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Life Cycle Thinking and its importance in the context of sustainability management: Review

Pensamento do Ciclo de Vida e sua importância no contexto da gestão da sustentabilidade: Revisão

Pensamiento del Ciclo de Vida y su importancia en el contexto de la gestión de la sostenibilidad: Revisión

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Abstract
Life Cycle Thinking (LCT) is considered a qualitative study because it describes the environmental impacts of a product or process. This perception allows us to identify the potential effects and resources used, allowing us to structure sustainable ideas, identifying and developing innovative solutions. Establishing the life cycle of a product requires planning and understanding the stages of the production chain, the continuous assessment of processes and their environmental functions, from the extraction of raw materials, transportation, manufacturing process, delivery to the customer and final disposal. Although LCT is considered a philosophy, Life Cycle Assessment (LCA) is a quantitative scientific method that allows you to express this thought. Through life cycle concepts and tools, it becomes possible to define the stages of a product's life cycle, assist decision makers in data analysis and implement sustainability with appropriate strategies and actions. However, the objective of this review is to describe concepts and definitions about LCT and LCA. It is hoped that researchers will be able to guarantee true sustainability in production, which will require careful assessment and multiple considerations based on an in-depth reflection on the product's life cycle.
Keywords: Environment; Environmental management; Sustainable production; Environmental impacts.

Resumo
O Pensamento do Ciclo de Vida (PCV) é considerado um estudo qualitativo por descrever os impactos ambientais de um produto ou processo. Esta percepção permite identificar os potenciais efeitos e recursos utilizados, permitindo estruturar idéias sustentáveis, identificando e desenvolvendo soluções inovadoras. Estabelecer o Ciclo de Vida de um produto requer planejamento e compreensão das etapas da cadeia produtiva, a avaliação contínua dos processos e suas funções ambientais, desde a extração da matéria-prima, transporte, processo de manufatura, entrega ao cliente e disposição final. Embora o PCV seja considerada uma filosofia, a Avaliação do Ciclo de Vida (ACV) é um método

científico quantitativo que permite expressar esse pensamento. Por meio de conceitos e ferramentas de ciclo de vida, torna-se possível definir as etapas do ciclo de vida de um produto, auxiliar os tomadores de decisão na análise de dados e implementar a sustentabilidade com estratégias e ações adequadas. Contudo, o objetivo desta revisão é descrever conceitos e definições sobre PCV e ACV. Espera-se que os investigadores consigam garantir uma verdadeira sustentabilidade na produção, o que exigirá uma avaliação detalhada e múltiplas considerações baseadas numa reflexão aprofundada sobre o ciclo de vida de um produto.
Palavras-chave: Meio ambiente; Gestão ambiental; Produção sustentável; Impactos ambientais.

Resumen
El pensamiento del ciclo de vida (PCV) se considera un estudio cualitativo porque describe los impactos ambientales de un producto o proceso. Esta percepción le permite identificar los efectos potenciales y los recursos utilizados, permitiéndole estructurar ideas sostenibles, identificando y desarrollando soluciones innovadoras. Establecer el Ciclo de Vida de un producto requiere planificar y comprender las etapas de la cadena productiva, evaluación continua de los procesos y sus funciones ambientales, desde la extracción de la materia prima, el transporte, el proceso de fabricación, la entrega al cliente y la disposición final. Aunque la PCV se considera una filosofía, el Analisis del Ciclo de Vida (ACV) es un método científico cuantitativo que permite expresar este pensamiento. A través de conceptos y herramientas del ciclo de vida, es posible definir las etapas del ciclo de vida de un producto, ayudar a los tomadores de decisiones en el análisis de datos e implementar la sostenibilidad con estrategias y acciones apropiadas. Sin embargo, el objetivo de esta revisión es describir conceptos y definiciones sobre PCV y ACV. Se espera que los investigadores puedan garantizar una verdadera sostenibilidad en la producción, lo que requerirá una evaluación cuidadosa y múltiples consideraciones basadas en una reflexión profunda sobre el ciclo de vida de un producto.
Palabras clave: Medio ambiente; Gestión ambiental; Producción sostenible; Impactos ambientales.

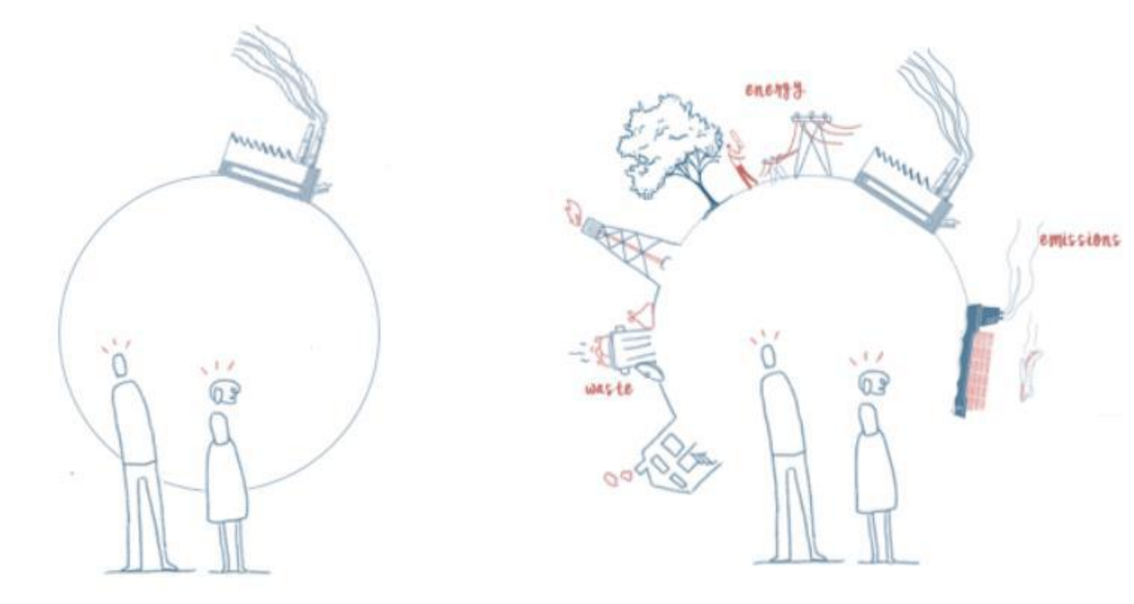
1. Introduction

In the past, when consumers had to choose between two similar products, it was easy to make the decision, just look at the cost and quality benefits and then choose the one that suited them best. Currently, the choices are more difficult. Consumers are motivated to be more aware of the effects and impacts on the environment and local economies (UNEP/SETAC, 2009).

Life Cycle Thinking (LCT) is considered a qualitative study that assesses the environmental impacts of a product or process. This insight allows us to identify the effects and potential resources used throughout its life cycle. Assessments based on this perspective describe different forms of assessment, followed by formalized approaches established in international protocols and scientific literature (MDB, 2014).

The programs and guides developed by the United Nations Environment Program (UNEP), Society for Environmental Toxicology and Chemistry (SETAC) and Life Cycle Initiative (LC Initiative), define LCT as a process that goes beyond the traditional focus (Figure 1) on production and manufacturing processes to include the environmental, social, and economic impacts of a product throughout its life cycle. While LCT is considered a philosophy, Life Cycle Assessment (LCA) is a scientific method that allows expressing this thought (UNEP/SETAC, 2012).

Figure 1 - Production and manufacturing processes without and with LCT.



Source: Life Cycle Thinking (LCT, 2021).

In September 2015, the United Nations announced the 17 Sustainable Development Goals, with 169 associated goals to be achieved by 2030. However, for these goals to be achieved, they need to be dated. It becomes impossible to convince leaders to employ sustainability when the goals are unknown, that is when there is no environmental education built. Therefore, to achieve the goals, environmental intelligence is necessary and the LCT is part of this intelligence (Bojarska et al., 2021).

LCT also allows you to structure sustainable ideas, identifying and developing innovative solutions. The compensatory exchanges stand out, which allow avoiding a single metric, generated by situations in which only one polluting agent is considered, by including all other relevant environmental impacts throughout the life cycle (European Commission, 2010).

The principle that using fewer materials is best for promoting sustainability may not always hold true if the full life cycle is not considered. According to a study sponsored by the Oregon Department of Environmental Quality (DEQ's, 2004), concrete forms and double-wall construction provide better thermal insulation, which reduces energy consumption. In this case, the energy reduction due to insulation outweighed the environmental costs of adding materials used in residential construction (MDB, 2014).

The same happens with the analysis of a product with high energy efficiency. The energy used during the use phase will be less than the energy used by products with low energy efficiency. However, realize that a high-efficiency product production will need more materials for its production than any conventional product. In this way, it is possible to conclude that the production will only be sustainable if the impacts generated to produce are smaller than the impacts avoided during the entire phase of use of the product. It emphasizes the existence of several types of relevant impacts besides energy, such as climate change, loss of biodiversity, and adverse social problems (LCT, 2021).

According to LC Initiative (2021) considers the two main categories of Life Cycle approaches: concepts and tools. The definition of “life cycle concepts” is based on the principles that guide and inspire the decision-making process. This conceptual vision defines all stages of the life cycle of a product or process and guides the correct application of tools, which are implemented by data and information. The tools also assist in decision making through data analysis, which thus implements sustainability, providing appropriate actions to be taken. Therefore, the objective of this review is to describe all the concepts about LCT and the ways to carry out a LCA in a production system. However, this review aims to provide a greater understanding of the system as a whole, its impacts and the complexity of the production system. As a result, it is expected that these evaluation techniques can be used by companies, organizations, academies, NGOs, governments, etc. Considering the need for evaluators with substantial knowledge on how to use, analyze and evaluate the techniques and how to interpret the results.

2. Methodology

As it is a narrative review study, this review offers methodological support for research focused on Life Cycle Thinking in the context of sustainability management. The main guides developed by the United Nations Environment Program (UNEP), Society of Toxicology and Environmental Chemistry (SETAC) and Life Cycle Initiative (LC Initiative), seek to describe concepts and guidelines so that more research can be developed. All bibliographic references selected in this study are part of databases consulted via Google Scholar, CAPES Periodicals, among others. The main question of this review tends to guide and integrate Life Cycle Thinking and Life Cycle Assessment in order to promote real sustainability in a production system.

2.1 Life cycle concepts

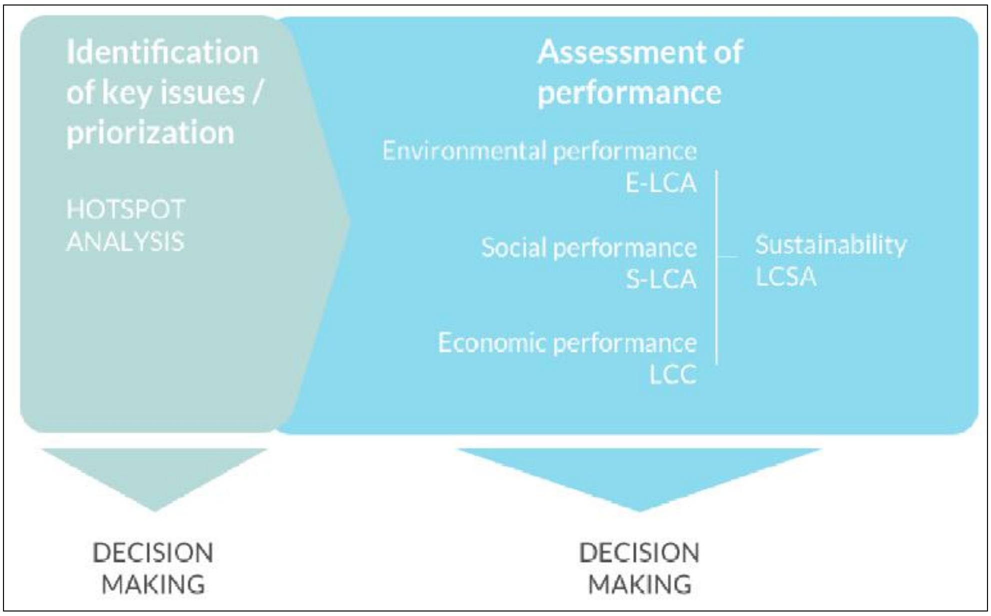
The LCT is considered the main concept, as it foresees the entire process of sustainable development covering all phases of the life cycle, in order to identify priorities for interventions based on the areas where there are greater opportunities. It is about understanding the environmental, social, and economic impacts in the decision-making management process (UNEP/SETAC, 2012).

The second concept is Life Cycle Management (LCM), which is based on the integration of LCT into management practices, that is, managing the entire life cycle of a system. A "system" can be a product, process, service, or even an organization, with the sole purpose of providing societies with more sustainable goods and services. Thus, a more effective way to support sustainable decisions is through the application of these concepts, combined with existing assessment tools (UNEP/SETAC, 2007). It is noteworthy that the LCT and LCM are considered qualitative studies.

2.1.1 Life Cycle Tools

Tools are life cycle approaches that aid decision making through the modeling and analysis of life cycle data for a product or service. The choice of the tool used is based on what one wants to achieve, with the definition of objectives and the scenario of action. It is important to highlight the magnitude of the life cycle measures that, when adopted, result in savings benefits, from the performance of the supply chain to the efficiency of internal operations. There is also a likelihood of increased production capacity and increased institutional capacity for innovation (LCT, 2021). Figure 2 is represented an overview of the main life cycle tools.

Figure 2 - Life Cycle Tools.



Source: Life Cycle Thinking (LCT, 2021).

2.1.1.1 Hotspot Analysis (HPA)

The Hotspot Analysis (HPA) is a useful and effective analytical tool in identifying areas to be prioritized for action. It allows for rapid assimilation and analysis of diverse information, including studies based on life cycle, market, scientific research, expert opinion, and specific stakeholder concerns. The HPA evaluate the environmental performance that combines environmental and socioeconomic data with commercial information, allowing to trace environmental pressures and impacts along the production chain (LC Initiative, 2019)

2.1.1.2 Life Cycle Environmental Assessment (E-LCA)

The Life Cycle Environmental Assessment (E-LCA) is an analysis tool or technique that assesses environmental performance through the life cycle of the product or service. The extraction and consumption of resources (including energy) as well as supplied to air, water and soil are quantified at all stages of the life cycle. From there, the environmental contribution potential in each impact category is evaluated. These categories include climate change, human toxicity and ecotoxicity, ionizing radiation and deterioration of primary resources (UNEP/SETAC, 2009).

2.1.1.3 Social Life Cycle Assessment (S-LCA)

The Social Life Cycle Assessment (S-LCA) is a tool applied to assess the social and sociological aspects of products, their actual and potential impacts (positive and negative), in relation to their life cycle. This tool includes everything from the extraction and processing of raw materials, manufacturing, distribution, use, reuse, maintenance, recycling, and final disposal of the product. An S-LCA uses generic and site-specific data that can be quantitative, semi-quantitative or qualitative and complements such as environmental analyzes and production and consumption economics (UNEP/SETAC, 2009).

2.1.1.4 Life Cycle Costing (LCC)

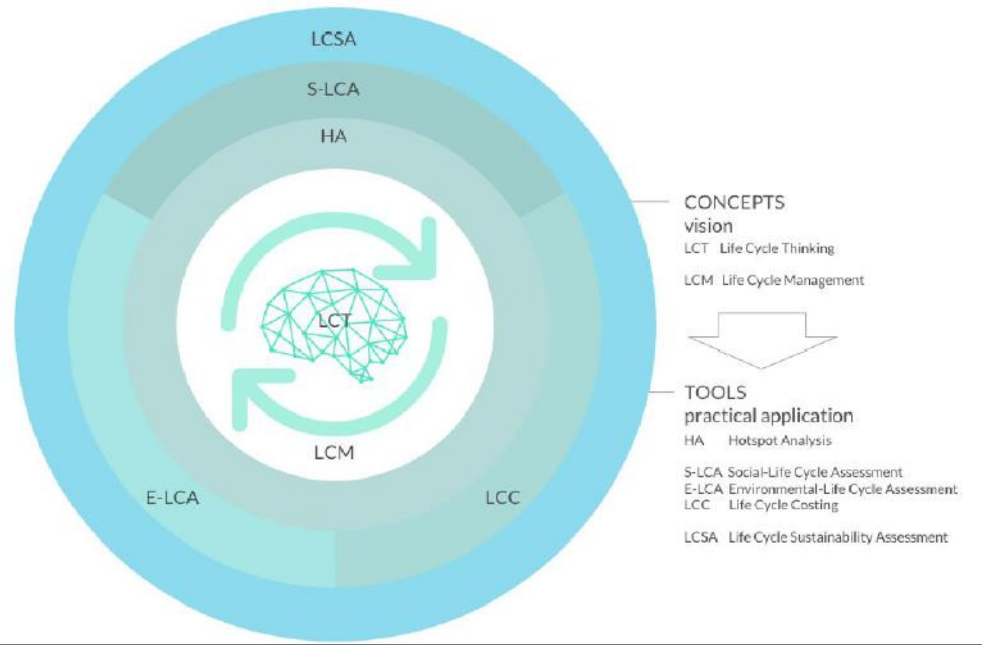
The Life Cycle Costing (LCC) is a tool that aims to assess all costs associated with the life cycle of a product or service. They are directly linked by one or more agents in the product's life cycle (supplier, manufacturer, consumer, and/or a final disposal), with the inclusion of positive or negative externalities for a society, which are available to be internalized in a decision future (Swarr, et al., 2011).

While the E-LCA has been standardized on the ISO 14040 series, the LCC and the S-LCA, are in line with the ISO 14040 (2006) framework , but differ in certain respects. There are no specific standards for LCC and S-LCA.

2.1.1.5 Life Cycle Sustainability Assessment (LCSA)

Based on the definitions and concepts about the life cycle, it becomes possible to identify how the applications of different tools work, supported by qualitative and quantitative data. This data provides us with an adequate means of evaluating the impacts arising from evaluated processes and also identifies the environmental, social and economic benefits. In this way, it is part of the combination and evaluation of acts and/or benefits, in order to integrate them into the decision-making process. This toool, Life Cycle Sustainability Assessment (LCSA), emerged as a response to the challenge of integrating and encompassing the three dimensions in the development of the LCSA (UNEP/SETAC, 2011). Figure 3 is represented an integration between concepts and tools from the previous life cycle.

Figure 3 - Life cycle concepts and tools.



Source: Life Cycle Thinking (LCT, 2021).

LCT is the key to realizing this strategy towards sustainability, allowing people, companies and colleagues to understand their role and identify what actions should be considered at the right time, and discovering creative ways to face the challenges. With the common goal of bringing LCT to decision makers, Life Cycle Initiative published in 2020 the Progress Report, in order to generate consensus on LCA methodologies and provide technical and policy support to achieve the goal of sustainable development (LCT, 2021).

2.2 What is LCA?

With the growing awareness of the importance of environmental protection and the possible actions associated with products, both manufactured and consumed, it has become necessary to develop methods to better understand and address the impacts. One of the techniques under development for this purpose is the LCA, according to International Organization for Standardization - ISO 14040 (2006) and 14044 (2006).

ISO14040 (2006) presents LCA as a technique to assess environmental and potential aspects associated with a product or service. This technique can also be considered a valuable tool for dealing with information about real impacts throughout the life cycle of products, from raw material acquisition, through production, use, post-use treatment, recycling and final disposal. Product life cycles involve material, energy and economic flows. Which, in turn, involves local acts, consumers and all authors in the chain (UNEP/SETAC, 2009).

Quantifying the potential impacts of LCA has its roots in the natural sciences. Flows are based on baseline data and baseline models (or resource consumption) are based on empirical data. In addition to the scientific core, an LCA requires the value judgment needed to assess the overall impact of a product system. The LCA employs value judgment consistently and transparently and, in some cases, allows practitioners to make modeling choices based on their own values, for example, in relation to the number of years in the future that impacts environmental factors should be considered in the assessment (Hauschild, et al., 2018).

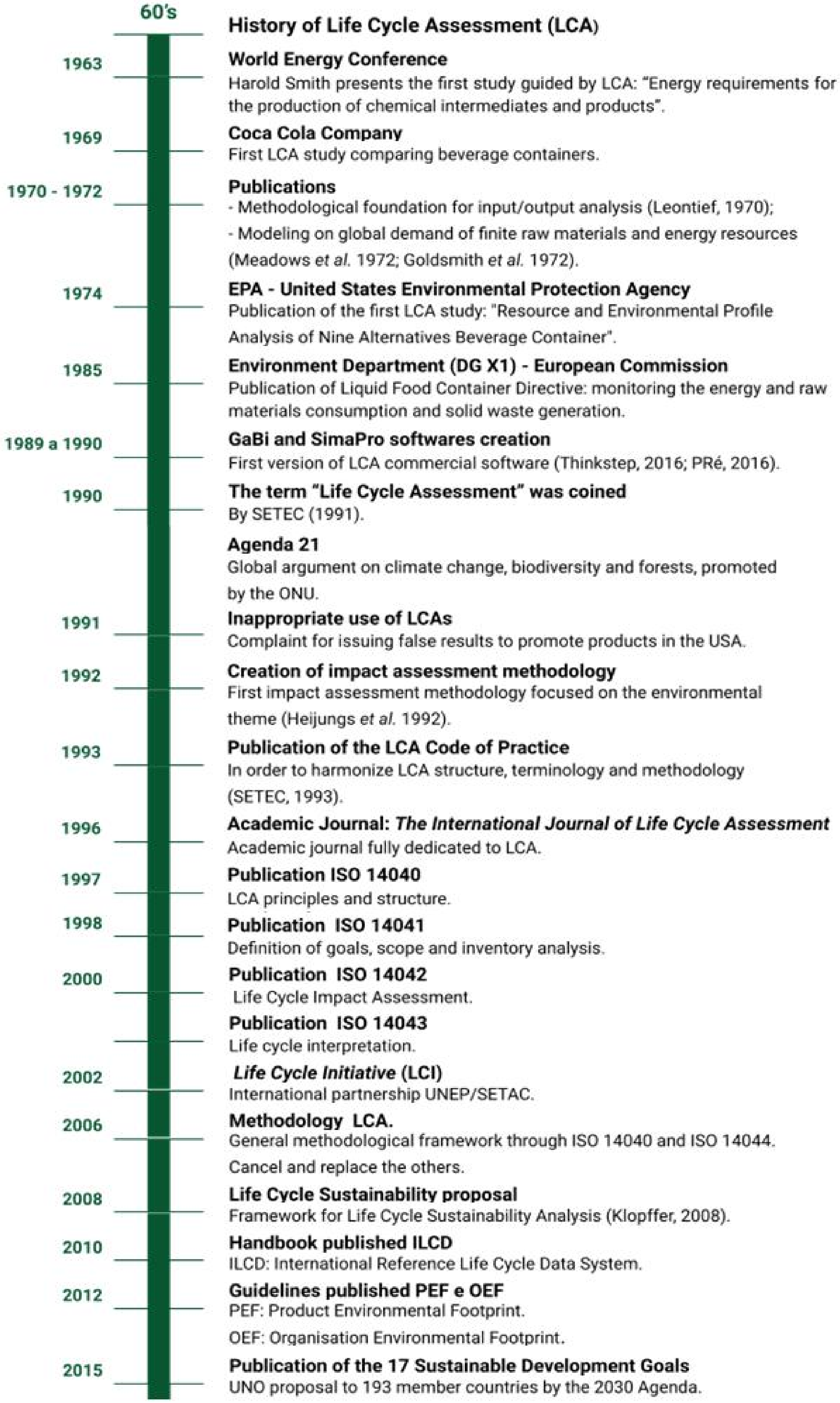
The LCA result of a product/service promotes opportunities for improvement and environmental performance of products at various points in their life cycle. It assists decision makers in strategic planning and selects relevant environmental performance indicators, including determination techniques. It also contributes to marketing with the implementation of an eco-labelling system or environmental declaration (ISO 14044, 2006; ISO 14040, 2006). These results will allow companies to know which aspects of their production are efficient, and where they can improve efficiency to reduce environmental impacts (UNEP/SETAC, 2009).

LCA can be considered one of several environmental management techniques such as Environmental Risk Assessment, Environmental Performance Assessment, Environmental Audit, Environmental Impact Assessment, among others. However, the LCA does not address the economic or social aspects of a product (ISO, 2006).

2.2.1 History and LCA evolution

Sustainable development aims to promote human well-being, contributing to current and future needs. No field of evaluation of products and processes, methodologies, techniques, and tools are developed to promote an improvement in the environmental and social conditions throughout the life cycle of a product. Since the 1960s, several efforts have been made to promote the pillars of sustainable development in a coherent and integrated manner in a productive process (Hauschild, et al., 2018; EPA, 2006; Guinée, et al., 2001). Figure 4 is illustrated the entire historical context of LCA.

Figure 4 - History of LCA.



Source: Hauschild, et al., (2018), EPA, (2006), Guinée, et al., (2001), adapted by the authors.

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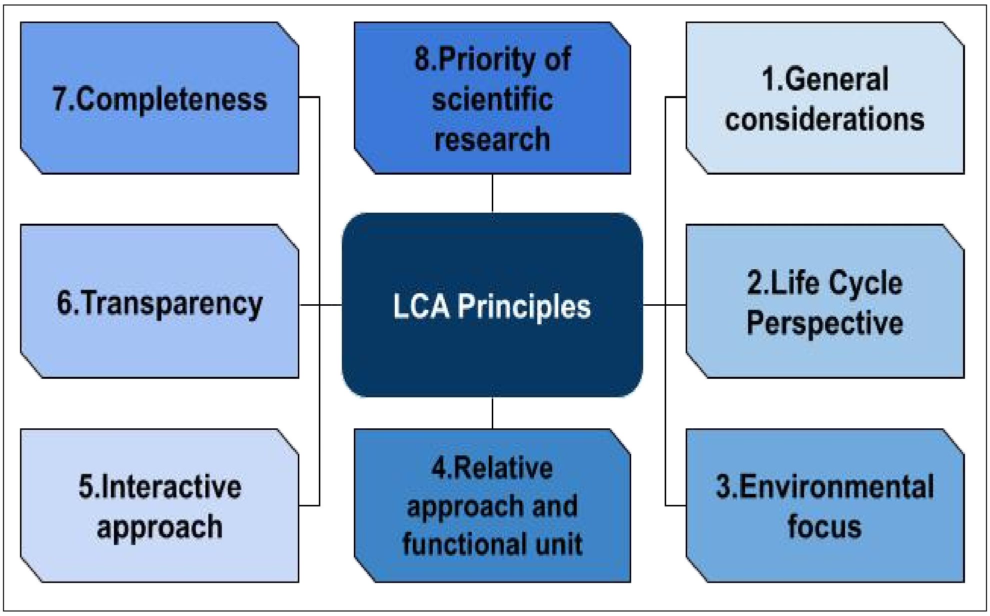
2.2.2 Methodological framework for LCA - ISO 14040

2.2.2.1 LCA Principles

The LCA principles are fundamental and are recommended to be used as a guide for decisions related to both planning and conducting an LCA. Figure 5 are considered the eight principles established by ISO 14040 (2006).

Figure 5 - Principles of LCA



Source: ISO 14040 (2006), adapted by the authors.

From an LCA perspective, the entire life cycle of a product is considered, from the extraction and acquisition of raw materials, manufacturing, use, post-use treatment, recycling and final disposal. LCA focuses on the environmental aspects and impacts of a production system. LCA is a relative approach structured around a functional unit. This functional unit defines what is being studied based on the Life Cycle Inventory (LCI). The iterative approach contributes to the completeness and consistency of the study and reported results. Demanding the complexity of the LCA, the solution is an important guiding principle in the execution, in order to guarantee an interpretation of the results (ILCD, 2014).

2.2.2.2 LCA Phases

According to ISOs 14040 and 14044 (2006), LCA has four phases of the study, starting with the definition of the objective and scope, moving on to an inventory analysis phase and impact assessment study, and finally the phase of interpretation of data.

The scope of an LCA depends directly on the intended object or use of the study. The depth and breadth of the LCA can vary considerably depending on the purpose of the particular study. A LCI analysis phase is the verification of the data from an inventory against the input/output of a system. This phase involves the collection of base data to achieve the objectives of the study in question. The Life Cycle Impact Assessment (LCIA) phase is the third phase of the LCA. The purpose of the LCIA is to provide additional information to assist in evaluating the results of a product system's LCI category to better understand its environmental significance. Life cycle interpretation is a final phase of the LCA procedure, in which the results of an LCI and/or an LCIA are summarized and discussed as a basis for carrying out recommendations and decision making in accordance with the objective definition and scope (ILCD, 2014; ISO 14044, 2006).

2.2.2.3 Environmental tools

Environmental impacts are usually defined through a LCA. Actual research on sustainability and Sustainable Development (SD) remains an open question. The indicators used to measure SD need to be developed to provide a basis for decision-making. Several different concepts and methods have already been developed for such as assessments, protection and/or social processes, products or activities (Cucek, et al., 2012).

Environmental tools such as Ecological Footprint (EF), Carbon Footprint (CF), Energy and Emergy Analysis, Material flow analysis, among others, were developed to conceptualize, quantify and guide on direct effects and indirect effects of human activity in the environment. These tools have a number of common characteristics and can be mathematically reduced to similar analyzes (Patterson, et al., 2017). Thus, the evaluation of environmental studies becomes more judicious when there is a combination of environmental accounting tools, not limited to just one perspective or criterion.

A "footprint" is a quantitative measure that states how human activities may or may not impact global sustainability (UNEP/SETAC, 2015). Hoekstra and Chapagain (2007), present tools such as footprints, used for an assessment of sustainability and its components, such as Rees (1992) creator of the Ecological Footprint (EF) and Hoekstra (2003) developer of the Water Footprint (WF). It is understood that the Carbon Footprint (CF) was developed through the derivation of the Global Warming Potential, in the early 2000s, defined by Hogevold (2003). The authors Galli, et al., (2012) defined Carbon Footprint (CF), Ecological Footprint (EF) and Water Footprints (WF) as the “footprint family”.

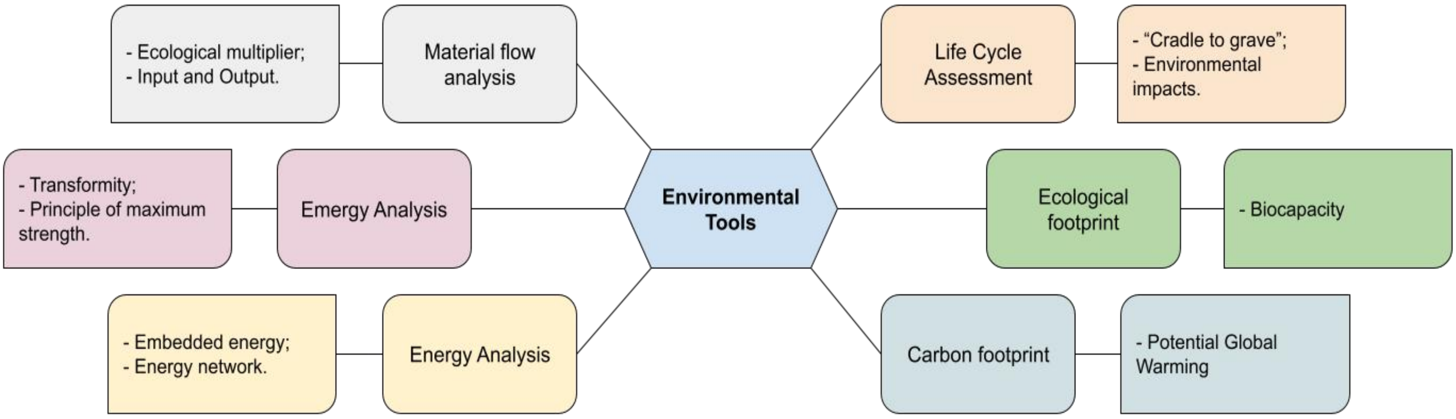
Studies proposed by Cucek, et al., (2012) compared the connection between different Footprint analysis tools. According to Postnote (2006) in the UK, considers CF the amount of CO^2 and other greenhouse gases (GHGs) emitted throughout the life cycle of a process or product; Dadd (2007) presents the CF as a result of LCT, applied to global warming; Wiedmann and Minx, (2007), define CF as an exclusive measure of direct and indirect inherited CO^2 throughout a life cycle. Among the tools for assessing the footprint, the CF calculators are the main tools used.

Environmental problems are related in one way or another to energy and thermodynamics, as energy is involved in all life cycles of a process. This tool was developed in the early 1970s, with a decline in interest in the 1980s with the advance of the water crisis (Patterson, et al., 2017). LCA can be applied to analyze energy systems or perform a separate analysis of energy aspects of a life cycle (Haes & Heijungs, 2007). Another important tool is the Exergetic Analysis, suitable for general statistical use, as a measure of stocks and resource flows, in addition to measuring the transfer of environmental waste (Ayres, et al., 1998).

Emergy Analysis quantifies the environmental work required to generate (ecosystem) goods and services used by humans. On the other hand, an LCA analyzes the performance of human processes and dominated systems. It is claimed that the use of inventory modeling principles behind the LCA method can improve an Emergency Analysis synthesis, which can be seen as a complementary tool, rather than an alternative, to impact assessment metrics cycles existing lives (Raugei, et al., 2014).

A material flow analysis has traditionally been used to track the production, use and consumption of materials (Hawkins et al., 2007). In this way, the application of a combined approach of Material Flow Analysis and LCA is commonly used to evaluate a complex production system. However, they are required to establish the form independently, rather than jointly (Turner et al., 2016). Figure 6 is presented the comparison of environmental accounting methods and their main concepts.

Figure 6 - Comparison of Environmental Accounting Methods.



Source: Patterson, et al., (2017), adapted by the authors.

2.2.3 LCA accounting structure: input, output and impact assessment data

2.2.3.1 The Life Cycle Inventory (LCI)

As described in the ISO 14040 (2006), LCA is a compilation and assessment of the environmental inputs, possibilities and impacts of a system product throughout its life cycle (ISO, 2006). The LCI is considered a crucial phase of LCA, being this a second phase, as it deals with the quantification and accumulation of data of inputs and processes of a system. Thus, the LCI method chosen must comprise the calculation technique, the relative advantages and limitations for the intended purpose (Islam, et al., 2017).

By quantifying requirements such as energy and raw material consumption, atmospheric effects, water consumption, solid waste generation, among other information, LCI directly interferes in the LCA of a product, process or activity (EPA, 2006). According to EPA documents (1993 and 1995) define the four steps of a LCI: process flow diagram, data collection plan, data collection, and outcome evaluation.

Suh and Huppes (2005), describe the existence of six methods of compilation of the LCI, namely: Process Flow Diagram, Product System Matrix Expression, LCI based on Input/Output, Layered Hybrid Analysis, Hybrid Analysis based on Input/Output and Integrated Hybrid Analysis. The authors concluded that for LCA studies, an input/output LCI database is more available and develops in regionalized cases, linked to a local system.

According to Islam, et al., (2017), the LCI has evolved, becoming a more robust tool for sustainable practices. Different LCI methods imply different levels of complexity and data requirements. As there are a large number of LCA software available on the market, scientific validation of LCI methodologies is possible. The authors concluded that in a faster ecological manufacturing decision, the LCI Input/Output is adequate, however, some data related to the process available in Hybrid Input/Output database, these provide a better result.

Guinée, et al., (2001) considers the ISO (2006) standard LCA, a biophysical accounting framework used to catalog the input materials of energy and natural resources that will provide in linked with each stage of the life cycle of a product. LCI theory in terms of its quantitative contributions, a specific set of environmental impact categories.

The LCA database most used today in scientific studies is Ecoinvent, with about 4,500 users in more than 40 countries, containing international LCI data on energy supply, resource extraction, material origination, products chemicals, metals, agriculture, waste management and transportation services. Each dataset is provided as a unit process and aggregate system process. In addition, reports are published with information on modeling procedures and assumptions, with databases specifically adapted to openLCA (GreenDelta, 2022).

Burhan, et al., (2020), describes Ecoinvent as an institution responsible for managing the main international database for LCA, based in Switzerland, published in September 2019 in its database, unprecedented results for Brazilian products. The updating of Brazilian data was made possible by the ICVAgroBR project, coordinated by Embrapa Meio Ambiente and financed by the Sustainable Recycling Industries (SRI) program of the Economic Affairs Secretariat of the Swiss government (Folegatti Matsuura, et al., 2017). A total of 632 new datasets were integrated into the new version of Ecoinvent, including LCI of some of the main Brazilian agricultural products, which contributes to the increase in their occurrence in the international market, which is increasingly demanding in terms of aspects environmental (Embrapa, 2019).

The Brazilian Institute of Information in Science and Technology (IBICT) in partnership with the Brazilian Agricultural Research Corporation (Embrapa) Environment, promotes the structuring of the National Bank of LCI of Brazilian Products (IBICT, 2020, 2021). According to Rodrigues, (2020), this database should reach 300 inventories available, mostly products from the agricultural chain. It also states that when the event is produced from its initial phase, it becomes a slower and more costly process. If the inventory is available in a database, the authors will be able to carry out the analysis, generate studies, without the need for complete data surveys.

During the structuring of the agreement that culminated with the availability of Brazilian data in the ecoinvent database, Embrapa formalized the donation of data to the National Bank of LCI, the SICV Brasil (SICV, 2020), managed by the Brazilian IBICT. In addition to international recognition, an update of the data will contribute to the practice of increasing access to national data by Brazilian professionals and researchers (Embrapa, 2019).

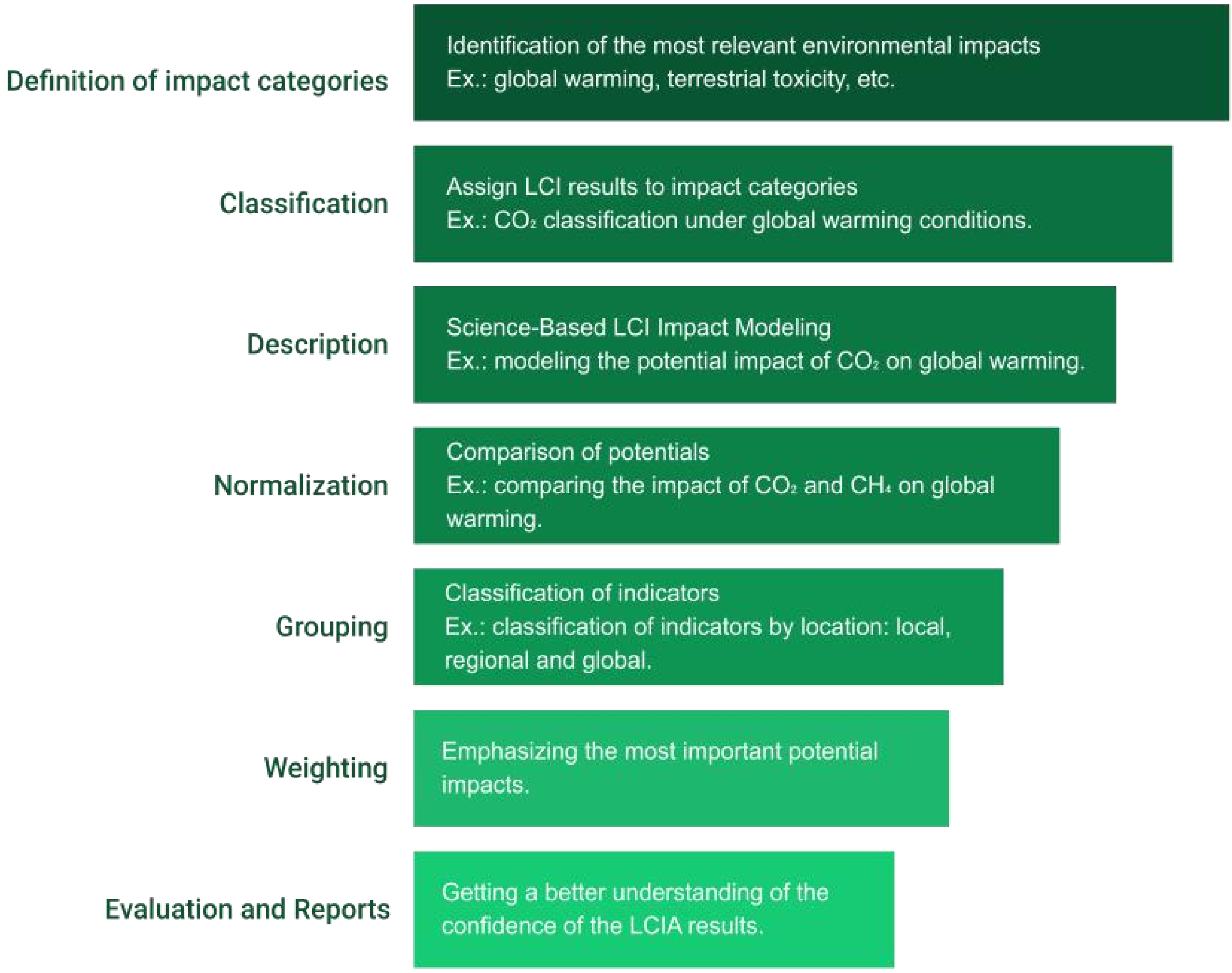
The inventory process can be considered a complete and more complex research, which can generate environmental product declarations, which is another way of demonstrating its environmental performance (Rodrigues, 2020). When documenting the results of the LCI, it is important to describe the entire methodology covered, define the applicable systems and the thresholds that have been adjusted, and any assumptions made in performing the inventory analysis. The result of the inventory analysis is a list containing the amounts of pollutants released into the environment and the amount of energy and materials consumed. This information can be organized for the life cycle stage (EPA, 2006).

The diversity of sources for LCI and LCIA databases contributes considerably to environmental studies. However, there is great variability in the nomenclature used in each font. In this way, the openLCA software contributes to the organization of different database flows and LCIA methods (GreenDelta, 2023).

2.2.3.2 LCIA - Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) phase is considered an assessment of the potential related to human health and the environmental impacts identified during the LCI, contemplating the third phase of an LCA. The LCIA aims to provide an aggregation of inventory data using additional information, such as (internationally accepted) performance levels, to understand / translate the magnitude and importance of the results for impact assessment (UNEP/SETAC, 2009). The steps to be followed as shown in the Figure 7, comprise an assessment of the impact of the life cycle, according to EPA (2006).

Figure 7 - Stages of Life Cycle Impact Assessment – LCIA.



Source: EPA (2006), adapted by the authors.

The ISO 14042, LCIA (ISO 2000), replaced by ISOs 14040 and 14044 (2006), describe LCIA in three stages, namely: impact category selection, correlation of LCI results and calculation of results of category indicators, which in turn will guarantee the results of category indicators. They point out as optional elements the calculation of magnitude, grouping and weighting.

LCIA analyzes according to (UNEP/SETAC, 2009) result in criteria for three areas of protection from damage: human health, ecosystem quality and natural resources. The definition of these areas aims to safeguard the values considered important to society. When considering the protected area “human health” it can be used aggregate impacts of morbidity and mortality as an indicators to measure damage to human health. Several methodological developments over the final decade indicate the need for an update to the LCIA Framework and guidance on cross-cutting issues within the LC Initiative.

First, it is observed the lists of impact categories verified as midpoint, damage level and data level according to a protection area. It is noteworthy that there are more flow items to be considered. Impact characterization models can link your LCI to the midpoint impact level or to the damage level, or directly to the damage level according to protected area, aggregated into broad categories. The weighting of damage category scores can include normalization, this is an optional step. Normalization and weighting can also be performed at the level of the midpoint impact indicator (Verones, et al., 2017).

Finally, a final phase of the LCA process is taken, the interpretation of the life cycle. Life Cycle Data Interpretation (LCDI) is seen as a systematic technique to identify, quantify, verify, and evaluate information based on all previous results, such as LCI and LCIA results (EPA, 2006).

The ISO 14044 (2006) defined the following two life cycle interpretation objectives: Analyze the results, arrive at the consequences, explain the limitations and provide recommendations based on the process of the previous LCA phases, and finally, report the results of the life cycle interpretation transparently; Provide a readily understandable, complete, and consistent presentation of the LCA results, consistent with the purpose and scope of the study.

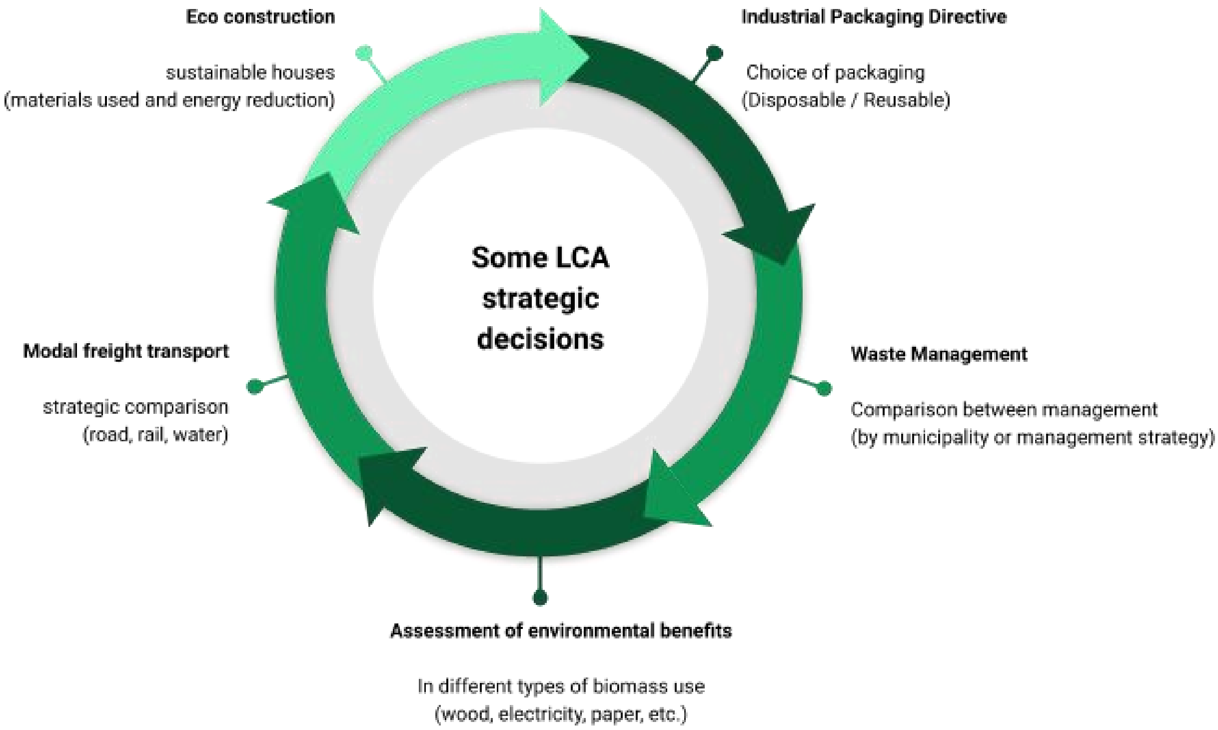
In the LCIA, several impact categories are considered, defined according to the objective and scope defined in the study. According to Pizzol, et al., (2011) the great challenge of the LCIA methodology is to evaluate the potential impact using an applicable procedure, considering a common unit of measurement, resulting in comparable data between impact categories. Another specific point is the development of methods that consider global and/or regional impacts, as has already been done in countries such as: Canada, Europe, Japan, the United States, among others. Therefore, these methods do not necessarily reflect the situation of countries like Brazil, which does not yet have specific LCIA methods for the environmental characteristics of the country itself. Methodologies are being improved and can be applied to life cycle impact assessment. (Motta, 2016), considers in his study that the carbon footprint impact category (CO2 eq.) is the most pioneering in LCA studies to be used in Brazilian companies.

2.3 Applications and limitations of LCA

Carrying out an LCA in a production process will provide greater understanding of the system, in order to identify the necessary actions and the complexity of the product system. The technique can be used by companies, associations, academia, NGOs, governments, etc. However, evaluators need knowledge on how to use the technique and how to interpret the results (UNEP/SETAC, 2009).

The main applications of LCA are linked to analyzing the origins of problems related to a given product; the comparison of variants in the improvement process of a given product; the projection of new products; and choosing from a range of comparable products. Similar applications can be distinguished at a strategic level, dealing with public policies and business strategies (Tukker, 2000). Ecolabeling programs are becoming increasingly important for promoting sustainability as they meet all specific requirements based on life cycle information (Guinée, et al., 2001). In the Figure 8 are shown some examples of wider LCA applications.

Figure 8 - Life Cycle Assessment Strategies.



Source: Guinee et al., (2001). Adapted by the authors.

The main characteristic of the LCA is its "holistic" nature, which is both its main strength and, at the same time, its limitation. The broad scope of a product's LCA can only be achieved at the expense of simplifying other aspects. In the Figure 9 are listed the main limitations of LCA, by Ginée, et al., (2001), EPA (2006), UNEP/SETAC, (2009).

Figure 9 - Limitations of LCA.

Source: Ginée (2001), EPA (2006), UNEP / SETAC, (2009); adapted by the authors.

For these reasons, it is recommended that a peer review process be established and implemented at the start of any study about a product or process and in all its life cycle stages UNEP/SETAC, (2009).

3. Final Considerations

Successful utilization and capitalization of the entire LCT and LCA methodology will ultimately require your evaluators to pay attention to multiple economic, social and environmental considerations, based on rigorous approaches to LCT and assessment and multi-objective optimization. These efforts will be essential to comply with the sector's social and environmental licenses in the regulatory, value chain and market contexts, which in turn are increasingly oriented towards compliance with sustainability in production.

Evidently, sustainability management presents major challenges and opportunities for industry. However, interventions in new technologies can be extremely promising in order to guarantee true sustainability in production. This will require an assessment and multiple considerations of economic and environmental sustainability, based on rigorous LCT and assessment approaches. It is noteworthy that the LCA of a product or process can be a comparative parameter for future assessments, as well as for data analysis in different production systems, having a comparative effect based on local information/data, bringing greater legitimacy to the results obtained.

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