BJ O&PM

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ISSN 2237-8960
Brazilian Journal of Operations & Production Management

STREAMLINED LIFE CYCLE ASSESSMENT TOOL FOR INJECTION MOLDING OF PLASTIC COMPONENTS: A LITERATURE REVIEW

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ABSTRACT

Goal: Companies are increasingly concerned about the life cycle of their products in the economic and environmental perspectives. One of the processes that generates great financial returns is the injection molding process. But this process results in many impacts to the environment. The environmental concern has generated many studies involving this theme and the difficulty of measuring the impacts generated by this process. In view of the environmental concern and the injection molding process this study aims to review ~~in~~ the literature on eco-design tools based on the Streamlined Life Cycle Assessment of plastic injection molded products.

Design / Methodology / Approach: The review of the literature was carried out by researching for complete articles published in three databases (Science Direct, Scopus and Web of Science), among the years 2013 - 2018, using combinations of keywords and Boolean operators.

Results: Several studies revealed that injection molding generates many impacts, such as the high consumption of electricity caused by the emission of greenhouse gases and use of raw material.

Limitations of the investigation: This paper is not free of limitations. The study analyzed the literature through three databases for a period of time and used a combination of keywords. It may be that some document has not been analyzed.

Practical implications: The development of a rapid tool for the application of LCA studies will allow quick decision-making to the managers in the environmental perspective, besides reducing costs, reducing time with the application of complex studies, and assisting the designer to develop the Eco-design.

Originality / Value: The study addressed the injection molding process and there are no studies in the literature that characterize this theme. Thus, a study that addresses this gap and evidences the importance of the development of an environmental tool that assists sustainable practices in the process of plastic injection molding becomes important.

Keywords: Sustainability; Plastic injection; Eco-design; LCA; Innovation; Evaluation tool.

ABEPRO
DOI: 10.14488/BJOPM.2019.v16.n1.a2

Brazilian Journal of Operations & Production Management
Volume 16, Número 1, 2019, pp. 33-42
DOI: 10.14488/BJOPM.2019.v16.n1.a3

1. INTRODUCTION

The organizational concern for environmental management is growing around the world. The need for the use of natural materials in the production process has stimulated the evaluation of the environmental performance of several production systems, aiming the development of sustainable solutions and improvements (Salvador et al., 2016). In this sense, the integration of environmental performance in product development projects in companies, seeks to achieve environmental improvements in their activities, aiming to reduce the negative effects generated during the process (ISO, 2006a).

The development of products with an environmental conscience allows companies to adopt sustainable measures, involving the use of tools that evaluate the production process in order to quantify potential environmental impacts (Chang et al., 2014). In this context, eco-design is observed as a tool that allows considering the environmental aspects in the life cycle of products. However, this tool does not quantify environmental impacts, and it is necessary to use a tool in parallel for this measurement (Zafeirakopoulos et Genevois, 2015).

Therefore, the union of the use of eco-design and a Life Cycle Assessment (LCA) allows finding steps that have potential environmental impacts and environmental performance evaluations (Zafeirakopoulos et Genevois, 2015). In addition, it allowed the analysis of different levels of eco-efficiency and socio-environmental impacts (Viana et al., 2016).

However, LCA is seen as a complex tool to promote environmental management because it consumes time and resources. In some cases its application may become impractical. Thus, the Streamlined LCA arises to use less time for its accomplishment, to lower costs and resources, but with the same truthfulness of the results of a complete LCA (Alvarenga et al., 2012).

One of the most consumed products in the society are those that use plastic. Thus, the environmental concern regarding its production, injection molding and its final disposal arises. Even with a large number of benefits related to this process, such as cost reduction and high production rate, there is a significant generation of environmental impacts related to energy use and Greenhouse Gas (GHG) emissions (Cheung et al., 2017).

Given the environmental concern in the production processes, a study that raises the tools that can be used to quantify the potential environmental impacts in different processes becomes important. Therefore, the present study aims to review the literature on eco-design tools based on the Streamlined Life Cycle Assessment of plastic injection molded products.

This study presents an opportunity to build an environmental tool for the injection molding process because a tool for this purpose has not been found in the literature. This leads to the generation of a study gap that must be met, in view of growing environmental concern and importance in reducing environmental impacts.

The next section presents in detail the methods used for the development of this study.

2. METHODOLOGY

This work is of an applied nature for generating knowledge through a practical application directed to the solutions of specific problems. In addition, this study presents a descriptive research, since it sought to describe specific information through a standardized data collection about the topic addressed. The procedure used in this study refers to a bibliographical research, since the results were obtained through searches in periodicals and norms.

In this sense, the search and analysis in the present study were conducted in steps, which are described hereafter. Initially, Figure 1 illustrates the sequence of actions to construct the review and show the number of articles presented in each database.

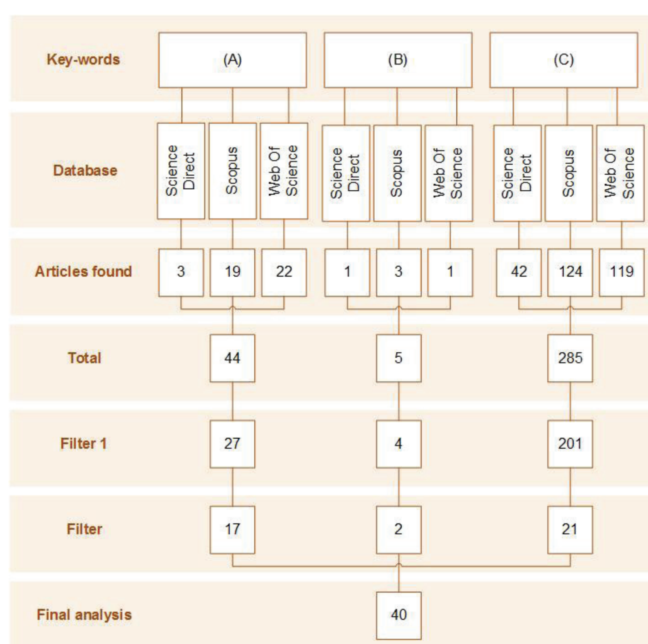

Figure 1. Number of articles presented in each database
Source: Own authorship (2018)

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The databases used in this study were Science Direct, Scopus and Web of Science. The same keywords combinations were used with the Boolean operators and truncation symbols, as can be seen in Table 1.

Table 1. Combination of keywords in databases
Source: Own authorship (2018)

(A)	(“LCA” OR “life cycle assessment” OR “life cycle analys*”) AND (“injection mould*” OR “injection mold*”)
(B)	(“ecodesign” OR “eco-design” OR “eco design”) AND (“injection mould*” OR “injection mold*”)
(C)	(“tool*”) AND (“LCA” OR “life cycle assessment” OR “life cycle analysis*” OR “streamlining* life cycle assessment”) AND (“ecodesign” OR “eco-design” OR “eco design”)

The search in all databases was performed on April 16, 2018. Full articles and review articles published in the period between January 2013 up to April 2018 were searched. After the search, the articles found were exported to a reference management program and two filters were carried out.

- Filter 1. Title Filter: all remaining titles were read and the articles considered not tightly related to the addressed topics were ruled out.

- Filter 2. Abstract Filter: all remaining abstracts were read and the articles considered not tightly related to the addressed topics were ruled out.

Therefore, the next section presents a discussion on the studies found in the literature that involve the theme of this study. It is presented the approach of eco-design and applications, LCA as a tool for measuring the potential environmental impact, Streamlined LCA in injection molded products, and a discussion on these subjects.

3. WORLD RESEARCH FOUND IN THE LITERATURE

3.1 Eco-design

Organizations increasingly consider the need to integrate environmental performance into product development projects with the aim of reducing harmful effects on the environment and achieving improvements in their activities (ANBT, 2014), finding in eco-design an important tool for the sustainable development of organizational activities (Jabbour et al., 2018).

The development of sustainable products is a trend in the field of environmental planning; thus, the eco-design concept adds environmental considerations to the product life cycle (Luiz et al., 2016). To Rebitzer et al. (2004) decisions at the design and development stage influence environmental impacts at all stages of the product life cycle.

On the other hand, the research community investigated the challenges and barriers to the eco-design adoption by the industry (Bey et al., 2013). The lack of application of eco-design lies in the difficulty of implementing and managing the tool since the product that must meet environmental requirements have quality and customer satisfaction, otherwise the product will not be sold (Karlsson et Luttropp, 2006; Pigosso et al., 2013; Luiz et al., 2016).

Van Hemel et Cramer (2002) point out that the incentives to implement eco-design have determined by the opportunities for innovation, product quality and market opportunities, as well as customer demand, legislation and incentives. Dekoninck et al. (2016) affirmed that the eco-design in the industry does not advance as expected in front of the deep knowledge of the surveys, indicating the few practices of the tool. In addition, Van Hemel et Cramer (2002) suggested that the difficulties are also related to the search for environmental improvements in design, which must also take into account economic and social factors, so that the environmentally improved products are accepted by the market.

Karlsson et Luttropp (2006) argue that eco-design should be based on a reliable analysis for the assessment of impacts within the product life cycle. Thus, the LCA is a useful tool for the analyzes, allowing a comprehensive evaluation and identification of the environmental profile of the products (Cobut et al., 2015) and can generate results that aid decision making in the planning and development of new products (Thabrew et al., 2009). Finally, Jeswiet et Hauschild (2005) showed that design is the main phase of the life cycle of a product.

In view of this, the studies found in the literature argue that the environmental impacts of the design phase should be supported by a eco-design tool. Therefore, the use of LCA combined with eco-design techniques can improve the environmental aspects of a product.

3.2 Life Cycle Assessment

The sustainable development of the goods and services process requires methods and tools that quantify and compare the potential environmental impacts (Rebitzer et al., 2004). To that end, ISO (2006a) refers to LCA as a tool aimed at raising environmental awareness of possible impacts associated with products, aiming to evaluate the environmental aspects and potential impacts of a whole process, product or service life cycle. To Barros et al. (2018) the use of LCA

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can bring valuable results to the study. In another point of view, Piekarski et al. (2013) suggested the LCA can be presented as an entrepreneurial tool for business management and green innovation.

The opportunities are related to environmental performance of the product, decision making, selection of environmental performance indicators, marketing (ISO, 2006a) classification and management decision support (Chang et al., 2014). The LCA highlights the potential environmental impacts of a product's lifecycle, from the purchase of the raw material to its final "cradle-to-grave" disposal (Luglietti et al., 2016), and provides lessons of the environmental impact (Barros et al., 2018a). The ISO (2006a) complements this approach with the existence of other stages that comprise the life cycle of a product, such as "gate-to-gate", "cradle-to-gate", "gate-to-grave" and "cradle-to-grave".

Therefore, the evaluation is performed through the compilation of inputs and outputs, helping the management in identifying opportunities for improvements in the production system. The application is to recognize the potential environmental impacts of its entire product life cycle.

3.3 Structure of Life Cycle Assessment

The tool is guided by the International Organization for Standardization (ISO) for two standards: ISO 14040, which addresses the structure and principles of the LCA (ISO, 2006a), and ISO 14044, which has the requirements and guidelines for the application of an LCA (ISO, 2006b).

In short, the LCA methodology, is composed of four phases: definition of objective and scope, inventory analysis, impact assessment, and interpretation (ISO, 2006a), which can be observed in Figure 2.

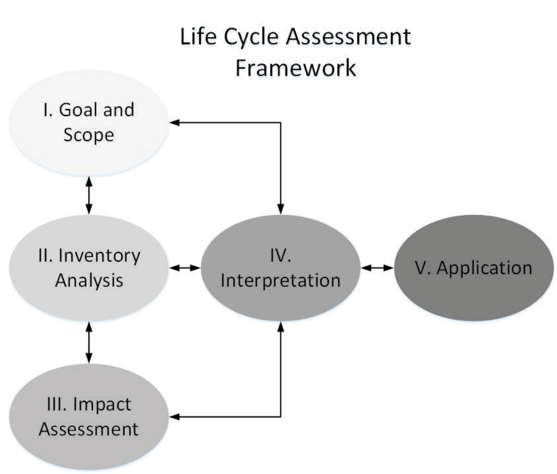

Figure 2. Stages of Life Cycle Assessment
Source: Adapted from ISO (2006a, b)

In the first phase, the evaluation study is done according to the definition of the objective and scope, as well as the delimitation of the study. In the second phase, the inventory analysis involves the collection and analysis of the input and output data of the process. In the third phase, the data collected in the previous phase are associated with specific impact categories. The most used examples of impact categories are: climate change, acidification, eutrophication, use of natural resources, and land use. Finally, in the interpretation the results are discussed, representing conclusions, recommendations and aid to decision making. To ISO (2006a, b) there is no single method for performing stroke, since it is iterative. Therefore, the LCA can be applications for product, process and/or activities.

3.4 Streamlined Life Cycle Assessment

For Vigon et Tolle (2002) the Streamlined LCA method reduces the necessity and the time of application of the LCA, according to the information. The Streamlined LCA can also provide decisive, efficient, reliable support in a short period of time (Rebitzer et al., 2004) and the toll is a source of quantitative information (Hochschorner et Finnveden, 2003). There are strategies for simplifying the analysis, such as the definition and scope of the study, data development, level of uncertainty, and available resources such as time, financial resources, and know-how (Rebitzer et al., 2004).

However, few studies use the Streamlined LCA, which makes it difficult to identify exactly the differences between the complete LCA and the Streamlined LCA. It is not easy to affirm the point where the Streamlined LCA stops and the complete LCA starts.

3.5 Plastic Injection Molding

The plastic is the main raw material of products that are processed by injection molding (Cheung et al., 2017). The material used in injection molding is the main source of environmental impacts in the process (Ribeiro et al., 2013). Thus, injection molding is the process that mostly uses plastic, because this material has great technological advances, achieved by thermoplastics. These materials are fused by heat transfer and solidified when cooled, without changing the chemical properties (Galdámez, 2017). This process has many benefits, such as high production rates (Cheung et al., 2017), the autonomy of the injection molding machines, the flexibility of the mold geometry, the easy maintenance of these molds, and the low cost-benefit of large production volumes (Galdámez, 2017).

The injection molding process is divided into five phases: mold filling, packing, cooling phase, plasticization phase,

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and ejection of the part (Elduque et al., 2015a). Faced with this, Cheung et al. (2017) argue that there is a lack of studies that involve research into the environmental effects of this type of process. Thus, the LCA is a promising tool to reduce the negative environmental impacts of the injection-molded plastic products process.

In this sense, it is observed that plastic injection molding presents several benefits. However, there is a need for systematic evaluations such as the use of LCA, Streamlined LCA or eco-design to prove the environmental performance of the plastic injection molding.

3.6 Life Cycle Assessment in Plastic Injection Molding

The main objective of the application of the LCA in the injection process is the production of ecologically correct products, seeking to study the environmental impacts of the injection molding process (Elduque et al., 2015a) and which elements will be optimized to reduce impacts (Elduque et al., 2015b). The LCA in the injection molding process was applied in polyethylene and high density pieces to evaluate the potential environmental impact of the injection molding process and the actual consumption of electricity (Elduque et al., 2015a).

Some studies were identified in the literature. Cheung et al. (2017) associated the LCA to Total Productive Maintenance (TPM), 5S (five Senses: Utilization (*Seiri*), Ordering (*Seiton*), Neatness (*Seiso*), Well-Being (*Seiketsu*), and Self-discipline (*Shitsuke*) and Cellular Manufacturing, achieving results of up to 41% reduction in energy consumption in the production process. In the same year, Huang et al. (2017) used LCA to analyze the impacts of energy consumption, GHG emissions and life cycle costs associated with additive manufacturing in injection molding. The result obtained by LCA shows that the additive manufacture has a potential energy reduction of 3% to 5% and of GHG emissions between 4% and 7%.

Another study developed by Hesser et al. (2016) used the LCA to compare environmental aspects of the manufacture of different composites used in injection molding. Ribeiro et al. (2013) presented a life-cycle structure that aims to support eco-design in the choice of materials for injection molded products. The study of these materials focused on the comparison between the economic and environmental performance of the materials used, as the polymers with plasticized starch present better environmental performance. Gallimore et Cheung (2016) used LCA to study injection-molded automotive plastic components, analyzing the use of different materials and manufacturing processes. Thus, the results show that the high density polyethylene material allows a 30% reduction in carbon footprint, 24% in air acidification, 26% in water eutrophication, and 15% in total energy consumption.

In addition, the study by Matarrese et al. (2017) focuses on the production of molds estimating the energy consumption in the injection molding process, since an LCA screening shows that most of the environmental impacts are in the energy consumption in the injection phase.

Thereupon, several studies have been found in the literature. Many of them applied the LCA tool and eco-design in plastic injection molding and presented positive results. Such results have reduced the potential environmental impact of injection molded products.

3.7 Eco-design in Plastic Injection Molding

The environmental impacts on the productive process generate concern for the organizations that seek strategies and methods that incorporate the design to the development of products for sustainable approaches (Luiz et al., 2016). According to Ribeiro et al. (2013), eco-design allows choosing alternative materials, seeking a better economic and environmental performance throughout the life cycle of the product. In the Injection molding the search for alternative materials can reduce the environmental impacts. The results showed that the materials used for injection molding is the main factor of environmental impact. However, if there is a recycling the impact may decrease and it is extremely important to carry out an analysis of the alternative materials.

Thus, as analyzed in the works, the use of LCA tool and eco-design can contribute to reduce potential environmental aspects in the products. The tools can support the economic and environmental aspects, as identified in some studies.

3.8 Assessment Tools Based on Life Cycle Assessment and Eco-design

The tools supported by LCA study for ecological design, present different levels of complexity, from very simple and generic tools to complex and time-consuming tools. Some allow for in-depth analysis, developing quantification of environmental impact and providing a detailed solution for improving a product's sustainable performance. However, there are tools that perform a preliminary analysis, generating recommendations for improvements (Ahmad et al., 2018). These tools seek to reduce efforts to carry out LCA and support eco-design (Zimmermann, 2012). The tools based on the complete LCA need resources and time. Given this, the development of tools that seek to focus on environ-

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mental aspects directed to the need in a relevant and direct way is inevitable (Zafeirakopoulos et Genevois, 2015).

The tools based on Streamlined LCA provide easy and fast information, supporting a variety of opportunity and decision-making situations. Its usefulness is related to the need and possibility of obtaining accuracy in relation to the specific decisions related to the product development project, facilitating the flow of information to a decision making based on the design (Verghese et al., 2010).

Given the approach to LCA and eco-design tools, Appendix A describes the tools found in the literature that use LCA to support product eco-design decisions. The search allowed finding tools that approach the Streamlined LCA for eco-design, such as Energy Saving (Zabalza et al., 2013); EcoT (Andriankaja et al., 2013); the methodology (Cluzel et al., 2013); the tool (Yousnadj et al., 2014) that joined LCA to PLM (Product Lifecycle Management) and ERP (Enterprise Resource Planning); the technique (Zafeirakopoulos et Genevois, 2015); and GENISI platform (Ng, 2016; Mengarelli et al., 2015).

In view of the above, it is possible to observe the use of LCA as a tool for eco-design application in the choice of alternative materials that result in lower costs and less environmental impacts. Thus, LCA is a methodology that allows the quantification of environmental impacts. As to the use of eco-design, it is possible to address an ecological design that involves environmental aspects in the development of products.

In injection molded processes there is a predominance of studies that present case studies using LCA to analyze the environmental impacts generated by the materials used. There is the use of the eco-design approach to compare materials that can be used in the process. The results of these studies show that the environmental performance of the manufacturing processes is mainly determined by the intense consumption of raw materials and energy.

The literature review showed that organizations are increasingly concerned about the life cycle of their products. In the context of this study, it was observed that there is no quick-approach tool for the application of Streamlined LCA directed to the plastic injection molding process.

4. CONCLUSIONS

A large number of case studies were observed; however, few literature reviews were found in this theme. Thus, this paper reviews the literature on eco-design tools based on the Streamlined Life Cycle Assessment of plastic injection molded products.

Some results were found in the literature review. It is evidenced the concern of organizations with the life cycle of their products and the integration of a sustainable approach that seeks to reduce the impacts generated. The use of tools can benefit the analysis of results for decision making in product development. LCA is widely used for this purpose and is seen as a tool to reduce the potential environmental impacts. When integrated with the eco-design technique it is possible to obtain a project that has sustainable approaches.

The injection molding process is known for the high consumption of raw material and energy. These are mainly responsible for the potential environmental impacts evaluated in an LCA study. However, this study presented an opportunity to build an environmental tool for the injection molding process. Therefore, future studies are suggested in order to deepen knowledge for the development of tools involving the LCA and eco-design projects in plastic injection molding.

ACKNOWLEDGMENT

The authors would like to thank the Editor of the Brazilian Journal of Operations & Production Management and the anonymous reviewers for efficient handling and valuable comments, improving this research on earlier versions of the paper. The present work was supported by the Coordination of Improvement of Higher Level Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq).

The authors declare no conflict of interest.

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APPENDIX A – Tools found in the literature

Tool	Complete / Streamlined LCA	Application location	Description	Reference
Model	Complete LCA	Wind Energy	Tool that allows reducing the amount of LCA parameters to evaluate the life cycle of different types of wind energy converters.	Zimmermann (2012)
Energy Saving	Streamlined LCA	Buildings	Specific methodology that seeks the lowest energy consumption through integrated planning, environmental performance evaluation of buildings and LCA, systematically approaching software alternatives, their strengths and weaknesses, available databases, utility of different indicators, aggregation, and definition of limits and options to simplify the process.	Zabalza et al. (2013)
EcoT	Streamlined LCA	Automotive	Database, in which parameters can be inserted so easily, assisting designers in the development of new products.	Andriankaja, Bertoluci and Millet (2013)
Sorting tree REACH/LCA	Complete LCA	Chemical Classification	Tool based on SimaPro 7.2 that allows assessing the level of risk associated with the product, evaluating its life cycle.	Askham, Gade and Hanssen (2013)
Methodology	Streamlined LCA	Primary aluminum industry	The methodology is limited to three of the four LCA exploration scenarios. This model allows the recommendation of good practices and recommendations centered on ecological design and continuous improvement.	Cluzel et al. (2013)
LCA combined with PLM and ERP	Streamlined LCA	NA	Methodology that combined the Streamlined LCA with the PLM system and the ERP to evaluate the product portfolio allowing project teams to consider environmental problems early in the project.	Yousnadj et al. (2014)
Analytical network logic tool: ANP	Complete LCA	NA	Methodology of dynamic approach of LCA with Analytic Network Process (ANP) to support the selection of projects for new sustainable products.	Wang, Chan and White (2014)
Analytical network logic tool: ANP	Streamlined LCA	Appliance (blender)	The ANP technique to evaluate and select the environmental aspect of a product, using LCA to promote Eco-design.	Zafeirakopoulos and Genevois (2015)
Computer Aided Design (CAD) use associated with LCA and Eco-design	Complete LCA	NA	Support the designer during the environmentally sustainable redesign of any product that can be modeled in a CAD environment.	Russo and Rizzi (2014)
Unnamed	Complete LCA	Systems connected to the photovoltaic network	Integrated structure that allows analyzing technical, economic and environmental criteria. The LCA is applied to evaluate the environmental impacts of the PV Grid Connected System (PVGCS), seeking an ecological design to the system.	Perez-Gallardo et al. (2014)
Methodology TRIZ	LCA Complete	Moped wheel	Set of specific guidelines to intervene in the product, limiting the trial and error approach to reduce the risk of re-projects.	Davide and Marco (2015)

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Volume 16, Número 1, 2019, pp. 33-42
DOI: 10.14488/BJOPM.2019.v16.n1.a3

Tool	Complete / Streamlined LCA	Application location	Description	Reference
ECORCE	Complete LCA	Road Pavement	Tool that aims to reduce the consumption of materials, water and energy through impact assessment quickly and easily.	Jullien, Dauvergne and Proust (2015)
GENISI	Streamlined LCA	Exhaust fan	Software engineering platform with different tools that support the environmental choices of the designers, allowing a quick environmental evaluation of the project choices, adopting the Streamlined tools of LCA.	Mengarelli et al. (2015)
Project Clean Sky	Complete LCA	Aviation industry	Database tool, which provides a third basis for decision making, addressing costs and weight, focusing on the end-of-life of a product.	Wimmer et al. (2015)
Machine tool LCA	Complete LCA	Power Consumption of a Machine	It allows quantifying effectively the energy consumption of an operating machine, seeking improvements based on ecological performance.	Züst et al. (2016)
LCEA	Complete LCA	Innovative windows Research and Development (R&D) project	Multi-criteria approach to life-cycle impact assessment with 14 impact categories. Based on an iterative process, which allows the comparison of environmental impacts of various components related to the design of innovative windows during. (DURING WHAT?)	Baldassarri et al. (2016)
Eco-design structure to drive sustainable innovations in wind turbines	Complete LCA	Power: wind power	LCA-supported eco-design tool that allows identifying environmental improvements, identifying the value added to LCA in product development across the eco-design structure, at different levels.	Bonou, Skelton and Olsen (2016)
Methodology based on the Analytic Hierarchy Process (AHP) method	Streamlined LCA	NA	The methodology allows decision-making based on the quantitative evaluation of the life cycle phases, designing and comparing alternatives of possible environmental impacts, facilitating in an effective and efficient way the eco-design approach to greener projects.	Ng (2016)
Checklist for the sustainable development of new products	Complete LCA	NA	Tool that allows the qualitative evaluation of the environmental, economic and social aspects during the early stages of the product development, for a complete evaluation of the life cycle, aiming at ecological and sustainable design.	Schöggl, Baumgartner and Hofer (2017)
LCA added to the CAD to develop a sustainable product design	Complete LCA	NA	Methodologies used for CAD and LCA are effective ways of integrating life-cycle-related data, interpretation of ACL results, and application to sustainable product design.	Chen, Tao and Yu (2017)
Computer aided material selection tool	Complete LCA	Aircraft structure	Material selection tool, computer aided. The selection is made through technical, economic and environmental performance for a given project, in a scenario of multidisciplinary and multiobjective optimization.	Calado, Leite and Silva (2018)

NA - Not applied.

Source: Own authorship (2018)

Received: 06 Aug 2018

Approved: 09 Jan 2019

DOI: 10.14488/BJOPM.2019.v16.n1.a3

How to cite: Ferreira, M. B.; Barros, M. V.; Piekarski, C. M. (2019), “Streamlined Life Cycle Assessment tool for injection molding of plastic components: a literature review”, Brazilian Journal of Operations & Production Management, Vol. 16, No. 1, pp. 33-42, available from: https://bjopm.emnuvens.com.br/bjopm/article/view/543 (access year month day).