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Use of life cycle assessment in sustainable manufacturing: review of literature, analysis and trends

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Abstract

The implementation of the management model with a Sustainable Manufacturing (SM) approach means thinking of processes that use natural resources in a responsible manner, promote the health and safety of all those involved and the integration of production cycle processes (production - distribution - consumption - recovery).

Literature shows that to make this management model feasible, it is recommended to map the entire production chain and the life cycle of products and processes.

One of the possible methods to map this process is to produce the Inventories in the Life Cycle Analysis (LCA), which makes an environmental balance of the processes and creates indicators for monitoring and decision making. With the construction of the Life Cycle Inventory (LCI), a clear flow chart is created of the entire manufacturing process, all the input and output flows and energy and the balance between them.

This means that a detailed map of the entire production process is obtained. With these details, it is possible to develop products, opt for technologies with better results, select significant environmental indicators and reformulate products or the process. The analysis of all life cycle phases permits the identification and evaluation of the process' critical phases, the opportunity to optimize inputs and energy, to indicate the most appropriate metrics for controlling and analyzing performance, and most especially, improve environmental performance, indicating the Life Cycle phase where impacts occur as well as identifying opportunities for greater economic efficiency and innovation. These data provide tangible subsidies for decision making based on sustainability criteria.

Through a review of literature, this paper proposes underscoring the importance of LCA in implementing SM, seeking to be an incentive for more in-depth research and for the creation of proposals that can make LCA accessible to the entire production sector in the country as soon as possible.

Brazil is in the initial phase of development of this management instrument with national characteristics and it does not deny the fact there is still a way to go before LCA can become accessible to most companies. This is mainly due to the difficulties in producing LCI as a result of costs as well as the need for complete chain information (reliability) and the existence of few LCI databases and a standard methodology to be applied in the country, important items for making the analyses feasible. This is of fundamental importance to promote the good positioning of Brazilian companies in the global market since other countries, mainly those in Europe, have been seeking sustainable equilibrium for a longer time.

The paper shows it is not possible to establish truly sustainable production processes without carrying out a LCA, and it also shows the method's direct relation to standardization processes, such as ISO 14001. We conclude that only a joint effort by the government, companies, universities, research institutes and class entities will make it feasible to use the system in the country.

Keywords: life cycle analysis; life cycle inventory; sustainable manufacturing;

1. INTRODUCTION

The World Commission on Environment and Development – WCED was created in the 1980s with the objective of analyzing issues involving development and environmental affairs. As a result of the Commission's work, the report "Our Common future" was written in 1987, from which the concept of "Sustainable Development" emerged. Sustainable Development is an idea based on a new way of thinking, acting and producing, in order to meet the needs of this generation without compromising future ones (WCED, 1991).

Sustainable development became a world goal, determining competitiveness of many companies. In this context, changing production management paradigms became indispensable, inevitable and urgent. The Sustainable Development (SD) seeks balance on the economic, environmental, social, spatial and cultural dimensions (SACHS, 1993, p. 24).

It is important to know which companies present truly sustainable behaviors, since many only engage in isolated actions, without understanding that reducing the unsustainability is not the same as creating sustainability (EHRENFELD, 2005).

Conroy (2007, p. 38) affirms that, concerning consumers, the trend is an increasing interest in sustainable, ethical, and certified products and suppliers. He stresses that "all companies will have to deal with this movement. The only issue is how fast they will find and take advantage of this market […]. The profitable opportunity now is in the sustainability sector".

Facing this, the challenge for companies is to establish as soon as possible, sustainable management involving all steps of the industrial process; encompassing in a more significant way the interaction between them and interested parties. In this context, the new model of development has objectives such as: optimizing use of natural resources; the mitigation of possible production and final products effects for the environment; the health and safety of all *stakeholders*; and the integration of production-distribution-consumption-recovery cycle processes, focusing on the recovery phase (ANNES, 2005).

Sustainability should be seen as a function of business, and necessary for the maintenance of competitiveness, in which:

> "The capitalist economy standard that the countries adopted after the Industrial Revolution caused, among other things, social unbalance, predatory exploitation and scarcity of natural resources. [...] The presented solution is the promotion of a new industrial revolution which would provide the sustainable economy based on natural capitalism, in which the ecosystem has capital value and there is a radical increase of resources productivity (RUTHES, 2006, p. 17)".

The foregoing is the basis of the concept of Sustainable Manufacturing (SM), which uses the methodology of the Life Cycle Analysis (LCA) as an important tool to map the phases of the production process; product life cycle, while presenting new possibilities for knowledge, informed decisions, and opportunities in the processes.

The main challenge is to avoid an "end-of-pipe" management way of thinking, which uses technologies to fix environmental impacts focusing on controlling and reducing residues, effluents and emissions (atmospheric emission filters, liquid effluents treatment station, solid residue treatment technology).

How is it possible to consider sustainable production processes in Brazil, if LCA, one of its central concepts, is still minimally disseminated, and poorly understood? Additionally, LCA is hampered in application due to the complexity of studies, difficulty in information gathering, and reliability of data, plus the need for aligning objectives and contexts among different studies for comparison.

The increasing number of companies seeking certification of their activities through the implementation of Management Integrated Systems, established by ISO 9001 (quality), ISO 14001 (environment), OSHA 18001 (occupational health and safety), shows a maturity process and gives opportunities for Brazilian companies to seek meet more international standards, thus increasing competitiveness and profitability.

According to the literature, LCA has been used in a systemic way mainly in European countries; that are already in the forefront of sustainable process. Reduced application of LCA concepts elsewhere can be explained by differing levels of organization and industrial sophistication.

Stano (2008) says that "two of the biggest problems developing countries have been facing in usage of LCA as a tool are: lack of a capable workforce and limited availability of databases with information about the LCA of basic industrial input".

Reviewing the most recent literature, the country's situation, and the sustainability trends, this paper analyses the importance of LCA in implementing SM. The main concepts, limitations and perspectives of SM and LCA are presented, as well as the relation between the LCA and the certifications of the ISO 14000 family, (mainly ISO 14001:2004) and the importance of this set of tools in promoting and implementing SM. It also has the objective of encouraging increased use of LCA, more research, and rapid implementation of LCA concepts in national production planning.

2. PRODUCT LIFE CYCLE ANALYSIS AND ITS EVOLUTION IN BRAZIL

Initial trials to utilize a tool that would facilitate decisions associated with emergent environmental demands, which appeared effective, appeared in early 1970. Stimulated by the *Resource and Environmental Profile Analysis* – REPA of Coca-Cola – used to compare types of soda packaging; while defining best option(s) – generated many studies, with software developed to help in analysis. (IBICT, 2008).

SETAC (The Society of Environmental Toxicology and Chemistry) defines LCA as “an objective process to evaluate the environmental loads associated with a product or activity, identifying and quantifying energy and materials utilized, and those wasted and left in the environment.” (SETAC, 1991 *apud* ANNES, 2005, p. 35).

LCA generates an analysis of all production processes, evaluating the environmental balance in all phases of the product and processes life cycle (LCI – Life Cycle Inventory). Subsequently, it is possible to perform evaluation of the environmental consequences associated with the process or product, analyze the environmental exchanges to obtain project approval, quantify the environmental emissions in each stage of the life cycle, and/or the process which contributes greatest impact. Also, one can evaluate the effects of absorption and inputs (Impacts evaluation).

Application of LCA enables various analyses including: raw material entrance; processing or preparing materials to be used in the process; the production process itself; packaging; distribution, and management of residue and sub-product (BARRETO *et.al*, 2007). Figure 1 details the activities that compose the 4 stages of LCA and provide important data for process and design management.

Thus, it is possible to develop products, elect better result technologies, identify the life cycle phase in which impacts occur, select significant environmental indicators, and reformulate products or the process, while identifying opportunities for a greater economic efficiency and possibly creating new products (Interpretation) (IBICT, 2008).

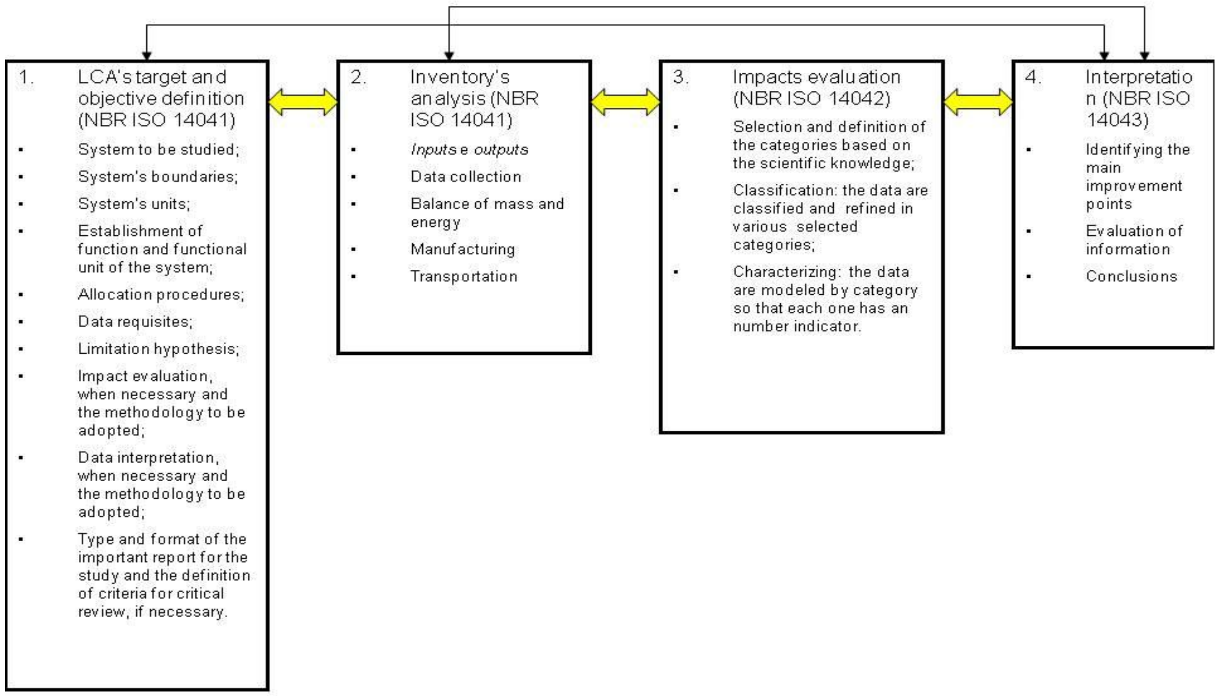

Figure 1. Stages of the process of the Product Life Cycle Analysis (adapted from: FRANCO; HINZ; VALENTINA, 2006; MORAES; TAKAHASHI, 2006).

In Brazil, studies and applications of LCA (Product or Process Life Cycle Analysis) are developing. Figure 2 shows a short historical summary of LCA development and illustrates the initial stages for implementation and dissemination.

During that period, study groups were formed bringing universities, non-government organizations and private and public companies together for the creation of the LCI Brazil – Brazilian Project of Life Cycle Inventory.

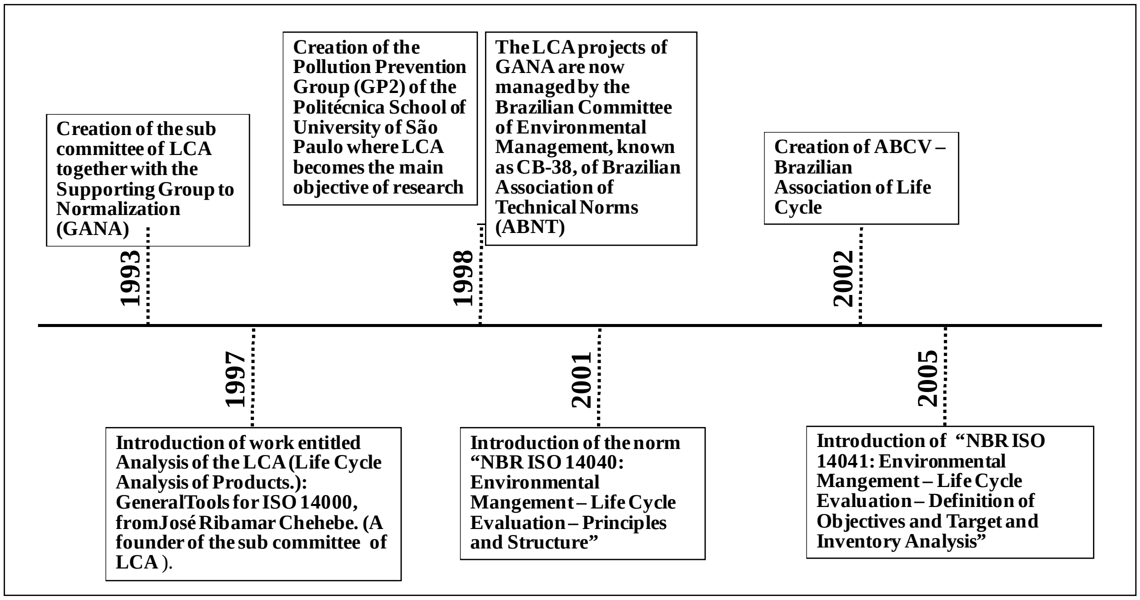

Figure 2. Historical line of LCA in Brazil (adapted from: KULAY; SEO, 2006)

One of the objectives of LCI Brazil is to develop a national database with information about the most useful and productive materials/products/processes for the country; helping companies to apply LCA according to the standard of ISO 14040, which guides the processes of LCA. The project also seeks to promote the culture and principles of LCA, while stimulating and encouraging teams from different productive sectors towards development and maintenance of the Brazilian LCI. Additionally, promotion of the development of innovations with enhancement of environmental impacts while optimizing the process via sharing relevant information. (PIRES, 2008).

The challenge of establishing a national data bank and a software system suitable with the reality of the country is huge, and requires investments from government and companies. In Germany the software development used 140 man-years of work over more than ten years of refinement. In Sweden, another country participating in LCA utilization, the data base construction cost was 1,15 million Euros. Japan expended some $10 million dollars (USD) in five years. (RODRIGUES *et.al*, 2008).

The most used software(s) for the LCA methodology are: GaBi 4.0; Team 4.0; Umberto 6.1; SimaPro 6.0; e LCA it (ANDRADE, 2005). However, Frühbrodt (2007, apud RODRIGUES *et.al*, 2008, p. 10) verifies that in the literature about 54 supporting tools for LCA are found, but only a few offer suitable support for analysis.

3. SUSTAINABLE MANUFACTURING

The main objective of Environmentally Conscious Manufacturing is to conceive products which can be recycled, remanufactured or reused (RASHEED; SARKIS, 1995).

The SM works to form "closed" systems and the utilization of the 4 R's – reduce, reuse, recycle, and recover, that, when used in the production processes can increase profits because it makes possible, among other things to use again the objects' systems and subsystems in their original form; to process determined products (systems and subsystems) again, though not necessarily in original form; to recycle discarded materials which could go back to industries as raw material for the production of new products. (BARBIERI, 2004).

Figure 3 illustrates graphically the concept of sustainable production design where, besides the 3 R's of recycling, recovery, and reuse, there are the variables DfD (disassembling), DfS (maintenance), DfM (manufacturing), DfA (assembling) e DfE (design for the environment).

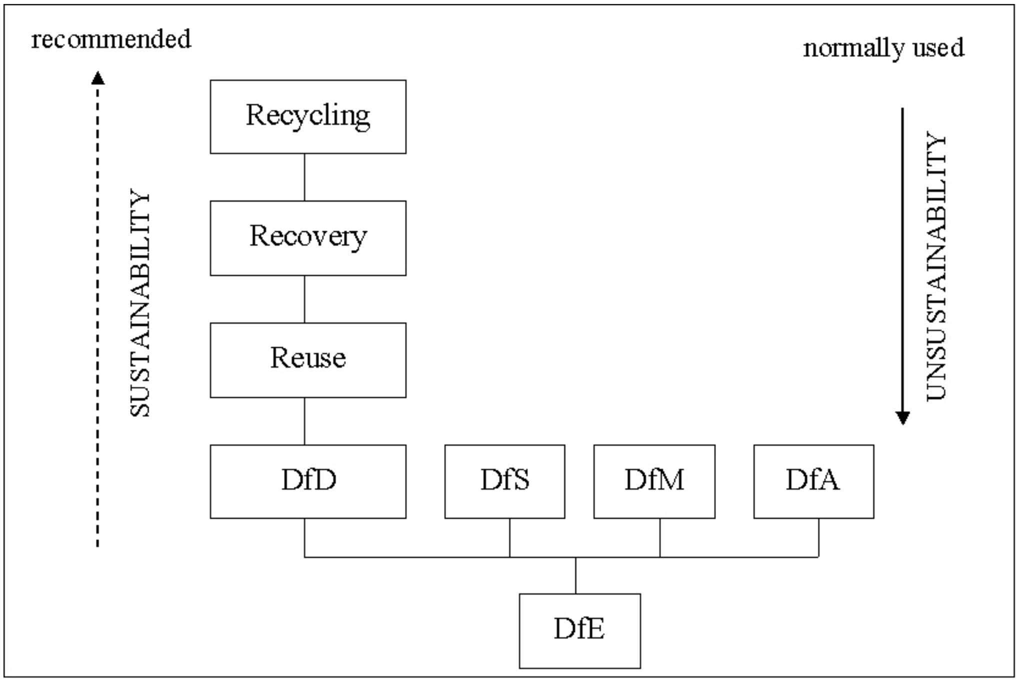

Figure 3. Conception of the Environmentally Conscious Product (ANNES, 2005, p. 26)

A concept that embodies sustainable production practices should be understood and implemented in an integrated, non-isolated way, and some effort is necessary to guarantee expected outcomes aligned with strategic planning. According to Annes (2005), this integration involves five main manufacturing areas and the variables for a productive graphic focused in the environment, are depicted in Figure 4.

Reaffirming the concept, the SM should acknowledge all phases of the Product Life Cycle and their impact on the environment in each stage to help guide decisions in order to: minimize the use of non-renewable resources, use responsibly renewable sources and minimize the disposal of toxic products in the environment (DfE), project products for a longer life (DfS) and to meet market needs (DfQ).

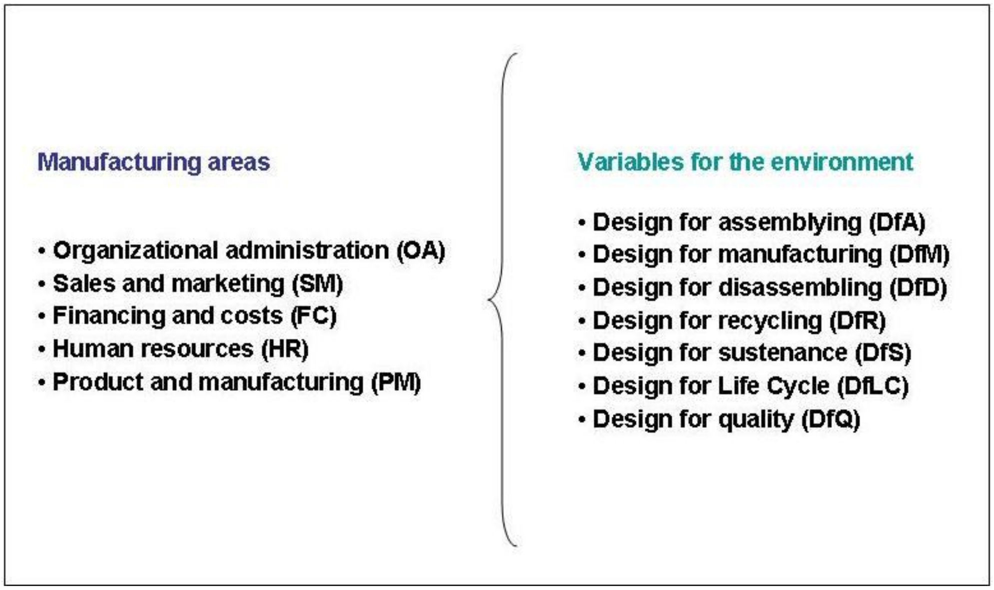

Figure 4. Integration for the sustainable manufacturing (adapted from: ANNES, 2005)

4. LIFE CYCLE ASSESSMENT IN SUSTAINABLE MANUFACTURING

Since the 1980s, there was a change in environmental management perspective because it was incorporated in production engineering. At this stage environmental control is integrated to productive processes, changing from a pollution control activity to a production function. The principle now is prevention (LIMA; LOBO, 2008, p. 2).

The same authors referring to Porter and Van der Linde (1995) emphasize that companies are going through a revolution where:

> [...] the companies need to calculate how much the pollution costs in terms of wasting resources and efforts and reduction of value for the consumer. This new view of the pollution as resources management ineffectiveness brings back the revolution of quality in the 80's. Fifteen years ago executives believed that investing in quality was expensive, because they saw the defects as something inevitable and not as a deficiency in the process. Today, the concept of having innovations not only improving quality but also reducing costs is spread. (LIMA; LOBO, 2007, p. 7).

Production engineering finds in LCA an important ally during process management, Almeida *et al*. (2005) detail some of these benefits:

> [...] the same way the LCA can be used as a tool to evaluate product and processes, it can also be utilized to evaluate the installations of companies environmentally responsible, considering the place selection, its development and infrastructure, products and processes of the main activity of the business, environmental interactions' related to the company's operations.

During Life Cycle Inventory (LCI), construction there is a clear flow chart of the whole manufacturing process, all entrance and exit flow of input and energy, and the balance between them, which means that a detailed map of the whole production process is obtained.

Thus, LCA can be a managerial tool for sustainable production. The analysis of all life cycle phases permits the identification and evaluation of the process' critical phases, the opportunity to optimize inputs and energy, to indicate the most suitable metrics for controlling and analyzing performance, and most especially, to improve environmental performance.

Gungor e Gupta (1998 *apud* ANNES, 2005) write that LCA is in the core of the implementation of a SM, and that it brings as benefits the enhancement of value to production and competitiveness in production, wherein:

> [...] the Environmentally Conscious Manufacturing (ECM) means production in a way that its environmental effects be minimized. The Environmentally Conscious Manufacturing consists in comprehending the product Life Cycle and its impact on the environment in each of the stages of the useful life, and making better decisions during the project and the manufacturing in a way so that the product's environmental attributes and the manufacturing process be kept in desirable levels. Having understood the Product Life Cycle, the information can be transferred to the up-to-date development of the product. (ANNES, 2005, p. 28).

The logic of the impact evaluation aims [...] to comprehend and evaluate the magnitude and importance of environmental impacts based on the inventory analysis (ALMEIDA *et.al*, 2005)".

Next, managers can make decisions such as: to minimize the use of toxic input, to reduce the consumption of energy and water, to mitigate the generation of residue and find opportunities so that what is generated is reutilized as a sub-product in other process, to decide on use of machines and equipments considering obsolescence, (reuse of parts) and also how to environmentally manage other activities related to the industry (maintenance, cleaning etc.). (ALMEIDA *et.al,* 2005).

4.1 Contribution of ISO 14000 certification(s) for the use of LCA in the implementation of sustainable manufacturing.

Named by Conroy (2007) as "Certifications Revolution", the world certification movement is vital to the dissemination and implementation of Sustainable Manufacturing. According to the author, the companies that do not take the initiative in establishing processes and creating more sustainable products will be the ones with smaller profitability and less acceptance of their brands:

> The news on the 21 century is that certifications form the verification of an independent third party, compromising the company with standards that are negotiated by all the *stakeholders*. The verifications show that the consumers need to buy by ethic standards and there are negative consequences for the companies. I call that accountancy with teeth, because you are bitten if you do not follow the standards. (CONROY, 2008, p. 38).

Corporate responsibility has become one of the main indexes in investment risk analysis, and certification of products and processes have become an official seal which validates maturity, good practice, high standards of management excellence.

With the increasing focus on environmental management, especially after 1970 with Coca-Cola's REPA, LCA started being used as a tool, becoming necessary to standardize and systemize criteria. The first works were realized by SETAC - *Society of Environmental Toxicology and Chemistry* and, after 1993, by *International Organization for Standardization* (ISO) which created the Technical Committee TC 207, responsible for elaborating the ISO 14000 series, which certifies the Environmental Management System and includes LCA (IBICT, 2008).

LCA, normalized by the ISO 14040 family created in 2001, is complementary to ISO 14001, and it is suggested it be used to expand on topics covered in ISO 14001, among them the analysis of aspect and environmental impacts; and operational control. The norms of the ISO 14040 family are:

- NBR ISO 14040:2001 – a general guide to the implementation of LCA in products and services;
- NBR ISO 14041:2004 – a guide to definition of the objective, plus inventory analysis;
- NBR ISO 14042:2004 – a guide to the evaluation of the life cycle impact.
- NBR ISO 14043:2005 – a guide to life cycle interpretation.

Based on the PDCA cycle (Plan, Do, Check, Action), the norms of the ISO 14000 family are tools that engender good environmental management and can interact with and complement other norms such as ISO 9001, OHSAS 18001 and SA 8000, forming an integrated management system, comprising quality, health and safety, and social responsibility spheres.

Application of norms is important, because if the spheres mentioned above are not managed and monitored in a satisfactory way, it is not possible to establish a SM. Norms' guidelines prepare, focus and provide the necessary tools so that a company can perform a LCA properly, and with a satisfactory bank of quality information for analysis.

5. FINAL CONSIDERATIONS

This paper focused on the analysis of the contemporary status of, and the global exigency for sustainable products and processes which demand a change in production management paradigms, focusing on the sustainability.

The recent literature about the LCA defines it as a multifunctional management tool which brings benefits such as: providing a discerning analysis of the whole chain; identifying weaknesses of the productive process; making feasible linkage of environmental management to the corporate strategy. Also, becoming a support for the decision making process, and refinement of operational design; to allow comparisons for decisions which can guarantee less impact both societal, and environmental.

With this analysis it is possible to notice the relation between SM and LCA, where the first depends on the global analysis dependent on the second for its implementation. It follows that the existence and feasibility of one is directly related to the other.

The fact is, that in Brazil, there is still a way to go before the use of this tool can become accessible to most companies, mainly due to the difficulties in producing an LCI. The high prices demanded, and the need for complete chain information (reliability), the existence of few LCI databases, plus a standardized methodology to be applied in the country are relevant items. Difficulties are inherent to the development of a new paradigm.

The limitations concerning the lack of a national model of LCA should not prevent Brazilian companies from continuing expansion of the movement towards ISO certification, and also not inhibit carrying out, even in a basic way initially, the evaluation of its products and process having standards of ISO 14000 as a basis.

This paper also has the goal of facilitating diffusion of the concepts of Sustainable Manufacturing and LCA's methodology, as well as applications and benefits. It is of fundamental importance for Brazilian companies to survive in the global market, to adapt, since other countries have already been seeking sustainable equilibrium for a longer time; guaranteeing a greater competitive advantage.

The solution will only be found in promotion of dialogue concerning SM and LCA themes and an increase in participants helping to form tools adapted to Brazilian realities. More studies about this topic are needed, mainly concerning construction of the national LCI, so Life Cost Analysis can become more feasible for Brazilian companies in the different industrial sectors.

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