (Garza-Reyes, 2015b). The resulting merged approach, i.e. Green Lean, has recently taken relevance in the scholarly literature (e.g. Verrier et al., 2016; Cherrafi et al., 2017a; Cherrafi et al., 2016; Garza-Reyes, 2015a; Garza-Reyes, 2015b) due to the synergetic characteristics of Lean and Green and the positive results associated to their integration.

In the same way, both LM and CP contribute to improving productivity, quality and enable the optimization of materials and other resources (Verrier et al., 2016; Yüksel, 2008), indicating also some synergetic characteristics between the two (Bergmiller and McCright, 2009). CP and LM have similar points for deployment in an organization, and together they can complement each other as they link systemic elements to waste reduction goals. LM deals with aspects of waste (Chiarini, 2014; Dües et al., 2013) whereas CP focuses on the inputs and outputs of raw material, resources, energy, water, among other resources (Silva et al., 2017). Dües et al. (2013) listed some differences between lean and green (which is related to CP) practices and they are: (a) the lean customer is driven and satisfied by achieving cost and lead time reduction, whereas the green customers are satisfied when the products help them being more environmentally friendly; (b) lean practices focus on performance and cost maximization, while green practices apply methods such as life-cycle assessment (LCA) to design the products so that every step in the product life-cycle is optimized from an environmental point of view; (c) in a lean environment the replenishment frequency of raw material or semi-finished product output is high since very little inventory is maintained. However, frequent replenishment results in an increase of transportation, which increases $CO_2$ emissions, contradicting the $CO_2$ reduction principles of green practices.

According to EPA (2007), both CP and LM seek to foster an organizational strategy that emphasizes employee involvement in problem solving and the search for improvement. Based on these similar characteristics, King and Lenox (2001) suggest that LM can be considered green, or rather, it leads to CP. Furthermore, Bergmiller (2006) identified that the infrastructure destined for LM serves as a catalyst to obtain improved CP results. Bergmiller and McCright (2009) conducted a study to explore the correlation between LM and CP. The results suggested that when CP is deployed in conjunction with LM, CP boosts LM, mainly in relation to production costs. Thus, their study generally concluded that there is a synergetic effect between the two when applied together. Silva et al. (2017) deployed a CP initiative under the umbrella of the LM's PDCA approach in a Brazilian beverage organization. Put together, this evidence suggests that similarly to Lean and Green, LM and CP can also synergize their philosophies, practices, methods and tools to obtain improved sustainability results in a company's operations. However, very little about this synergy has been reported in the scholarly literature (Silva et al., 2017; Bergmiller and McCright, 2009), especially compared to the now relatively extensive literature on Green Lean (e.g. Abreu et al., 2017; Verrier et al., 2016; Cherrafi et al., 2017a; Cherrafi et al., 2016; Garza-Reyes, 2015a; Garza-Reyes, 2015b).

To address this research gap, this paper proposes a Lean Cleaner Production Benchmarking (LCPB) method to assess the practices and culture of the application of CP in organizations. According to Kuriger et al. (2011), to succeed in the combination of LM and CP, it is important to work with appropriate assessments/indicators that combine production and sustainability metrics (Abreu et al., 2017; Campos et al., 2015). Therefore, the proposed LCPB method is based on evaluating the management aspects of people, information, products, suppliers and customers, management and process, as well as the LM practices that contribute to a more eco-efficient production. The method centres on the benchmarking methodology, and it was applied in some organizations to assess their practices and performances regarding CP. Often companies do not have a structure focused on CP, but because of actions in the context of LM, they may indirectly contribute to achieve CP. For this reason, the proposed method also evaluates the application of LM practices that contribute to CP.

The rest of the paper is divided as follows: in Section 2 the literature review is presented; Section 3 contains a description of the proposed Lean Cleaner Production Benchmarking method; the results and analysis are presented in Section 4; and in Section 5 the conclusions are presented.

## 2. LITERATURE REVIEW

In this section we delve into the factors that underpin the proposed Lean Cleaner Production Benchmarking (LCPB) method. Therefore, in this review we focus on discussing the background, main characteristics and benefits of CP, the relationship of LM and the environment, and lean benchmarking.

### *2.1 Cleaner Production (CP)*

Historically, CP dates back to the 1980s, when programs based on this concept and aimed at transforming the unsustainable patterns of production prevailing in various locations were initiated from Greenpeace campaigns of the United Nations Industrial Development Organization (UNIDO) (Santos et al., 2015). CP seeks the conservation of raw materials and energy in production processes, eliminating toxic materials and aiming at reducing the toxicity of all wastes before they are generated by a process (UNEP/Unido, 2017). Regarding products, CP focuses on their life cycle and seeks to reduce the environmental impact from the extraction of raw materials to its final disposal. CP acts comprehensively and directly at the source, seeking to evaluate the: (1) processes of extraction and quality of raw materials; (2) energy used (i.e. generation, distribution, and consumption); (3) type of transport used to supply the process, until the distribution of the products; (4) characteristics and volume of the packages adopted, checking their destination after their use and the possibility of recycling; and (5) use and final destination of the product after the end of its useful life (such as recycling and the implications of disposal) (Schaltegger et al., 2008).

With the implementation of CP, companies can better understand its industrial processes, through their constant monitoring, to maintain and develop an eco-efficient production system. According to Zeng et al. (2007), CP should be integrated into Quality, Environmental Management, and Occupational Health and Safety systems. This will provide a comprehensive management system to organizations. Similarly, the implementation of CP provides a number of advantages. Nilsson et al. (2007) sum up benefits that include reductions in the: consumption of raw materials and resources, volume and load to be treated in water and liquid effluents treatment plants, materials to be disposed of in landfills, number of accidents, and costs as well as the ease of compliance with environmental legislation. In addition, CP implementation also leads to the improvement of products and processes, and the application of new technologies that altogether can increase competitiveness and improve the image of a company.

The development of a structure for pollution control is an incentive to the adoption of CP, since the costs of end-of-pipe techniques become higher, and this reduction of expenses favors the economic return of investments in process improvements (Silva et al., 2017). However, in countries where environmental legislation is not yet well structured, CP represents an opportunity to reduce environmental impacts, thus contributing to the preservation of the environment. Since 1994, the United Nations Environment Program (UNEP), in partnership with UNIDO, has established the National Cleaner Production Centers (NCPCs) program to encourage the creation of centers, especially in developing countries (UNIDO, 1999). The centers provide basic services such as disseminating the benefits of this strategy, personalized technical assistance to companies, training specialists and building local capability, disseminating technical information, assisting in the preparation of investment projects and assisting local government (UNEP/UNIDO, 2017).

### *2.2 Lean and the Environment*

Various researchers have recently started to explore and address environmental concerns with the support of methods and tools that were traditionally employed to drive operational and quality improvements (e.g. Abreu et al., 2017; Cherrafi et al., 2017a; Cherrafi et al., 2017b; Cherrafi et al., 2016; Verrier et al., 2016; Garza-Reyes, 2015a; Garza-Reyes, 2015b; Dües et al., 2013; etc.). This has resulted in the emergence of a research stream that has explored the integration of LM with the green paradigm, and the potential contribution of LM to enhance environmental performance.

In this line, evidence found in the scholarly literature suggests that LM and its relationship with the environment has been explored in relation to: (1) the synergies and divergences of LM and the green paradigm (e.g. Garza-Reyes, 2015a; Garza-Reyes, 2015b; Dües et al., 2013), (2) the potential benefits of integrating these two in different contexts (Garza-Reyes et al., 2016; Franchetti et al., 2009), (3) the impact of integrating LM and green practices on the performance of organizations, and (4) how they could be theoretically integrated (Cherrafi et al., 2017b; Bergmiller and McCright 2009).

Furthermore, a number of frameworks have been developed in order to enable the effect of LM on environmental performance and some of its tools adapted to also assist in its improvements. For instance, Pampanelli et al. (2014) proposed an integrated lean and green approach that resulted in the reduction of production waste and environmental impact, and one of their conclusions was that Kaizen can support sustainable manufacturing. Cherrafi et al. (2017b) presented a framework that methodically guides companies to integrate and implement green, lean and six sigma. In terms of the adaptation of LM tools to support the enhancement of sustainability and environmental performance, value stream mapping (VSM) has been one of the most widely used for this purpose (e.g. Folinas et al., 2014; Kurdve et al., 2011; Wills, 2009; Torres and Gati, 2009).

However, despite the aforementioned works provide evidence of the now relatively extensive role that LM is playing on addressing sustainability and environmental concerns, its integration with CP seems to have been far more limited (Silva et al., 2017; Bergmiller and McCright, 2009). This has been discussed and demonstrated in the Introduction section, and calls for further research in this field.

### *2.3 Lean Benchmarking*

Benchmarking was developed in the late 1970s, through a study conducted by Xerox Corporation, as a philosophy to identify, understand and replicate the best practices that helps the company to maximize its performance (Boxwell, 1994). According to Bhutta and Huq (1999), benchmarking is the process of identifying the highest standards of excellence for products, services, or processes, and then taking the necessary actions to reach those standards. In recent years, growing competitiveness and the increasing popularity of LM has demanded its benchmarking (Dal Forno et al., 2016). This is because, according to Knuf (2000), it is difficult to recognize the embracement of LM and where a company stands on this aspect in relation to other organizations (Tomelero et al., 2017).

Lean Benchmarking (LB) has the objective of generating information to support the strategic planning of LM implementation, and it can be used at both levels, i.e. general organizational or more specific (e.g. department or process) levels (Tomelero et al. 2017; Seibel, 2004). In recent years, a handful of studies have explored and considered LB as an approach to drive the improvement of processes (e.g. Tomelero et al., 2017; Dal Forno et al., 2016; Kumar and Kumar, 2016). However, its use to address environmental and sustainability issues has only been attempted by Tomelero et al. (2017). In their work, Tomelero et al. (2017) integrated environmental aspects in LB by proposing Lean Environmental Benchmarking (LEB). Their study was focused on the implementation of the LEB method for the management of cutting tools. Realizing the potential benefits of synergizing LM and CP to assess CP practices and the contribution of LM on these, as well as the effectiveness of LB/LEB to evaluate performance, this study proposes a Lean Cleaner Production Benchmarking (LCPB) method. This method is discussed in detail in the upcoming sections.

## 3. LEAN CLEANER PRODUCTION BENCHMARKING (LCPB) METHOD

In this section, the steps taken for the development of the LCPB method are presented. These include: the definition of the companies to be studied, the data collection instrument, the methodology for applying the proposed LCPB method, and the analysis and interpretation of results obtained from its application.

### *3.1. General Overview of the LCPM method*

The proposed LCPB method was developed in order to understand how companies are acting in relation to CP. The following variables were evaluated: (a) Management/Responsibility, (b) People, (c) Information, (d) Supplier/Organization/Customer relationship, (e) Product Development, (f) Production Processes. These variables were gathered from different publications, in which they were not structured as proposed in this paper (Hourneaux et al., 2014; Gunasekaran and Spalanzani, 2012; Lee, 2009; Altham, 2007; Handfield et al., 2002; Jasch, 2000). These variables are related to CP and can hence contribute to a lower environmental impact. Also, a checklist for evaluating LM practices was proposed in order to understand and assess which practices are most applied. For the structuring of this checklist, only LM practices that contribute to environmental sustainability, according the literature, were considered (Pampanelli et al., 2015; Yusup et al., 2015).

The proposed LCPB method seeks to identify how companies behave towards a more sustainable production, that is, if they are adopting measures that result in a lower environmental impact, considering products and processes, through preventive actions.

### *3.2. Definition of Companies*

Medium and large manufacturing companies were selected to participate in this research, since these companies usually have a well-defined organizational structure in order to allow investments in the implantation of LM and CP. Each of the selected medium and large companies were approached in person.

Initially, 74 companies were contacted in the southern region of Brazil. The companies were provided with detailed information on the objectives of the research and how it would be carried out. In the end, 16 companies accepted to participate in the study, making themselves available to answer the questionnaire prepared to evaluate Cleaner Production.

### *3.3. Data Collection Instrument*

A questionnaire instrument was prepared with the purpose of having a diagnosis of the practices of the companies, enabling the decision for preventive actions regarding the preservation of the environment. One or more employees from the participant organizations filled the questionnaire. The participation of two or more employees was required in cases where process and product issues were broad in the company's structure. Each meeting, aimed at completing the questionnaire, with the companies lasted approximately 90 minutes.

The questionnaire initially sought information regarding the participant company. This information included: number of employees, deployed certifications, annual turnover, segment, company capital composition (national and international), percentage of the market in which it operated (internal and external), if there was any application of a LM program, and if in this LM program there were concerns focused on evaluation and studies aimed at reducing the environmental impact. Some of the questions present in the questionnaire are below:

1. Is there any official program for cleaner production? Yes ( ) Since when? ____________ No ( )
2. When applying value stream mapping (VSM), the environmental impacts resulting from the process are considered? Yes ( ) No ( )
3. Check one of the alternatives regarding the status of the company about the application of the environmental standard ISO14000:

   ( ) Not considered
   ( ) Interested in future deployment
   ( ) There is planning for future deployment
   ( ) Currently deploying
   ( ) Implemented successfully
   ( ) ISO 14000 certified. How many years has it been certified for? _________

The name of the companies participating in this research is not disclosed due to confidentiality reasons. Each company is hence identified as E01, E02, E03, etc.

### *3.4. Lean Cleaner Production Benchmarking Method*

The Lean Cleaner Production Benchmarking (LCPB) method is structured based on six variables that have been identified as fundamental to the successful implementation of CP. These variables include (1) Management/Responsibility; (2) People; (3) Information; (4) Supplier/Organization/Customer; (5) Product Development; and (6) Production Process. It is worth mentioning that the LCPB method seeks to provide a diagnosis to verify whether CP is effectively carried out by the companies, and what their performances are regarding preventive actions to the environment.

#### *3.4.1. Evaluation Phase*

The purpose of this phase is to carry out the assessment of the 62 developed indicators related to CP, which compose the proposed LCPB method. The indicators within each of the six variables are divided between practice indicators (PR) and performance indicators (PF), as shown in Figure 1.

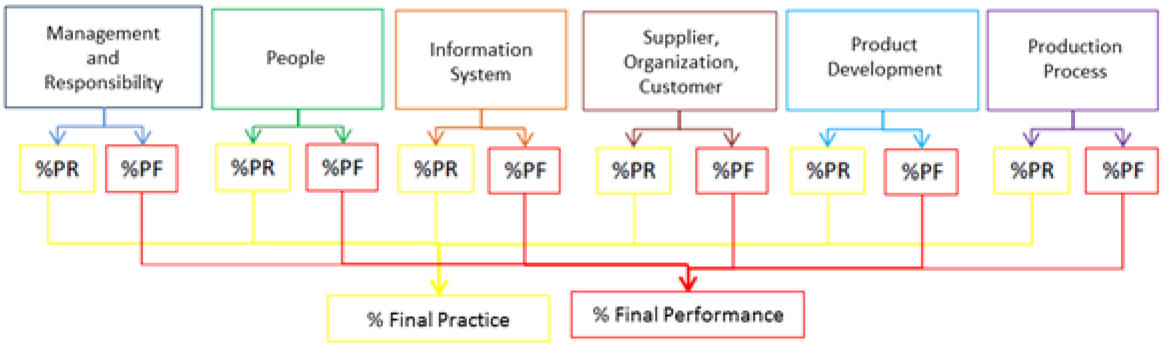



**Figure 1. Variables to asses Practice and Performance**

The definition of the indicators that compose the LCPB method was derived from the extensive literature review on the themes related to this research, and some of those publications are Hourneaux et al. (2014), Altham (2007) and Jasch (2000). The structure and content of the indicators in this paper are different from those found in the literature, since most indicators are quantitative measures such as: electrical energy consumption, water consumption, wood residues, plastics residues, paper consumption, amount of scrap, materials used, etc. For the evaluation of these indicators, it was necessary to contact each company and to arrange a meeting with professionals to complete the questionnaire. The participation of more than one employee was necessary when process and product questions were very broad for the company's structure, resulting in the need for a greater precision in the answers.

In the evaluation of each indicator, a scoring system that ranged from 1 to 5 was used. The meaning of each score value is as follows:

- Score 1: the element is not deployed or there are major inconsistencies in the deployment. It corresponds to 20% of practice and performance.
- Score 2: the element is deployed, but there are minor inconsistencies in the deployment. It corresponds to 40% of practice and performance.
- Score 3: the element is fully deployed. It equals 60% of practice and performance.
- Score 4: the element is fully deployed and has effective results. It is equivalent to 80% of practice and performance.
- Score 5: the element is fully deployed, with effective results, and exhibits continuous improvement over the past 12 months. It is equivalent to 100% of practice and performance.

The final indices of practice and performance are obtained by calculating the partial indices of practice and performance raised for each of the six variables. These final indices correspond to the current diagnosed state in relation to Cleaner Production. The consolidation of the partial results in the final result is given by a simple average based on the percentage of the partial values.

*3.4.2. Phase of Analysis of Results*

In this phase, the results of the indices obtained through the interviews are presented, using charts, for their discussion regarding the adoption of the deployed practices and the obtained performances. The following charts are used: Practice versus Performance, Radar, and Bar (Tomelero et al., 2017; Seibel, 2004).

The Practices versus Performance chart is obtained through the final indices generated from the consolidation of the partial results. The horizontal axis represents the final index of practices implemented in the company, whereas the vertical axis represents the final performance index obtained. The scale varies from 0% to 100% in both axes. The area of the chart is divided into four quadrants (Hanson et al., 1994), and each company is positioned in a quadrant, which are as follows:

(a) Quadrant I: high practice (>60%) and high performance (>60%);
(b) Quadrant II: high practice (>60%) and low performance (<60%);
(c) Quadrant III: low practice (<60%) and high performance (>60%);
(d) Quadrant IV: low practice (<60%) and low performance (<60%).

Companies located in quadrant I have the best conditions for CP concepts to be applied successfully.

Companies positioned in the second quadrant have good conditions for the implementation of CP, since they already have practices in progress, but the performance still does not correspond to the level of practices implemented. There is probably a lack of incentives or information communicated to the employees to favor the development of preventive actions, or it is necessary to investigate possible actions that will improve performance.

The companies located in quadrant III have a good performance related to CP, probably due to extreme employee effort or indirect actions such as LM, quality management and/or an environmental management system.

Finally, companies located in quadrant IV present a very unfavorable situation to implement CP. In this case, the company probably does not yet have a sufficient organizational and physical structure for a change process in order to implement CP efficiently. Investment and incentives to develop projects for CP are probably reduced, or non-existent at all.

Considering the radar chart, the standard of excellence for the evaluation of CP corresponds to 100%, in terms of practice and performance for each of the six variables under study. Sixty percent is considered as a minimum performance milestone necessary to favor and provide success in the implementation of CP. The radar chart shows the aspects (strong or weak) of each variable. The bar chart can be used to identify, for each variable, which indicators are the most developed and which ones are more deficient.

The indicators for the evaluation of practices and performance of each of the adopted variables to evaluate CP in companies are described below.

### *3.4.3. Indicators of the Variable Management and Responsibility*

In this variable, indicators were conceived to understand how companies are structured to apply CP considering the issue of management and the division of responsibilities within the structure of companies. For these, incentives and management support were considered fundamental for the successful implementation of preventive improvements. The practice and performance indicators related to the variable Management and Responsibility are presented in Table 1.

**Table 1. Practice and performance indicators related to the variable Management and Responsibility**

| Indicators | Description |
|---|---|
| | ***Practice*** |
| MR-01 | Deployment of Cleaner Production policies through a structure of qualitative and quantitative indices |
| MR-02 | Cleaner Production progress goals are defined and have been effectively communicated |
| MR-03 | There is commitment of top management to implementation of Cleaner Production |
| MR-04 | There is an incentive plan for the progress made in implementing the principles of Cleaner Production |
| MR-05 | Top management has chosen to abide by a plan for the development of Cleaner Production and not short-term operations (end-of-pipe) |

| | |
|---|---|
| MR-06 | Stimulating and encouraging atmosphere for executing the goals established by the policies of the Cleaner Production, valuing the participation of people |
| MR-07 | Employees involved in Cleaner Production are from various levels of the company |
| ***Performance*** | |
| MR-08 | Performance indicators related to Cleaner Production: This indicator has the purpose of analyzing the performance of practice indicators MR-01 and MR-02 |
| MR-09 | Deployment progress and Cleaner Production practices at all levels of the company: This indicator aims to analyze the performance of practice indicators MR-01, MR-03, MR-04, and MR-07 |
| MR-10 | Incentive of top management to the practices of Cleaner Production: This indicator seeks to analyze the performance of practice indicators MR-03, MR-04, MR-05, and MR-06 |
| MR-11 | Plan to develop Cleaner Production: This indicator analyzes the performance of practice indicators MR-01, MR-02, MR-03, and MR-05 |
| MR-12 | Availability of employees for the progress of Cleaner Production: Indicator MR-12 evaluates the performance of the practice indicators MR-06 and MR-07 |

*3.4.4. Indicators of the Variable People*

In this variable, the indicators were conceived in order to understand whether the companies actually invest in employees to obtain CP. For this, factors including training on the subject under study, eco-team formation, and availability of resources for the preparation of employees who will work towards obtaining CP were considered. The practice and performance indicators of the variable People are described in Table 2.

**Table 2. Practice and performance indicators related to the variable People**

| Indicators | Description |
|---|---|
| ***Practice*** | |
| P-01 | Availability of a training structure for employees |
| P-02 | Training programs focused on the concepts and tools for Cleaner Production at all levels of the organization |
| P-03 | Assignment of teams to implement and monitor the actions focused on the application of Cleaner Production concepts, as well as the clear specification of lines of authority. |
| ***Performance*** | |
| P-04 | Employees trained in Cleaner Production concepts: This indicator seeks to evaluate the performance of the practice indicator P-02 |
| P-05 | Teams for the application of Cleaner Production: Indicator P-05 is used to evaluate the performance of the practice indicator P-03 |
| P-06 | Top management provides resources for actions to be consistent with Cleaner Production practices: Indicator P-06 seeks to evaluate the performance of practice indicators P-01 and P-02 |
| P-07 | Trainings are often held for various audiences: This indicator analyzes the performance of the practice indicator P-02 |

*3.4.5. Indicators of the Variable Information*

The aim of this indicator is to evaluate the structure and availability of information related to CP for the whole company, considering the importance of the information to encourage as well as identify the critical factors that need more attention. It enables actions to be carried out seeking to ensure better performance aimed at reducing the environmental impact. The practice and performance indicators related to the Information variable are presented in Table 3.

| Table 3. Practice and performance indicators related to the variable Information | |
|---|---|
| Indicators | Description |
| ***Practice*** | |
| I-01 | Information is available to the entire organization as needed |
| I-02 | Knowledge is shared through the organizational structure |
| I-03 | The financial indicators are structured in a way to assess and report the advances in relation to the Cleaner Production |
| I-04 | There is a decentralization of information, which is close to the users associated with the process being analyzed |
| ***Performance*** | |
| I-05 | Updating information regarding Cleaner Production: This indicator has the purpose of evaluating the performance of the practice indicators I-01, I-02, and I-03 |
| I-06 | Reduction of expenses and costs with the adoption of Cleaner Production practices: This indicator aims to evaluate the performance of the practice indicator I-03 |
| I-07 | Dissemination of results obtained with Cleaner Production: This indicator seeks to analyze the performance of the practice I-01, I-02, and I-03 |

### *3.4.6. Indicators of the Variable Supplier/Organization/Customer*

The indicators of the variable Suppliers/Organization/Customer are used to evaluate whether there is a relationship between them during the development of products and processes in order to favor CP. The practice indicators related to the Supplier/Organization/Customer variable are described in Table 4.

| Table 4. Practice and performance indicators related to the variable Supplier/Organization/Customer | |
|---|---|
| Indicators | Description |
| ***Practice*** | |
| SOC-01 | Participation of suppliers/customers in the process of developing cleaner products and processes |
| SOC-02 | Customers and suppliers participate in continuous reviews in the area of product and process development |
| SOC-03 | Incentives with suppliers/customers to achieve Cleaner Production |
| ***Performance*** | |
| SOC-04 | Projects involving suppliers/customers in the development of cleaner products and processes: This indicator is used to evaluate the performance of the practice indicators SOC-01 and SOC-02 |
| SOC-05 | Compliance with the requirement of customers regarding the prevention of environmental impacts: This indicator evaluates the performance of the practice indicators SOC-01 and SOC-02 |

### *3.4.7. Indicators of the Variable Product Development*

The variable Product Development is intended to analyze how the studied company works towards CP in relation to its products developed and produced. The practice and performance indicators related to the variable Product Development are shown in Table 5.

| Table 5. Practice and performance indicators related to the variable Product Development | |
|---|---|
| Indicators | Description |
| ***Practice*** | |
| PD-01 | Integrated product development, with the participation of all functional areas of the company, as well |

| | |
|---|---|
| | as other agents such as customers, suppliers, third sector institutions, aimed at preventing environmental impacts |
| PD-02 | Life cycle management principles are applied in the process of developing new products |
| PD-03 | There is redesign of the products to eliminate any environmental problems related to their manufacture, use, and contributing to recycling |
| PD-04 | A material that can cause environmental problems is replaced by another material that is not problematic or causes less damage to the environment |
| PD-05 | Studies are carried out seeking to develop components so that they can be easily recycled and reused in the company's products. PD-06: Studies are carried out to increase the life of the product |
| ***Performance*** | |
| PD-07 | Reduction of the amount of material and/or components that cause damage to the environment: This indicator assesses the practice indicators PD-02 and PD-03 |
| PD-08 | Adoption of materials less harmful to the environment: This indicator assesses the practice indicators PD-02, PD-03, and PD-04 |
| PD-09 | Redesigned products with lower environmental impact. It assesses the performance of practice indicators PD-02, PD-03, PD-04, PD-05, and PD-06 |
| PD-10 | Use of recycled materials and/or components: It assesses the performance of the practice indicators PD-04 and PD -05 |
| PD-11 | Components developed to facilitate recycling: This indicator evaluates the practice indicators PD-04 and PD-05 |
| PD-12 | Increased product life: It evaluates the performance of practice indicators PD-02 and PD-06 |

### *3.4.8. Indicators of the Variable Production Process*

The variable Production Process is used to analyze how the studied company is working towards CP in the context of production. The practice and performance indicators related to the variable Production Process are shown in Table 6.

**Table 6. Practice and performance indicators related to the variable Production Process**

| Indicators | Description |
|---|---|
| ***Practice*** | |
| PP-01 | Process redesign aimed at eliminating environmental impacts |
| PP-02 | Remanufacturing: restore a used product to a "new" condition |
| PP-03 | Internal consumption: the company uses the waste it generates |
| PP-04 | Use of packaging and pallets that can be reused in the process |
| PP-05 | Transfer the responsibility for materials and waste to third parties with greater capacity to treat the material or waste |
| PP-06 | There is separation of waste during the process: an action in which waste streams of waste are separated into their individual components, before being recycled, reused or consumed |
| PP-07 | Regular reviews of value chains throughout the organization are carried out for continuous improvement and reduction of environmental impact |
| PP-08 | The company evaluates, controls and seeks to reduce the release of harmful gases into the atmosphere |
| PP-09 | The company evaluates, controls and seeks to reduce water consumption |
| PP-10 | The company evaluates, controls and seeks to reduce energy consumption |
| PP-11 | The company adopts lean manufacturing practices (technologies, methodologies, and tools) to reduce environmental impacts |
| PP-12 | The company evaluates, controls and seeks to reduce solid waste generated |
| PP-13 | The company evaluates, controls and seeks to reduce hazardous, harmful and toxic materials |
| ***Performance*** | |
| PP-14 | There was reduction of solid waste generated with the adoption of Cleaner Production. This indicator is |

| | |
|---|---|
| | used to evaluate the practice indicators PP-02, PP-03, PP-04, and PP-12 |
| PP-15 | Reduction of water consumption with the adoption of Cleaner Production. It evaluates the performance of practice indicator PP-09 |
| PP-16 | Reduction of energy consumption with the adoption of Cleaner Production |
| PP-17 | Reduction of the emission of harmful gases to the atmosphere with the adoption of Cleaner Production. It evaluates the performance of practice indicator PP-08 |
| PP-18 | Adoption of returnable packaging. This indicator verifies the performance of practice indicator PP-04 |
| PP-19 | Reduction of environmental impacts with the adoption of lean manufacturing practices (technology, methodology, and tools). This indicator assesses the performance of the practice indicator PP-11. It is worth mentioning that this indicator will also be used to evaluate the checklist developed for Lean Manufacturing practices |

### *3.4.9. Checklist of Lean Manufacturing*

Since various studies have indicated the contribution of LM to CP (e.g. Boltic et al., 2013), in this work a checklist of LM was created to verify which of its practices are being applied. The checklist developed in this work was adapted from Nogueira (2007), and is presented in Table 7. It is worth mentioning that the content of the checklist resulted from a literature survey to verify the main practices of LM that contribute to CP.

**Table 7. Checklist of Lean Manufacturing**

| | Not Applied | Very Weak | Weak | Strong | Very Strong |
|---|---|---|---|---|---|
| Rapid Exchange of Tools and Dies | | | | | |
| Jidoka | | | | | |
| Kaizen | | | | | |
| Total Production Maintenance (TPM) | | | | | |
| Cellular Manufacturing | | | | | |
| 5S | | | | | |
| JIT | | | | | |
| Quality Control – Zero Defects | | | | | |

The checklist evaluation is based on five possible answers: NA: Does not apply (weight = 0.0); VW: very weak application (weight = 2.5); W: weak application (weight = 5.0); S: strong application (weight = 7.5); VS: very strong application (weight = 10.0).

Equation (1) is used to calculate the score for each company to identify which LM practices are most used and applied in each of these.

$$SCORE = \frac{10.0 * \sum VS + 7.5 * \sum S + 5.0 * \sum W + 2.5 * \sum VW}{\sum VS + \sum S + \sum W + \sum VW + \sum NA} \quad (1)$$

## 4. RESULTS AND ANALYSIS

This section presents the results of the proposed LCPB method applied to the sixteen companies that participated in this research. Initially, the companies are characterized and, then, the general result of practices and performance of CP presented, as well as the results of the indicators for each variable. Finally, the analysis of the result of the LM checklist is presented.

### *4.1. Characterization of the Studied Companies*

Analyzing the 16 participant companies, 75% of them were classified as large companies, whereas 25% corresponded to medium-sized enterprises. The research included companies from the following industrial segments: automotive, household appliances, agricultural, metal-mechanics, metallurgy, motors, odontology, plastics, and textiles.

All the studied companies had deployed the ISO 9001 standard or were already certified - Quality Management System (QMS). On average, these management systems had been applied for a minimum of 15 years. Even if the companies did not prioritize environmental issues in their competitive strategy, when adopting and implementing a quality management system, this indirectly favors improvements in aspects related to environmental performance (Wiengarten and Pagell, 2016), as will be seen later.

Considering Environmental Management Systems (EMSs) (Kurdve et al., 2014; Jabbour et al., 2013), 10 companies (63%) had ISO 14001 certification (Campos et al., 2015; ISO, 2004). Two companies (13%) were already in the process of implementing an EMS, and 2 companies (13%) had already plans for their future deployment. Of the 10 companies that were ISO 14001 certified, five of them (50%) had an official program for CP.

OHSAS 18001 (2007) was only implemented in 25% of the studied companies, and only three of these companies were certified for Safety and Health. The companies that had implemented OHSAS 18001 were E01, E02, E07, and E09.

### *4.2. Results of Cleaner Production Benchmarking*

The majority of the studied companies (63% = 10 companies) did not present a specific program aimed at obtaining CP. The sustainable actions adopted by these companies were usually consequences of improvements mainly focused on production issues, costs, and customer requirements. The companies that adopted an official program for CP were E01, E04, E05, E07, E10, and E16.

#### *4.2.1. Overall Result of Practices and Performance*

This section presents the general results of practices and performance obtained by each studied company in relation to CP. Figure 2 shows the general results of practices and performance obtained for the 16 studied companies. Companies with a red symbol (25%) were medium-sized, whereas companies with a green symbol (75%) were large-sized organizations.

Regarding the position of the companies in the chart, 44% (7) were classified in quadrant I, 6% (1) in quadrant II, 6% (1) in quadrant III, and 44% (7) in quadrant IV. The general average of the companies classification was in quadrant IV (blue symbol), with values of 57% for practices and 57% for performance. Company E09 (large-sized) achieved the highest practice and performance indices (83% for each), while company E16 (medium-sized) obtained the second best result regarding practice (83%) and performance (78%) of CP.

Company E07 (medium-sized) was the only one located in quadrant III, presenting low practices (59%) and high performance (61%). E07 presented a high degree of application of LM practices and, therefore, these actions probably contributed to the achievement of high CP performance. In addition, E07 had implemented EMS, QMS, and OHSAS, which also contributed to the achievement of a high CP performance due to an integrated management system. However, it is important to emphasize that the level of practices (59%) obtained by company E07 was not significantly low and not so far from the adopted minimum (60%), as the level of performance obtained (61%) is neither significantly high nor so distant from the least favorable (60%) for the implementation of CP. These data permitted the identification of some improvement opportunities for company E07, which can be specified after analyzing the radar chart that describes the behavior of the indices of practices and performance.

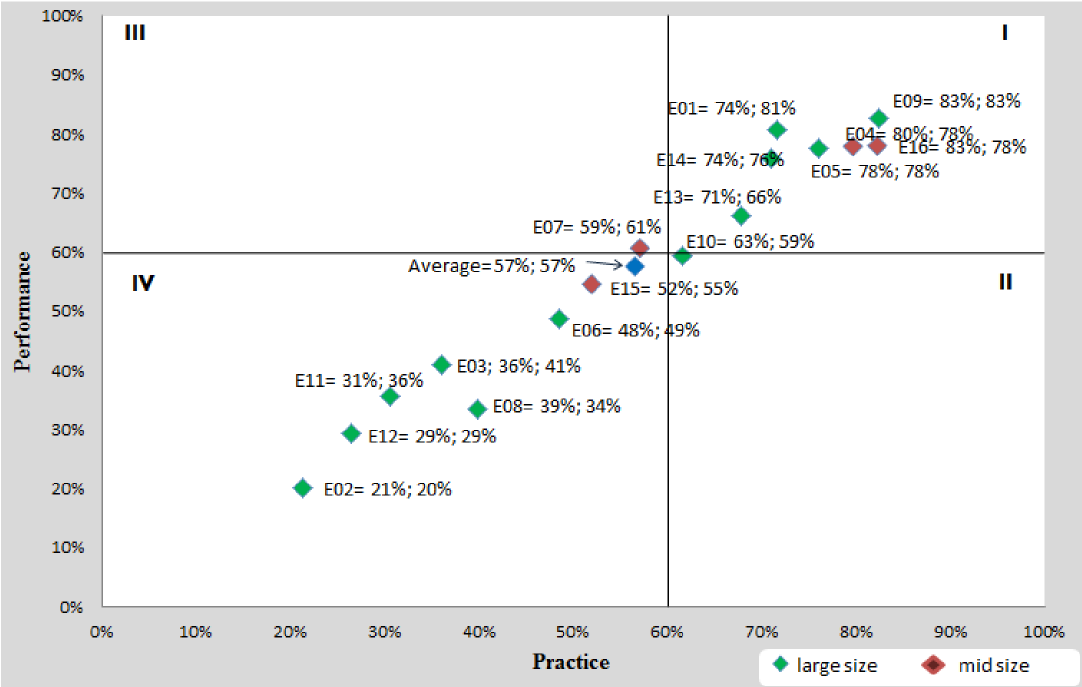



**Figure 2. General chart showing the Practices x Performance obtained by the studied companies**

Company E10 was the only one located in quadrant II, with 63% of practice and 59% of performance. This company was in the process of implementing ISO 14001, which ended up reflecting in larger values of CP practices. Its performance below 60% was due to the company was still structuring the preventive actions. In addition, this company applied some LM practices.

The seven companies located in quadrant IV presented low levels of practices and performance regarding CP. All of them had adopted ISO 9001, but only E02 and E06 had an ISO 14001 certification. Another important point is that the companies that had the lowest CP practice and performance values (E02 and E12) applied more LM practices than companies E03, E08, and E11, which were also located in quadrant IV. Analyzing in more detail companies E02 and E12, the likely explanation for these companies to present low indices of practice and performance for CP, even with some application of LM, may have been due to the actions of LM being more focused on productivity issues than on actions that contribute to CP.

There were seven companies located in quadrant I: two medium-sized companies (E16 and E04) and five large-sized enterprises (E01, E04, E05, E09, and E13). All of these companies had implemented ISO 14001 and, thus, a QMS was considered as a very important factor for obtaining CP. Kaizen (continuous improvement) was widely used in company E13 for the purpose of environmental evaluation and improvements. On the other hand, although company E09 had larger indices of practice and performance compared with E13, it did not have an official CP program, but adopted actions and practices in order to achieve eco-efficiency.

In order for companies positioned in quadrants II, III, and IV to improve their results and achieve higher performance and performance indices, it is necessary to invest in the improvement of practices. In this line, benchmarking indicators can serve as reference to identify the most critical points that need to be improved. Thus, it is recommended that: (a) for companies in quadrant II the lowest points related to performance should be analyzed; (b) companies in quadrant III should investigate which practices are the most deficient and seek to improve them; (c) companies in quadrant IV should analyze both practices and performance to achieve better results in both.

The radar chart was obtained by analyzing the average of all the companies studied as well as the average values of practices and performance for each variable that favored CP, see Figure 3.


**Figure 3. Radar Chart showing the averages of practice and performance obtained by the studied companies**

Figure 3 indicates that the points related to the practice and performance of the variable Suppliers/ Organization/Customers are positioned externally to the hexagon formed by the red line, i.e. they were above 60%. However, all the other values were below 60%, showing a deficiency in CP application for most of the variables analyzed.

For the low indices of CP practice and performance, only six companies (37%) presented a specific CP program. Although the other studied companies did not have a program for CP, they developed certain activities related to CP. Since these actions are usually reactive and unstructured, the values of both practice and performance are low.

The points located more internally to the hexagon formed by the red line are practices of Management/Responsibility, and performance of People. Due to the lack of a CP program, there is hardly any support from management to obtain it, as well as an internal structure for actions to be carried out in favor of CP. This ends up affecting mainly the variables Management/Responsibility and People.

The main factors that contributed to the low value of practice of Management/Responsibility were: there are no incentive plans for the progress made with the implementation of CP (MR-04), management chose to perform end-of-pipe actions (MR-05), lack of a stimulating atmosphere for obtaining CP (MR-06), and lack of participation of staff from various levels of the company to obtain CP (MR-07).

In the case of the low performance value of the variable People, the main factors that contributed to it were: low employee training in CP concepts (P-05), absence or low amount of teams assigned to CP actions (P-06), and low amount of training on the CP concept (P-08).

*4.2.2. Indicators' Results for each Variable*

In this section, the scores assigned to the indicators of the variables that comprise the LCPB method are presented, and for some indicators a description of the actions that the companies performed to obtain positive results is given

*(a) Results of the indicators of the variable Management/Responsibility*

The average of the company's scores for each indicator related to the variable Management/Responsibility are shown in the bar chart in Figure 4.

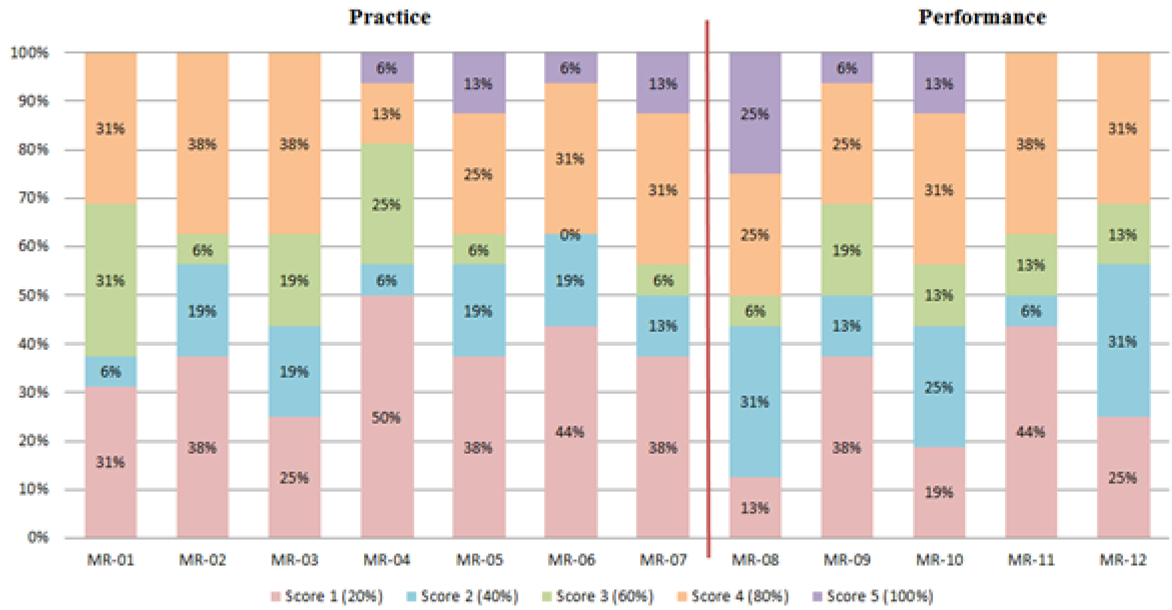



**Figure 4. Bar chart containing the average of the scores of the studied companies for each indicator of the variable Management/Responsibility**

The result for indicator MR-01 shows that companies had environmental concerns and sought the use of quantitative and/or qualitative indicators to control and reduce environmental impacts. The main indices employed were quantitative, such as water and energy consumption and solid and liquid waste generation. Five companies that had a score of 4 in the indicator MR-01 had an ISO 14001 certification, providing a detailed environmental management, and allowing the creation of indicators to control aspects related to the impact of their operations on the environment, which consequently ended up contributing to CP.

Regarding indicator MR-02, most of the interviewed companies did not present a program for CP but, even so, they sought to work in a way that generated a lower environmental impact, because they were either were in the process of implementing ISO 14001 or were already certified.

Practices referring to indicator MR-05 showed that companies were seeking to avoid end-of-pipe actions and prefer to carry out activities aimed at CP. The main actions included in CP's implementation plans were focused on: the conscious use of materials, water, and energy; the replacement of harmful materials by less detrimental ones; and product changes.

Regarding indicator MR-06, it was verified that the number of companies that stimulated the achievement of the established CP goals was low. This was due to the low availability of time for the activities to be developed, as well as the lack of investment for improvement actions.

Regarding indicator MR-10, 57% (9) of the companies had incentives from top management to achieve eco-efficiency through actions that were covered by CP. However, it was noticed that the greatest incentives were still focused on the production process, and the actions on the products were significantly reduced.

Analyzing the performance of the companies regarding a plan for the development of CP (indicator MR-11), the companies that had score 4 were those that had a program destined to CP. Companies with scores 2 and 3 did not have a CP program, but carried out actions such as ISO 14001, ISO 9001, and LM implementations, which contributed to CP.

The performance indicator MR-12, which addresses the availability of people for the progress of CP, indicated that the availability of people acting in the progress of eco-efficient actions was low.

*(b) Results of the indicators of variable People*

The average of the company's scores for each indicator of the variable People is shown in Figure 5.

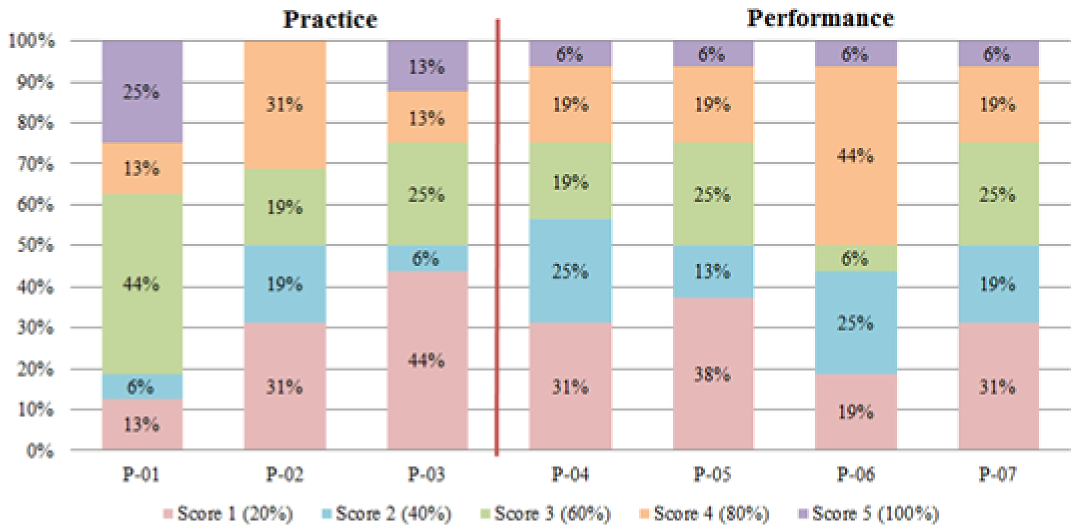



**Figure 5. Bar chart containing the average of the scores of the studied companies for each indicator of the variable People**

Figure 5 suggests that, in general, the studied companies presented a structure for conducting training. Thus, for indicator P-01, 81% (13) of the companies had available space for employees to be trained on a number of subjects, including CP.

Regarding indicator P-02, five (31%) companies did not present any type of training for the concepts of CP and sustainability, consequently obtaining a score of 1. Company E07, which implemented a CP program, had score 2 in indicator P-02, meaning that in this company CP concepts were addressed very superficially, besides the trainings being usually intended for people whose activities are directly related to the environment.

Indicator P-06 shows that top management provides resources for actions to be consistent with CP practices. Thus, it is necessary to increase the incentive of top management in order to allow the development of teams destined to CP so that adequate preventive actions are carried out.

*(c) Results of the indicators of the variable Information*

The average of the company's scores for each indicator of the variable Information is shown in Figure 6.

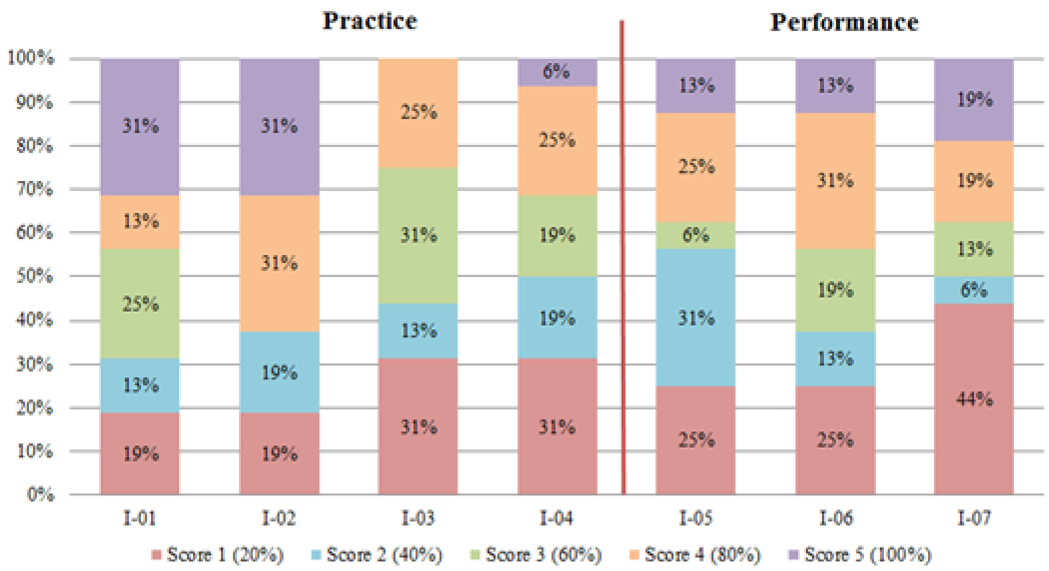



**Figure 6. Bar chart containing the average of the scores of the studied companies for each indicator of the variable Information**

For indicator I-01, 69% of the companies considered that information was available and employees had easy access to it. Regarding indicator I-02, 62% of the companies considered that knowledge of information and practices regarding CP was shared (scores 4 and 5), and only 19% (3) of the companies indicated that there was no sharing of knowledge related to CP.

According to the performance indicator I-06, 25% (4) of the companies were not able to reduce expenses with the adoption of CP practices. This result included companies that did not have an official CP program. Companies E01 and E09 obtained a score of 5 for indicator I-06. In this case, company E01 had an official CP program, whereas company E09 did not have an official program, although since 2006 it had adopted a guide to achieve CP.

Indicator I-07 showed that there was a dissemination of the results obtained with CP within the whole organization, and the results were normally displayed in a mural and distributed across the company.

*(d) Results of the variable Supplier/Organization/Customer*

The average of the company's scores for each indicator of the Supplier/Organization/Customer variable is shown in Figure 7.

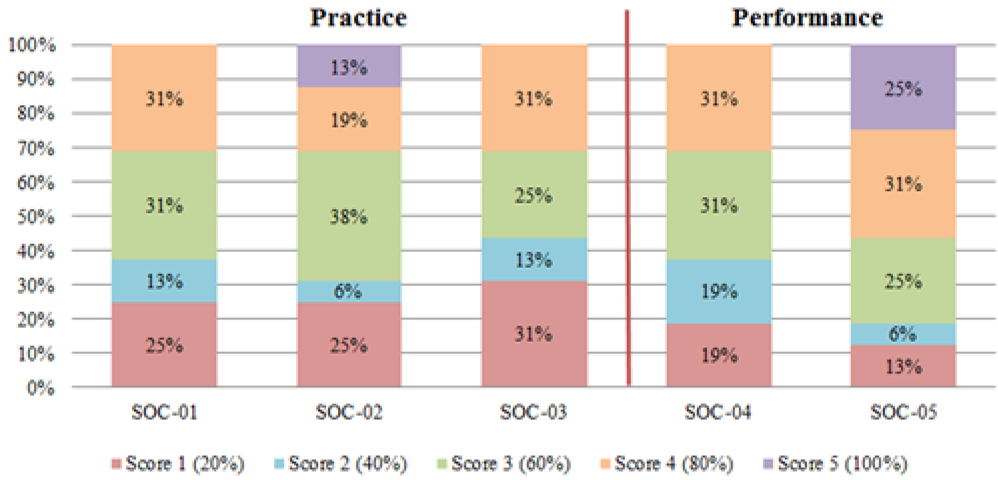



**Figure 7. Bar chart containing the average of the scores of the studied companies for each indicator of the variable Supplier/Organization/Customer**

Indicators SOC-01 and SOC-02 showed a strong participation of suppliers and customers in the process of developing new products and processes, as well as in their revision. However, the participation of suppliers and customers in the continuous revisions in the development of products and processes was much stronger.

Indicator SOC-03 indicated that companies were concerned with the processes and products adopted by suppliers and customers. In the case of suppliers, audits were usually carried out to ascertain the required environmental standards.

Performance indicator SOC-04 suggested the frequent participation of suppliers and customers in the development of cleaner products and processes.

*(e) Results of the indicators of the variable Product Development*

The fifth variable was related to product development, and its results are shown in Figure 8.

Indicator PD-01 showed the strong participation of different areas of the companies in the development of products. It was verified that the companies invested with the purpose of integrating the areas in order to reduce environmental impact.

Regarding indicator PD-02, there is a practice of life cycle management, but this practice is more focused on the process than on product.

Indicator PD-03 suggested that there were few environmental practices aimed at improving the product with a lower environmental impact. The companies carried out very few structural modifications in the products seeking to reduce environmental impact, and usually the improvements occurred through the substitution of harmful materials for less harmful materials.

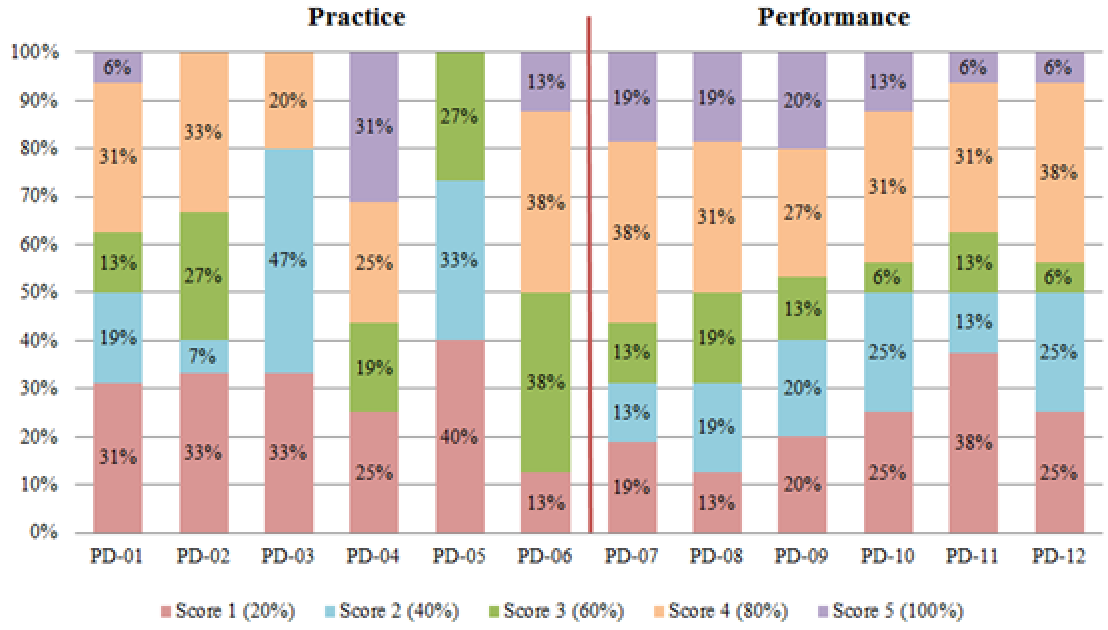



**Figure 8. Bar chart containing the average of the scores of the studied companies for each indicator of the variable Product Development**

The score of indicator PD-05 was significantly low, it corresponded to the actions of the companies to develop components so that they were easily recycled and reused in the company's products. The companies with score 3 (27%) carried out the following actions: adapted the product connections in order to favor disassembly in its reprocessing, and used a type of material in the structural parts of the product that allowed reprocessing.

Considering the performance indicator PD-10, it was observed that 50% of the companies had scores 3, 4 or 5, i.e., they used recycled materials and/or components. One of the studied companies applied reverse logistics and, in this case, some components that returned due to some failure were reused in the production line.

*(f) Results of the indicators of the variable Production Process*

The last variable refers to the production process, and the result is presented in Figure 9.

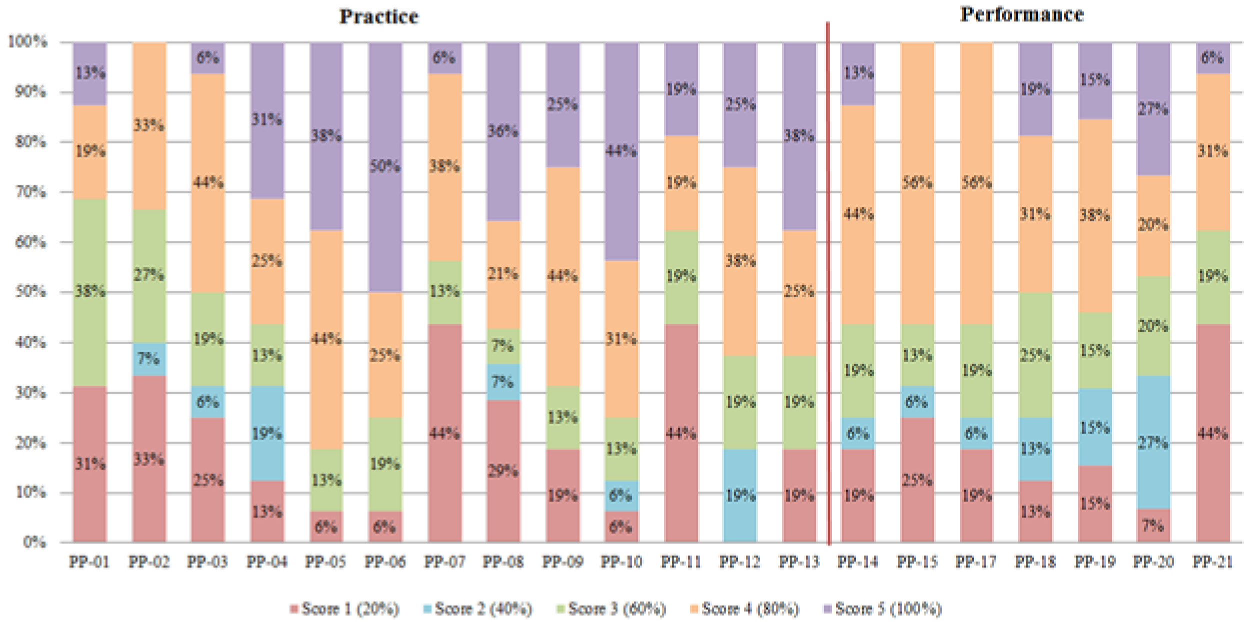



**Figure 9. Bar chart containing the average of the scores of the studied companies for each indicator of the variable Production Process**

Analyzing indicator PP-01, a large number of companies carried out the redesign of their production processes seeking to eliminate environmental impacts. Thirty one percent (5) of the studied companies did not apply redesign actions to reduce environmental impact. It was observed that the initial actions of the companies regarding the change of process were focused mainly on productivity.

The practice of using returnable packaging and pallets, represented through indicator PP-04, suggested that companies had been seeking to adopt this practice. In the majority of the companies, returnable packaging and pallets were adopted due to a request from their customers and not by an internal action aimed at reducing the environmental impact or costs associated with them.

The PP-04 practice indicator is related to the performance indicator PP-18, and it was observed that practice was higher than performance. This indicates that companies did not adopt the practice of returnable packaging for all products, raw materials or even processes.

Considering the release of harmful gases into the atmosphere (indicator PP-08), companies with scores 1 and 2 both in practice (PP-08) and in performance (PP-17) presented emission values within established standards, but did not carry out periodic control to assess the release conditions.

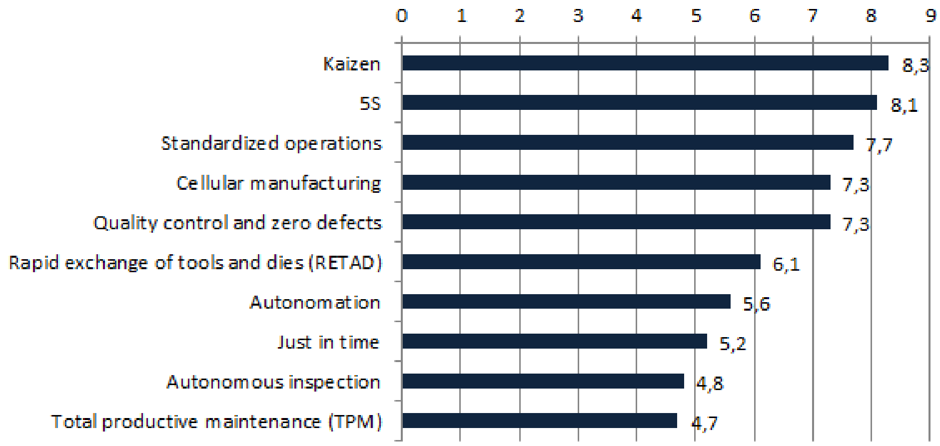
Performance indicators PP-15 and PP-16 analyzed the reduction of water and energy consumption respectively. These indicators reflect the scores obtained in indicators PP-09 and PP10. Thus, the performances of the companies were much more effective seeking the reduction of energy consumption than the consumption of water.

The performance of the PP-19 indicator indicated that the great majority of the studied companies (56%) obtained good results regarding the reduction of the environmental impact with the adoption of LM.

### *4.3. Characterization of Lean Manufacturing*

It was verified that 88% of the studied companies had an official program for LM, and the average time of implementation for such program was six years. A LM program is considered official when the company has a structure and team destined to apply the concepts and tools of LM. Companies E03, E08 and E15 do not have an official program for ME.

Company E01 achieved a “Very Strong” application of LM to obtain the CP, it was hence located in quadrant I (Figure 2). The companies that obtained a “Strong” classification (E04, E05, E09, E10 and E16) were also located in quadrant I. Companies with a “Weak” evaluation (E03, E06, E07, E11 and E12) were located in quadrant IV; two companies (E13 and E14) located in quadrant I also obtained a “Weak” classification for the application of LM to obtain CP. Through the results shown in Figure 10, the main LM practices used in the various stages of the production process were kaizen, 5S, cellular manufacturing, and standardized operations. In the evaluation of the LM practice checklist, kaizen was the LM practice that obtained the highest score in relation to the degree of application and practice in the process.




| Application | Amount of companies | Companies |
|---|---|---|
| Strong (8.0 ≤ score ≤ 10.0) | 4 | E04,E07,E09,E14 |
| Medium (6.0 ≤ score ≤ 7.9) | 7 | E01,E02,E05,E06,E10,E12,E16 |
| Weak (3.0 ≤ score ≤ 5.9) | 5 | E03,E08,E11,E13,E15 |

**Figure 10. Result of the LM checklist, and scores of the LM tools**

The result of the application of the LM checklist showed that most companies presented a score between 6.0 and 7.9 regarding the practices (Figure 10). This indicated that the implementation process of LM had not yet been consolidated in most of the studied companies and, therefore, not all of the LM practices that favor obtaining CP were applied in the companies, or were still undergoing improvement.

The application of LM practices occurred especially in the variable Production Process. Comparing the results obtained with the LCPB and the LM checklist, shown in Table 8, it was observed that of the four companies that presented an strong application of LM, three of them (E04, E09, and E14) were located in quadrant I. Companies E09 and E14 scored 4 in indicators PP-11 and PP-19, while company E04 scored 5 in indicator PP-11.

**Table 8. Some results of the LM checklist and the Lean CP benchmarking**

| | Variable PP | | PP-11 | PP-19 | Quadrant | LM Score | There is an official lean program |
|---|---|---|---|---|---|---|---|
| | Practice | Performance | | | | | |
| **E04** | 4.0 | 3.5 | 5 | 4 | I | Strong | Yes |
| **E07** | 4.0 | 4.0 | 5 | 4 | III | Strong | Yes |
| **E09** | 4.5 | 4.1 | 4 | 4 | I | Strong | Yes |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **E14** | 4.0 | 4.0 | 4 | 4 | I | Strong | Yes |
| **E01** | 3.9 | 3.9 | 5 | 4 | I | Medium | Yes |
| **E02** | 1.4 | 1.0 | 1 | 1 | IV | Medium | Yes |
| **E05** | 4.5 | 4.6 | 4 | 5 | I | Medium | Yes |
| **E06** | 3.1 | 3.6 | 1 | 1 | IV | Medium | Yes |
| **E10** | 3.2 | 3.3 | 3 | 3 | II | Medium | Yes |
| **E12** | 1.5 | 2.3 | 1 | 3 | IV | Medium | Yes |
| **E16** | 4.7 | 3.3 | 3 | 3 | I | Medium | Yes |
| **E03** | 1.9 | 1.7 | 1 | 1 | IV | Weak | No |
| **E08** | 2.3 | 1.6 | 1 | 1 | IV | Weak | No |
| **E11** | 2.7 | 2.1 | 1 | 1 | IV | Weak | Yes |
| **E13** | 4.4 | 3.9 | 3 | 1 | I | Weak | Yes |
| **E15** | 3.4 | 3.2 | 1 | 1 | IV | Weak | No |

Company E07, located in quadrant III, also had a strong application of LM: score 5 in indicator PP-11 and score 4 in PP-19. Companies that had strong LM practices (E04, E07, E09, and E14) obtained a score of practice and performance equal to 3.5 or higher.

Company E02 had the worst CP performance. However, it presented a medium application of LM practices. Therefore, although company E02 did not have a CP culture and practice, some actions adopted through LM favored the achievement of good results regarding Cleaner Production.

Among the companies that adopted indicators to verify the performance obtained by LM to obtain CP, the reduction in environmental impacts was mainly related to the reduction of energy consumption, generation of solid waste (mainly packaging), and liquids (lubricants).

## 5. CONCLUSIONS

The proposed LCPB method seeks to evaluate the application of Cleaner Production in companies of different sizes in order to diagnose the strengths and weaknesses in its application. With this diagnosis, companies can develop actions to improve their practices and performance regarding CP. With the results obtained from the proposed LCPB method regarding the practices and performance of the companies, it can be adopted by organizations as a management practice of aspects related to CP and, thus, plans and decisions can be made considering points that are not normally visualized.

It was verified that cost was the priority factor in decision-making by companies, and quality came in the second position. Then, companies sought to invest in greater flexibility for the development of products and in actions seeking to preserve the environment. Therefore, it was noticed that the studied companies did not prioritize actions and practices that caused less impact to the environment.

All the studied companies were ISO 9001 certified. In addition, ten of those companies were ISO 14001 (2004) certified, and four of those ten companies had an OHSAS 18001 (2007) certification. The results showed that the application of this Integrated Management System contributed to Cleaner Production.

Only six companies presented an official program for Cleaner Production, while the other companies that did not have this program sought to develop preventive improvements that ended up impacting directly on the environment and favoring CP. Of the six companies that had the official CP program, five of them had ISO 14001 certification, and four of those companies were positioned in quadrant I in the general practice and performance chart (Figure 2).

It was expected that large companies, by having a more organized structure and greater capital to invest in CP, would had better results regarding preventive actions beneficial to the environment. However, the results showed that two midsize companies were located in quadrant I and were among the three best results of practice and performance for CP. The midsize company located in quadrant III achieved 59% in practice, whereas the midsize company in quadrant IV achieved 55% in performance. On the other hand, six large companies were located in Quadrant IV.

It should be noted that company E09, which achieved best practice and performance (Figure 2), did not have an official CP program. Thus, although a specific program for CP was important, it was verified that a CP program was not essential for applying preventive actions in the company's processes that were effective to reduce environmental impacts.

The company with the worst result was E02, having obtained 21% for practice and 20% for performance. An interesting fact is that this company had both ISO 9001 and ISO 14001 certifications, and had implemented OHSAS 18001 (not certified). Although such integrated management system was observed in this company, the adoption of CP- related practices was very low. It was observed that this company sought to satisfy both the standards and satisfy certain customer needs, and meeting these customer requirements prevented the company from pursuing preventive actions aiming at reducing environmental impacts. Consequently, in this case the integrated management system did not contribute to obtaining CP.

The variable Production Process (PP) obtained the best score of all variables, considering all the companies studied, and the practice indicator obtained a higher score than the performance indicator. It was observed that usually the preventive actions adopted by the companies were linked to the production, and there were few actions that sought, for example, to change the product to minimize environmental impacts.

As for the feedback of the professionals of the companies studied, regarding their opinion about the proposed method, the comments made by most companies were that the method contributed significantly to their clarification regarding the CP practices, being a rich source of information that will help considerably in guiding the companies in the search for improvements and preventive actions related to the environment.

Regarding the application of LM to obtain CP, only one company considered CP in decision-making in LM improvements. In addition, five companies indicated that at least once they considered environmental aspects in improvements involving LM. Therefore, most companies claimed that they did not consider aspects of CP in LM improvements and practices and, therefore, the reduction of the environmental impact in these companies was due to improvements implemented exclusively related to LM.

With the application of the LM checklist, it was verified that companies with high practice and performance (located in quadrant I) presented a strong application of lean practices. The scores for these companies varied from 3 to 5 for practice indicator PP-11 (adoption of LM practices to reduce environmental impacts) and performance indicator PP-19 (reduction of environmental impacts with the adoption of LM practices).

The vast majority of companies located in quadrant IV present the result of the LM checklist as "Weak". In addition, for the vast majority of these companies the scores for indicators PP-11 and PP-19 were 1. Therefore, it is important that companies are aware of the contribution of LM to CP.

One difficulty of the proposed LCPB method is the application of the questionnaire in companies, as often companies are reluctant in completing questionnaires.

From the results obtained and observations made throughout this research, the following future research directions are suggested: (a) application of LCPB method in a larger number of companies, including small enterprises. In this way, a larger database can be created, contributing to a better understanding of the current situation of companies regarding the application of preventive actions regarding the environment; (b) evaluating the influence of variables such as numbers of employees, annual turnover, company segment, company capital composition, and percentage of the market on the practices and performances of companies; and (c) performing a study to follow the application of LM and its contribution to obtaining CP, and structuring indicators to show the effective reduction of environmental impacts.

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