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ORIGINAL ARTICLE

How to consider life cycle thinking into ISO 14001? A step-by-step method for small and medium-sized companies and a case study in waste management

Como considerar o pensamento do ciclo de vida na ISO 14001? Um método passo a passo para pequenas e médias empresas e um estudo de caso em gestão de resíduos

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Abstract: ISO 14001 certification offers numerous benefits to companies, including improved efficiency, market access, and the fostering of an environmental organizational culture. However, many organizations, especially small and medium-sized enterprises (SMEs), struggle to grasp and integrate Life Cycle Thinking into their processes, products, or services, as it's a requirement for ISO 14001:2015 certification. This article aims to present a step-by-step method for incorporating life cycle thinking into ISO 14001:2015 implementation, aligning it with Sustainable Development Goals (SDGs). The methodology comprises three steps: i) a systematic literature review to identify life cycle thinking practices within ISO 14001:2015; ii) a detailed proposal for integrating LCT into ISO 14001:2015; and 3) a case study in a briquette manufacturing facility using this method for waste management. The results highlight that organizations can incorporate life cycle thinking into various ISO 14001:2015 clauses through simple and fast for use tools and activities, concurrently advancing SDGs. It's imperative for SMEs to integrate life cycle thinking into ISO 14001 implementation not only for tangible and intangible benefits but also because future ISO 14001 versions are expected to impose stricter life cycle requirements.

Keywords: ISO 14001; Environmental management systems; Small and medium-sized enterprises; Sustainable development goals; Streamlined life cycle assessment; Industrial ecology.

Resumo: A obtenção da certificação ISO 14001 pode trazer vários benefícios para as empresas, como processos mais eficientes, acesso a novos mercados e até mesmo o desenvolvimento de

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uma cultura organizacional ambiental. No entanto, muitas organizações, em particular as pequenas e médias empresas (PMEs), enfrentam dificuldades para entender o que é e como considerar o Pensamento do Ciclo de Vida em seus processos, produtos ou serviços, uma vez que isso faz parte dos requisitos para obter a certificação ISO 14001:2015. Portanto, o objetivo deste artigo foi propor um método passo a passo para incluir a ACV nas atividades de implementação da ISO 14001:2015 como parte do cumprimento de seus requisitos. Além disso, o método proposto foi relacionado ao cumprimento dos Objetivos de Desenvolvimento Sustentável (ODS). Assim, a metodologia foi dividida em três etapas: i) uma revisão sistemática da literatura para identificar estudos anteriores envolvendo práticas para incorporar o Pensamento do Ciclo de Vida na ISO 14001:2015; ii) uma proposta de método passo a passo que permite a inclusão desse pensamento na ISO 14001:2015; e iii) uma descrição de estudo de caso em uma fábrica de briquetes para o gerenciamento de resíduos. Os resultados demonstraram que, por meio de um conjunto de atividades e ferramentas simples e de rápida aplicação, uma organização pode incluir tal pensamento em muitas das cláusulas da ISO 14001:2015, ao mesmo tempo em que contribui para o cumprimento dos ODS. Por fim, é importante para as PMEs considerar o Pensamento do Ciclo de Vida nas etapas de implementação da ISO 14001, não apenas por motivos de resultados tangíveis e intangíveis, mas principalmente porque espera-se que a próxima versão da ISO 14001 seja mais rigorosa em relação à necessidade de seguir os requisitos do ciclo de vida.

Palavras-chave: ISO 14001; Sistemas de gestão ambiental; Pequenas e médias empresas; Objetivos de desenvolvimento sustentável; Avaliação do ciclo de vida; Ecologia industrial.

1 Introduction

Waste management is necessary because the inefficiency of resources in production activities leads to the generation of waste from the use of raw materials. According to the World Bank, global waste generation is expected to reach 3.4 billion tons by 2050, nearly double the amount produced in 2010 (Kaza et al., 2018). The problem becomes even more significant when considering the entire value chain of products. For instance, according to the FAO (2014), if food wastage were a country, it would rank as the third-largest greenhouse gas emitter. Additionally, Steffen et al. (2015) and Oliveira et al. (2021) explain that global socio-economic development exerts pressures and impacts on the environment, with waste generation being one of the driving forces behind this situation. Currently, the world operates with only 9% circularity, revealing a significant gap between waste generation and value creation in a life cycle approach (Fraser et al., 2023).

Organizations are striving to achieve better environmental performance throughout their value chains, considering the increasing pressures from different stakeholders such as clients, government agencies, society, consumers, etc., and this is reflected in the 2030 Agenda (United Nations, 2015) which introduced the Sustainable Development Goals (SDGs).

With that in mind, for Small and Medium Enterprises (SMEs), an alternative to achieving SDGs and minimizing waste throughout the value chain may be related to the implementation of an Environmental Management System (EMS), which the most well-known example being based on the International Organization for Standardization (ISO) 14001 Standards (Poltronieri et al., 2021). ISO 14001 allows greater visibility of the organization in the market and environmental improvements, by defining environmental policies, and responsibilities and achieving goals by using a continuous improvement system based on a continuous improvement process, i.e., a Plan-Do-Check-Act cycle (PDCA) (ISO, 2015).

Arimura et al. (2016) pointed out that ISO 14001 grants flexibility to facilities regarding the types of environmental goals they wish to establish, encouraging the management of environmental impacts, through internal management procedures. According to Stevens et al. (2012), organizations need to understand how to manage and control their environmental, which can be achieved through understanding their internal processes in a PDCA cycle. Salim et al. (2018) emphasize the necessity of cross-country research collaboration and the adoption of demand-driven approaches in global waste management policy-making. The authors suggest that relying solely on the ISO 14001 standard may pose challenges not only for the implementation by SMEs but also for the advancement of public policies in this field.

Regarding SMEs, they represent a significant portion of companies nowadays, accounting for up to 90% of global companies, contributing up to 40% of national income in emerging economies (World Bank, 2020), and involving a significant share of the environmental impacts worldwide (Graafland & Smid, 2016). Thus, SMEs' engagement with EMS can reflect not only in environmental benefits, but also an important source of competitive advantages such as enhanced reputation, environmental responsibility, access to new markets, customer satisfaction, compliance with legislative processes, more efficient processes, and better chances of financing (Granly & Welo, 2014; Puglieri & Iritani, 2021), and meeting the needs of stakeholders (ISO, 2015).

Despite the approximately 307,059 companies certified with ISO 14001:2015 worldwide (ISO, 2018), Musa & Chinniah (2016) and Seiffert (2008) point out that SMEs have difficulties in implementing ISO 14001 due to several reasons, such as budget limitations, lack of human resources and access to financing. Pesce et al. (2018) state that SMEs also expressed concern about the costs involved in the certification process and the lack of integration with sustainability tools.

Johnstone & Hallberg (2020) address that SMEs comprise the largest sector of the global economy, requiring environmental management to achieve sustainable improvements. In this sense, Oliveira et al. (2017) and Johnstone & Hallberg (2020) emphasize that the adoption of ISO 14001 in SMEs should be based on the interrelationship of symbolic and substantive performance over time and space, as resources and personal values of the owner-managers who drive internal change. This statement is corroborated by Renatus & Geldermann (2016) research, when they discuss that there is a lack of tools to support environmental decisions, focusing on the specific needs of SMEs. Furthermore, few SMEs know and/or integrate Life Cycle Thinking (LCT) approaches and tools in their production process (Oliveira et al., 2018) and sometimes, the use of other well-known techniques oriented to products decision-making, such as Life Cycle Assessment (LCA), can be expensive and time-consuming (Oliveira et al., 2021; Puglieri et al., 2020).

In 2015, ISO 14001 Standards were updated and they included LCT as part of their mandatory requirements. However, this new requirement is not clearly presented, raising questions about understanding what is and how to consider LCT in the organization's processes, products, or services (Poltronieri et al., 2021). Thus, this requirement revealed a new challenge for SMEs interested to implement or already certified in ISO 14001 EMS (Landeta-Manzano et al., 2017). Additionally, with the recent developments in applications of the 17 SDGs from the 2030 Agenda, operational methods to assess all SDGs are lacking (Laurent et al., 2020), and this could represent an additional limitation for SMEs to improve their resource efficiency.

In a preliminary literature review, no previous studies were found to present tools or activities regarding the inclusion of LCT in business processes as part of compliance with the requirements presented by ISO 14001:2015, which represents an opportunity for this paper to cover this gap. The only two studies found through a literature review include the use of SWOT analysis to diagnose SMEs' satisfaction with ISO 14001 (Pesce et al., 2018) and a multicriteria analysis tool, offering support for decision-making in the face of environmental issues (Renatus & Geldermann, 2016). Moreover, there are still few papers focused on methods to assess impacts of SDGs resulting from projects and or activities of companies for more sustainable production (Menussi et al., 2023; Laurent et al., 2020; Weidema et al., 2020).

Therefore, considering this scenario in which SMEs often show difficulties related to the ISO 14001 implementation and in face with the LCT as a mandatory requirement in the ISO 14001:2015 guidelines, the goal of this paper is to propose a step-by-step simple method to incorporate LCT into the ISO 14001:2015 implementation steps. Additionally, this paper shows how the developed method contribute to advancing the SDGs based on its integration with the framework recently proposed by Life Cycle Initiative (2023).

Finally, this article is organized as follows: section 2 presents the materials and methods used to conduct this study; section 3 presents the step-by-step method proposal; section 4 presents the application of case study and discussion of the results; and, finally, section 5 ends with the conclusions and remarks.

2 Materials and methods

The methodology used to conduct this study was divided in four phases, as detailed in the in the following subsections.

2.1 Phase 1 - Life cycle thinking inclusion into the ISO 14001:2015

A literature review was carried out using a script that constituted the search for the portfolio of activities and tools existing in the literature, which considers the LCT practices inclusion into the ISO 14001 for SMEs.

Thus, the following combination of keywords was defined: ("small and medium-sized enterprises" OR "small and medium enterprises" OR "SME") AND ("life cycle") AND ("ISO 14001"). The term "life cycle" was chosen because it is a general term that encompasses life cycle thinking, life cycle perspective, life cycle approach, life cycle assessment, and life cycle management, among others. Subsequently, the search was carried out in Science Direct, Scopus, and Web of Science databases, on March 21, 2023, through the application of three filters: i) Documents: Full Articles and Review Articles; ii) Terms: Articles containing the combined terms of the keywords in the title, abstract and/or keywords; and iii) Time Restriction: No time restriction. The total number of studies was 16, but only 7 articles were found after excluding duplicate articles from the databases. Of these articles, only 2 of them were related to the topic of this study. Note there were found no previous studies in the literature pointing out activities and allowing for the inclusion of LCT in the guidelines of ISO 14001:2015 for SMEs.

Pesce et al. (2018) proposed an application of SWOT analysis in the Chinese context of ISO 14001 adoption by companies with a focus on stakeholder engagement and resource management. Renatus & Geldermann (2016) developed a multicriteria tool for use by SMEs in corporate environmental management information systems. These two references were important to subsidize the development of the proposed method to include LCT into ISO 14001 with accordance on Phase 2.

2.2 Phase 2 - Step-by-step method proposal to include LCT into ISO 14001

Activities and tools found in the literature were classified according to two criteria:

Criterion 1: to reflect the reality of SMEs which often includes difficulties related to the availability of financial resources and advanced knowledge in environmental practices and tools;

Criterion 2: activities and tools which should be related to ISO 14001:2015 clauses, i.e., making part of the Plan-Do-Check-Act structure.

According to this, the proposal of the activities and tools were combined in a step-by-step method considering easy and quick implementation efforts, low cost, and low need for technical skills in environmental sciences by the team of an SME'. At the same time, these activities and tools should be useful to comply with any of the following ISO 14001:2015 clauses: the context of the organization; leadership; planning; support and operation; performance and evaluation; and improvement (ISO, 2015).

A detailed description of the proposed method is given in section 3.

2.3 Phase 3 - Relationship between the LCT proposal to 14001 and the SDGs

Completing the proposal of a step-by-step method to include LCT in ISO 14001:2015, the linkage and potential benefits between the proposed activities/tools and the 17 SDGs were discussed. For the integration proposal, we adopted the framework developed by Life Cycle Initiative (2023).

First of all, the defined application context was the screening approach, i.e., the Life Cycle SDG Screening (LCSS) Life Cycle Initiative (2023). This approach should be used when companies want to reuse their existing procedures and life cycle data and information to understand which products, processes, and/or impact categories contribute to which SDGs. It is a semi-quantitative approach similar to the recent approach also used by Laurent et al. (2020) to assess the sustainability implications of research projects against the SDGs. The main idea is to identify SDG hotspots along the life cycle of products and analyze how SMEs can influence these SDG hotspots and generate relevant information for the EMS.

The steps of LCSS are similar of a regular LCA study. The idea is to use LCSS at the end of the PDCA cycle in the proposed method, to better supply an Action Plan for improvements in the EMS, as well as to support communication about contributions to the SDG.

The LCSS generates relevant information at two levels: for each of the 17 SDGs as a whole, and each of the targets of each SDG of interest to a company Life Cycle Initiative (2023). The results of LCSS are organized in a scoring matrix structure:

The ++ score indicates a positive contribution, i.e., the measured performance is much better than the benchmark; the **+ score** is also a positive result, but it indicates that the performance is only better than the benchmark; the **0 score** means a negligible or unknown contribution, and the performance can be considered equal to the benchmark; the **- score** is a negative contribution indicating that the performance is worse than the benchmark; and the - -**score** means a much worse performance than the benchmark from the Life Cycle Initiative (2023) and Laurent et al. (2020).

The benchmark describes a reference situation for comparison of the LCSS results. Life Cycle Initiative (2023) explains that it is possible to use a representative product as a baseline or to compare multiple products that fulfil the same function, so different products serve as a benchmark for each other. In this paper, we used a baseline scenario (section 2.4) as the current landscape of the SME company under investigation, and we proposed a new system representing a project with expected results after the implementation of the new system.

Finally, to indicate improvements for the SMEs, a 3-point scale for assessing the results were extracted from Life Cycle Initiative (2023): i) If any of the linked targets score as negative to that SDG, the overall score for that SDG is considered a negative contribution (scoring as - or --); ii) In none of the linked targets score as negative to that SDG, and at least one linked target score as a positive contribution, the overall score for that SDG is considered a positive contribution (scoring as + or ++); and iii) If none of the linked targets score as negative or as a contribution to that target SDG, the overall score for that SDG is considered neutral (scoring 0).

To calculate the results for each of the targets, the proposed method used a list of over than 200 indicators proposed by the United Nations (2015) to guide governments toward sustainable development in 2030. For the case study in this paper, the evaluated company selected specific indicators that are important for achieving their strategic EMS's targets, which will be addressed in section 4.4.

2.4 Phase 4 - Case study description

This last phase of the research presents a case study. Qualitative and quantitative data was used for an SME company located in Brazil according with the steps for application in Figure 1.

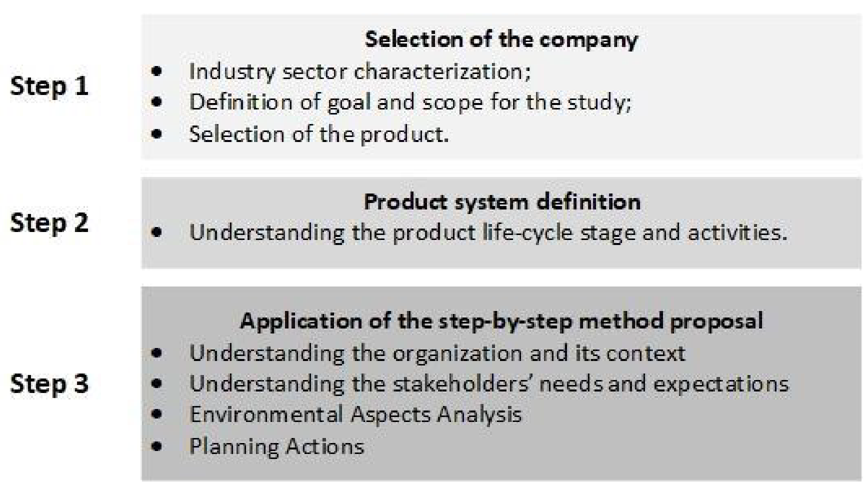

Figure 1. Steps for the case study.
Source: Own authorship.

Following the steps in Figure 1, step 1 involves selecting the anonymous SME located in the city of São Carlos, São Paulo State, Brazil, which produces wood briquettes from wood solid waste. The briquette is a compact block with high density, which can be used primarily for business (burning furnaces, bakeries, and pizzerias) and for industrial purposes (boilers and kilns), and is produced under mechanical compression and high temperatures conditions (Silva et al., 2022).

The goal and scope of this case study were to identify opportunities to improve the environmental performance of the wood briquette industry using the step-by-step method described in section 3. Afterward, the conclusions, pros, and cons of using this proposed method were discussed.

The company produces around 10 tons of briquettes per day, with the product primarily used for heating boilers in manufacturing plants and for commercial applications (restaurants ovens, bakeries, etc.). Residual wood (sawdust, 50% humidity and 50/50 eucalyptus/pine fractions) and other wood by-products are the main input flow for briquettes production (Farrapo et al., 2023), and the composition and additional information of the wood briquettes case study are: nominal density (1,000-1,300 t/m^3); ash content (0.5-1.5%); heat content (4,000-4,800 kcal/kg); briquette final diameter (80 mm); briquette length (250-400 mm).

For the implementation of the LCT, it was necessary to follow some of the main elements of a formal LCA, such as defining the limits of the product system (Figure 2). This is the first step of applying the proposed method and starts the case study description. The system boundaries have a cradle-to-grave perspective and consist of unit processes defined by the studied company.

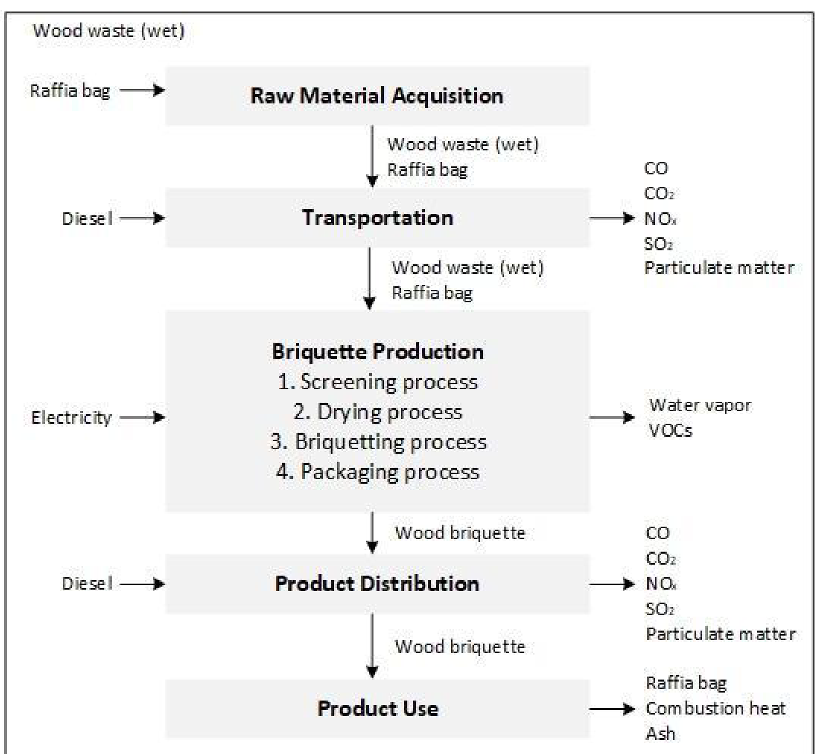

Figure 2. Product system and main inputs/outputs flows of wood sawdust briquettes.
Source: Own authorship.

Thus, the product life cycle begins with the transportation of wood waste to the briquette manufacturer. Sawdust (composing a mixture of pine and eucalyptus species) is a solid waste with 50.0% humidity and comes from wood sawmills in the southwest region of São Paulo State. The transportation of wood sawdust is done by trucks with a payload of 9.69 tons and an average distance of 100.0 km. The transport mode is based on light goods vehicles with one wood raw material delivery per week.

The wood sawdust is stored at the briquette industry until the beginning of the manufacturing process. The first process is the screening of wood sawdust to separate the desired wood particle sizes from the remaining wasted material. The screening process is carried out using screening machines with 10 mm of diameter to separate the desired particle size. The classified wood is dried to a nominal moisture content of 10.0% (wet basis), using a drum dryer. Heat is generated in an industrial furnace fuelled by part of the dried wood sawdust as fuel.

The wood particles after classification and drying processes follow the briquette machine. A piston briquette machine is used by the studied company to produce wood briquettes. The function of the briquette machine is to compress wood sawdust through coups, using a hydraulic piston to force the wood particles to cross a tube/mold. This process is known as extrusion, and temperatures can reach 150-200 °C due to the friction of material with the machine mold.

Due to the high temperatures during the extrusion process, a chemical change occurs in the anatomical structure of the wood particles. The wood material becomes denser and more concentrated, and the result is named a briquette. The briquette machines used by the companies are electrically supplied, and the final geometrical shape of products is tubular or cylindrical briquette blocks.

The product is cooled until thermodynamic equilibrium with the external environment, and then it is packaged 30.0 kg bags for distribution to customer (pizzerias, bakeries, restaurants, brickyards, other industries, etc.).

For the distribution process, it was assumed a distance of 10.0 km from the company's gate to a local set of customers. The transportation process is mainly carried out by diesel trucks with payload of 1.3 tons and is managed and paid by the company.

Additional data for the phase of using the briquettes were obtained from local consumers (restaurants, pizzerias, bakeries) located in São Carlos' downtown, which consume briquettes as the main fuel in the oven for preparing the products (pizzas, bread, meals), chosen because they are representative customers of the factory under study - approximately 45% of the total sales are coming from local customers in the city. Other biomass fuels, such as charcoal and firewood, are also energy alternatives for the selected customers; however, this article emphasizes assessing only the life cycle of briquettes.

For data collection, secondary data from literature and databases were considered when primary data were not available. For example, atmospheric emissions from diesel consumption in transport activities were calculated using IPCC (2006) characterization factors for greenhouse gas releases. The main inputs and intermediate products can also be seen in Figure 2.

Lastly, the case study presents in step 3, the analysis and opportunities for the briquette company through the application of the step-by-step method.

3 The step-by-step method proposal

3.1 Method scope

This step-by-step method is based on the same ISO 14001:2015 clauses, meaning that activities and tools are associated with the following PDCA steps: organizational context o; leadership; planning; support and operation; performance and evaluation; and improvement. From that, Figure 3 presents a view of LCT integration and tools into ISO 14001:2015.

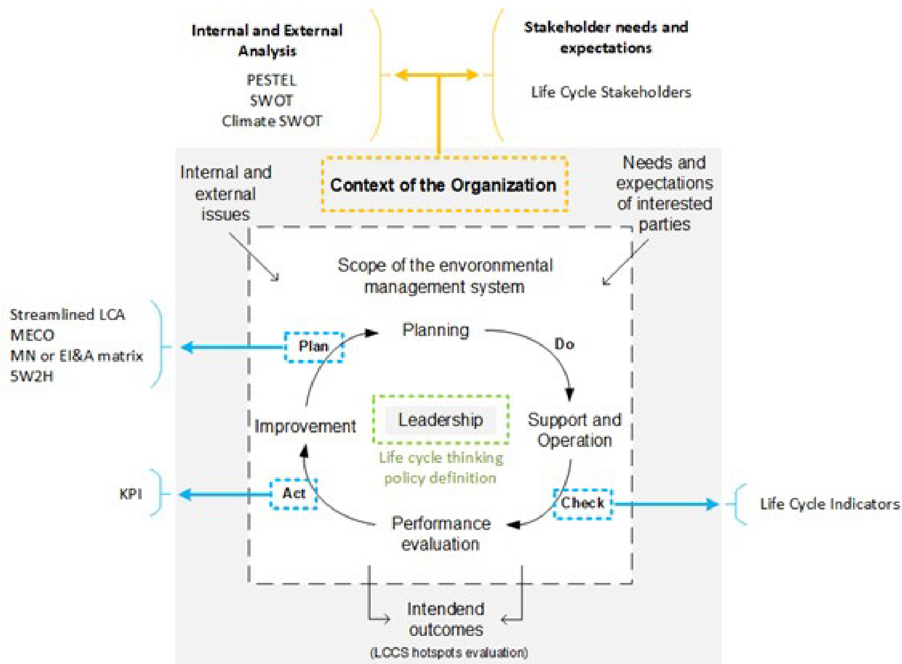

Figure 3. The step-by-step method proposal.
Source: Own authorship.

The Proposal in Figure 3 increases the organization's understanding of its life cycle and where there are opportunities to improve its environmental performance. Table 1 presents, for each PDCA step and ISO 14001:2015 clauses, a set of activities and tools presented by this study, aiming to promote the inclusion of LCT in ISO.

Table 1. Tools and Activities for inclusion of LCT into ISO 14001:2015.

PDCA step	ISO 14001:2015 clauses	LCT Recommended Activities	Recommended Tools for use
Pre-PDCA step	4.1 Understanding the Organization and its context	Identification of future trends in the organizational life cycle which may affect its ability to implement and keep the ISO 14001 EMS	PESTEL analysis
Pre-PDCA step	4.1 Understanding the Organization and its context	Identification and analysis of internal (strengths and weaknesses) and external issues (opportunities and threats) in the organizational life cycle which can affect its ability to implement and keep the ISO 14001 EMS	SWOT analysis

Table 1. Continued…

PDCA step	ISO 14001:2015 clauses	LCT Recommended Activities	Recommended Tools for use
Pre-PDCA step	4.1 Understanding the Organization and its context	Identification and analysis of internal (strengths and weaknesses) and external issues (opportunities and threats) in the organizational life cycle which can assist strategic decisions involving actions to reduce climate change impacts	Climate SWOT
Pre-PDCA step	4.2 Understanding the Stakeholders' needs and expectations 6.1.3 Legal requirements and others	Identification of stakeholder's needs and expectations, from cradle to grave, promoting opportunities to improve the environmental performance of the organization in its life cycle	Life Cycle Stakeholders
Pre-PDCA step	5.2 Environmental policy	Establishment and the implementation of a life cycle thinking policy	Life cycle thinking principles (European Union, 2010)
Plan	6.2.1 Environmental aspects	Quantitative assessment of environmental aspects and impacts of products/services throughout the organizational life cycle, supporting the decision-making process	Streamlined LCA (Str-LCA), e.g., MECO Matrix
Plan	6.1.4 Planning actions	Prioritization and proposition of an action plan for the highest environmental aspects and impacts identified throughout the organizational life cycle	Environmental Impact & Aspect Matrix, MN Matrix, and Life Cycle Stakeholders
Plan	6.2.1 Environmental objectives 6.2.2 Planning to achieve objectives	Definition of environmental objectives and action plan, including required resources, responsibilities and schedules for the whole organization's life cycle	5W2H
Check	9.1 Monitoring and measurement 9.3 Management review	Quantification of environmental impacts for each stage of the organization's life cycle	Life Cycle indicators
Act	10.2 Nonconformity and corrective action	Strategic assessment of the achievement of targets related to the reduction of environmental impacts	key performance indicator (KPI)

Source: Own authorship.

Each tool presented in Table 1 is described below to evidence the understanding of its functionality and how it can contribute to the LCT into the ISO 14001:2015 clauses.

3.2 LCT tools

3.2.1 PESTEL analysis

The PESTEL Analysis (see this and the other tools described in Appendix 1) can assist the environmental management team in identifying future trends in the organizational life cycle which may affect its ability to implement and keep ISO 14001, in accordance with the 'understanding the organization and its context' clause. Trends in the political, economic, social, technological, environmental, and legal spheres should be analyzed from a cradle-to-grave perspective, since changes in the supply chain or product's end-of-life, may also influence strategic planning and environmental decisions within the organization. Thus, strategic decisions can be made regarding these trends, while simultaneously promoting several SDGs, e.g. raw material and water scarcity may lead to actions on innovation and processes optimization (SDGs 6, 8, 9, 14 and 15) and non-renewable materials and energy can be replaced with renewable alternatives (SDGs 7, 12 and 13).

3.2.2 SWOT analysis and climate SWOT (Pesonen & Horn, 2014)

Complementing the PESTEL analysis, a SWOT analysis, and other environmental tools based on it are suggested to enable the identification and analysis of the current internal issues (strengths and weaknesses) and future external issues (opportunities and threats) in the organizational life cycle.

3.2.3 Life cycle stakeholders (UNEP, 2017)

This tool is suggested to identify the needs and expectations of stakeholders by introducing an LCT analysis and promoting opportunities to improve the environmental performance of the organization from a cradle-to-grave perspective. In this sense, Life Cycle Stakeholders can be a useful tool to attend the 'Understanding the needs and expectations of stakeholders' and 'Legal requirements and others from the 14001's clauses, since legal requirements can be identified from local to global regulators stakeholders.

Through identifying the needs and expectations of stakeholders, several SDGs can be developed by the organization. Some examples may include training in environmental management practices for the workers, promoting innovation (SDG 9), security procedures to avoid accidents (SDG 8), producing energy-efficient products for consumers (SDG 13), and opportunities for recycling (SDG 12). Looking at the life cycle stakeholders, the organization can also take the benefits to reach SDG 17, to find the right business partnerships.

Life Cycle Stakeholders is also a powerful and recommended tool to be used in the 'planning actions' clause since solutions can be directed to positively affect those stakeholders throughout the organization's life cycle.

3.2.4 Life cycle thinking principles (UNEP, 2017)

The principles of Life cycle thinking are not defined by the application of tools, but by guidelines, and their understanding is fundamental for the establishment and implementation of a life cycle thinking policy. Thus, for the 'environmental policy' clause, it is recommended that top management considers that an organization's environmental impacts are associated with its entire life cycle, not only within its physical limits. By developing actions aimed at minimizing impacts in the whole life cycle, the organization can enjoy eco-innovation and greener manufacture of products (SDGs 8 and 9), greater resource efficiency and green consumption (SDG 12), carbon footprint reduction (SDG 13), waste management (SDGs 6, 14 and 15), and other benefits (European Union, 2010).

3.2.5 Streamlined LCA (Str-LCA) tools

With Str-LCA tools, the aim is to perform a quantitative assessment of the environmental aspects and impacts of products in the organizational life cycle. In this case, inputs to organizational processes, such as the consumption of materials, water, and energy (SDGs 6, 12, and 13), and the outputs, e.g., greenhouse gases, solid waste, and effluents (SDGs 6, 13, 14 and 15) are systematically identified and analyzed.

3.2.6 Environmental Impact & Aspect Matrix (EI&A Matrix) and MN matrix

The aim of these two tools is to prioritize and propose an action plan for the highest environmental aspects and impacts identified in the organizational life cycle, in order to meet the 'planning actions' clause.

A formal EI&A matrix can have its analysis of impacts and aspects expanded to include the entire organization's life cycle, including environmental impacts and aspects of suppliers, distributors, clients, consumers, and recyclers.

Although the MN matrix is considered a Str-LCA tool, it has the same function as an EI&A matrix.

An environmental action plan can include actions for the entire life cycle of the organization, helping it to innovate processes (SDG 9), reduce greenhouse gases emissions in production, transportation, and use phases (SDGs 7 and 13), adopting renewable raw materials on its products (SDG 12), reducing water consumption during industrial and use phases (SDGs 6 and 14) and contributing to the preservation of life (SDG 15).

3.2.7 5W2H

Although 5W2H (see Appendix 1) is usually presented as a quality management tool, some examples are found in academic literature proposing it also as an environmental tool (Silva et al., 2013). Here, it is suggested that the 5W2H be used as a complement of EI&A and MN matrices. To include the LCT, objectives, responsibilities, and schedules should be defined having in mind the suppliers, logistics operators, sellers, and other partners in the organization's life cycle.

3.2.8 Life cycle indicators and KPIs

Life Cycle Indicators and KPIs are used to monitor environmental impacts for each stage of the organization's life cycle as required by the 'Monitoring and measurement' and 'Management review' clauses. Midpoint impact categories, such as emissions to soil (SDG 15), air (SDG 13) and water (SDGs 6 and 14), as well as resource consumption (SDG 12) can be prioritized for use in the EMS action plan.

4 Case study application: results and discussions

Here we described the results obtained from the briquette industry case study.

4.1 Understanding the organization and its context

In the 'understanding the organization and its context' clause, a SWOT analysis was done (Figure 4) and the following results were obtained with the agreement of the company representatives as stakeholders participating in the method application:

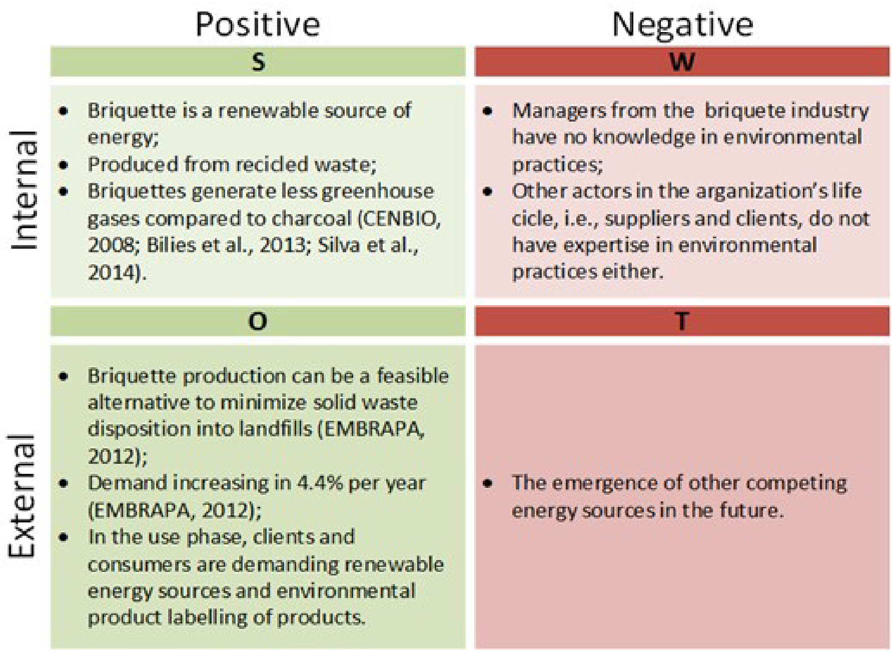

Figure 4. SWOT analysis.
Source: Own authorship.

From the results of the SWOT analysis, it was possible to determine the following strategic goals lined up to UN's SDGs: i) Development of actions to minimize greenhouse gases emissions to strengthen briquette as a sustainable and renewable source of energy. Therefore, it was selected SDGs 7, 12 and 13 for application of the method; and ii) To extend the environmental benefits of using briquette to increase its competitiveness and market share.

4.2 Understanding the stakeholders' needs and expectations

The main stakeholders in the supply chain were wood waste suppliers, logistics suppliers, trade and biomass associations, the ministry of energy, universities and research centers, family members of workers and residents close to the briquette factory, and retailers, distributors, and end customers. **Supply chain**: the reuse of wood waste by the briquette industry is an ecological solution considered by wood industries; **Professional interest**: Brazilian ministries are seeking circular solutions to reduce waste generation and increase the reuse of materials. Trade associations and biomass associations are interested in strengthening the briquette sector, lobbying national government departments for commercial, industrial, and environmental issues to officially formalize an ecological identification system for the briquette and the bioenergy sector as a whole. **Personal interest**: residents near the briquette producer may have a personal test in sustainability issues and/or more options for biomass sources for residential applications. In this case, the briquette could replace coal and firewood in residential applications and, at the same time, become a more widely used product. **Customer**: clients and consumers are more interested in obtaining information about the environmental performance of products and energy sources, opening opportunities for eco-labelling.

4.3 Environmental aspects and planning actions clauses

4.3.1 Simplified LCA

In these two clauses of ISO 14001:2015, a combination of Str-LCA approaches was applied: MECO matrix (Wenzel et al., 2000) and MN matrix of impacts (Sánchez, 2020). The Life Cycle Stakeholders tool was also integrated with the aforementioned tools (UNEP, 2017).

It is well-known that Str-LCA is a less complex and expensive process than a formal LCA, especially for SMEs companies. Str-LCA approaches use some elements from conventional LCA. In this case, for the MECO and MN matrices, a functional unit and a basis scenario were prepared for the geographical and technological scope of the study. For the local consumers in the city of São Carlos, it was defined as a functional unit of 1 kg of briquettes as local consumption (each 1 kilogram with 10-12% humidity and 4,600 kcal/kg of calorific value).

Material and energy balances were performed to check environmental flows into the MECO matrix. This matrix can also be organized according to the steps of raw materials obtaining, transportation of inputs, production, distribution, use, and end-of-life. For this case study, only the end-of-life phase was excluded from the system boundaries, as briquettes are totally consumed during the use phase.

Afterward, environmental impacts were evaluated. To this end, another Simplified LCA method was adopted by Sánchez (2020). Sánchez's (2020) method is an allocation of points based on a list of environmental aspects and impact categories. Then, the magnitude of impacts (MN) can be calculated and it is given by Equation 1, as follows:

$$\mathrm{MN} = \mathrm{Ab} + \mathrm{R} + \mathrm{Fq} + \mathrm{Rv} \tag{1}$$

Where:
- MN – environmental impact magnitude;
- R – relevance of impact;
- Ab – geographical coverage of impacts;
- Fq – frequency of impacts;
- Rv – reversibility of impacts.

High MN results mean high life cycle environmental impacts. The Appendix 2 shows a list of criteria for the MN calculation and gives a risk degree to classify MN results (Tables 1A, 2A and 3A).

4.3.2 MECO Matrix and MN results

The Life Cycle Stakeholders (UNEP, 2017) was once again to assist environmental managers in thinking about how they could contribute to reducing the main hotspots in the briquette life cycle. The focus was on finding solutions to minimize environmental aspects with high MN results and controllable risk degree.

The MECO matrix was selected for this paper because it is considered a classic approach for Str-LCA, while MN indicators were chosen to evaluate environmental impacts based on the results of the MECO matrix, and the Life Cycle Stakeholders is a method that permits to identify and propose improvements to solve the main life cycle hotspots in a front-end perspective, i.e., involving raw material suppliers, customers and other professionals and individuals interested in the supply chain.

For the functional unit of 1 kg of sawdust briquette, the MECO matrix was applied and results follow in the Appendix 3 (Table 4A). The data for the consumption of materials and energy during the briquette production was collected from records of the evaluated company, as well as for diesel consumption during the transportation of wood sawdust and raffia bags.

The production flows were calculated using emission factors available in the IPCC (2006). Thus, the emissions of CO and CO_2 from the combustion of wood briquettes were estimated from stoichiometric carbon balances.

In the briquette production phase, a first screening process is used to separate particles of wood waste, and approximately 10.0% (0.043 kg) of wood waste is lost due of particle oversizing. The remaining 90.0% of wood waste follows the dry process. Wood particles are dried up at 10.0% of humidity by an industrial dryer with wet sawdust processing capacity of 2,150 kg/h . For each 2,150 kg/h of wet sawdust processed, 827 kg/h of water vapor is generated and 220 kg/h of dry sawdust is consumed by the drier furnace.

Thus, the consumption of 2.15 kg of wet sawdust was calculated the for this study. Subtracting 10.0% of loss (i.e., 0.215 kg), it was found to have a final output of 1.94 kg of wet sawdust. This amount corresponds to the production of 1 kg of briquette, generating of 0.75 kg of steam, and 0.20 kg of sawdust for the furnace supply.

The briquette machine can produce briquettes up to 1000 kg/h, and requires 2,150 kg/h of sawdust (50.0% moisture). Thus, 2.15 kg of wet sawdust is needed to produce 1 kg of briquette. At the end of the process, the raffia bag (0.05 kg) is used to package the produced briquette (1 bag = 1.5 kg capacity).

Finally, the briquette is distributed to the customer. Then, it is used in bakeries, restaurants, etc. to generate 4,600 kcal of heat/ kg of briquette, resulting in emissions of 1.05E-05 kg of CO and 1.65 kg CO_2.

From the results, it is possible to verify the material balance and the production phase as the access point of the life cycle, mainly due to the higher consumption of resources and the generation of emissions. Atmospheric emissions from diesel combustion processes were highlighted in the “Chemical” category due to the raw materials transportation and product distribution activities.

Due to the lack of data limitations, volatile organic compounds (VOCs) and ash generation were not included in the MECO matrix. VOC emissions are generated during the sawdust drying process, while ashes are solid residues generated during the process of burning briquettes for cooking and/or heating purposes.

In addition, indirect greenhouse gases emissions due to electricity consumption and indirect flows due to the generation of sawdust and the production of raffia bags were not calculated. On the other hand, the quick results obtained with this LCA screening approach in an SME company are highlighted.

An energy balance of the MECO matrix reveals there is a net energy footprint of 4,311.5 kcal per kg of burned briquette. The calculation was made assuming a calorific value of 10,500 kcal⁄kg for diesel, and so, results showed a total energy consumption of 39.4 kcal during the raw materials transportation (or 3.75×10^{-05} kg of diesel), and 23.1 kcal during the product distribution phase (or 2.2×10^{-04} kg of diesel). For the briquette production phase, it was found to have 54.21 kcal of electricity consumption (or 0.063 kWh). This result highlights the high embodied energy contained in the biomass briquette.

The next step was to apply Equation 1 to calculate MN indicators and classify the results according to the risk degree. The environmental aspects identified into the MECO matrix were used as a reference for calculating he MN indicators.

From Appendix 2, the results showed 28 environmental aspects distributed among the different stages of briquettes life cycle. Regarding the MN results, 50% were classified as high priority, 47% were moderate impacts and approximately 3% were classified as low impact. Most of the high priorities were irreversible and classified as uncontrollable. On the other hand, most of the moderate priorities are reversible and controllable if mitigation actions can be planned and properly implemented.

In total, approximately 47% of all the aspects were classified as controllable, especially for resource consumption (renewable and non-renewable sources). Most of the aspects were considered uncontrollable because they are results from chemical reactions during biomass and diesel burning and the wood particles drying process.

4.3.3 Life Cycle Stakeholder

Figure 5 presents a Life Cycle Stakeholder action plan for the briquette company case study and then opportunities are discussed.

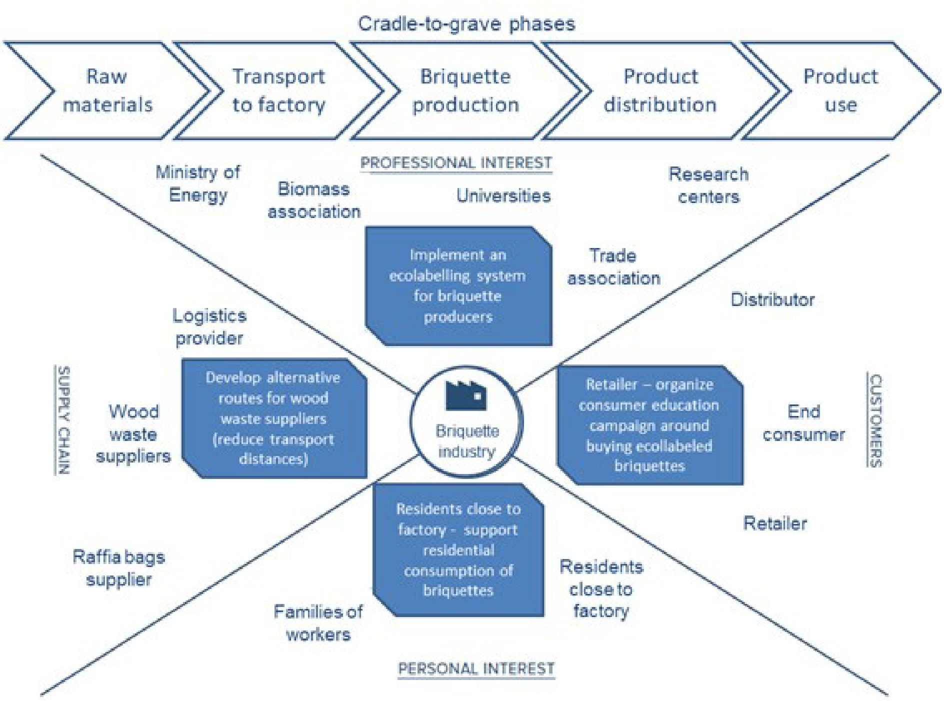

Figure 5. Life Cycle Stakeholder action plan for the briquette company case study. **Source:** Own authorship.

Supply chain: establish alternative routes for suppliers, in order to reduce transportation distances and obtain a substitution of diesel oil with others (such as of biodiesel or diesel with a lower sulphur content). This suggestion may minimize emissions of CO, CO_2, NOx, and SO_2. In an LCA study on wooden furniture, Iritani et al. (2015) state that in Brazil most logistics systems are still based only on road traffic, which is why it is important to look for more sustainable fuel options, especially in the transport of heavy loads, such as wood or waste;

Professional interest: Eco-labels and environmental declarations are important elements for communication and advertising (Fruntes, 2014). In Brazil, eco-labels have started to become more relevant recently, and Brazilian ministries, universities and institutes play an important role in this regard. Thus, the results of LCA from this study could be used as a pilot project to assist the evaluated briquette company in obtain this benefit. The partnership with trade associations and biomass associations can be useful to gain more leverage to pressure national government departments for commercial, industrial and environmental issues to officially formalize an ecological identification system for the briquette sector. Finally, an environmental label in this case does not imply that the briquette is environmentally better than alternative options (for example, firewood or charcoal), but it does show a transparent statement of the environmental impacts of the product's life cycle and can be a market advantage to win over consumers with proactive environmental concerns;

Personal interest: residents near the briquette producer can conduct personal testing on sustainability issues and/or more options for biomass sources for residential applications. As most of the briquettes are produced to serve the domestic market in the region, a promising practice is to support local consumption of residential supplies. In this case, the briquette could replace coal and firewood in residential applications and, while also becoming a product with broader usage.;

Customer: sustainable consumption campaign based on promoting the purchase of eco-labeled products. An educational campaign could be prepared by the evaluated company to show the environmental benefits of using briquettes. In Brazil, eco-labels are still under development (Moura, 2013), but recently, the Brazilian Institute of Information in Science and Technology (IBICT) launched the Brazilian Life Cycle Inventory Database - “SICV Brasil”, which aims to promote LCA in the national economy (IBICT, 2016), supporting the implementation of Type III eco-labels in the country (Dórea et al., 2022).

Bringing back the strategic goals defined through the SWOT analysis, the proposed action plan can assist the briquette industry to reach both of them. Developing actions to minimize greenhouse gas emissions to strengthen a sustainable and renewable source of energy can be done by reducing transportation distances in the supply chain. For the second strategic goal, eco-labelling practices can enhance the benefits of using briquette to increase its competitiveness and market share. However, before implementing this action plan it is necessary to evaluate the SDGs hotspots in this new production system.

4.4 Life cycle SDG screening (LCSS)

The last part of the application of the developed method involves a potential comparison between the new system and the baseline system in terms of the 17 SDGs affected by the product system under investigation. The baseline system and the new system are compared in Table 2.

Table 2. The baseline vs. new proposed system for the briquette production case study.

Baseline system	New system
The production of 1 kg of briquette made with wood sawdust for the domestic market.	An alternative production model for 1 kg of briquette made with wood sawdust for the domestic market including an action plan to assistance:
- The current system showed that 50% of the life cycle environmental aspects were classified as a high priority, while 47% were moderate impacts;	*- Developing actions to minimize greenhouse gas emissions. This can be done by reducing transportation distances in the supply chain and/or by changing the fuel to biofuel. Benefits are expected for SGDs 7, 12, and 13.*
Most of the high priorities were irreversible impacts;	*-Eco-labelling practices to extend the benefits of using briquettes to environmentally aware customers. Benefits are expected for SGDs 4, 12, and 17.*
- The current system showed 47% of all the aspects were classified as controllable, especially for resources consumption.	

Source: Own authorship.

For the comparative assessment, it was selected SGDs 7, 12, and 13 were selected for the application of LCSS evaluation, as previously defined in section 4.1. However, the new system in Table 2 highlights the possibility of including social and economic SDGs as well, contributing to SDGs 4 (quality education), and 17 (partnerships for the goals). The scoring matrix shown in section 2.3 was applied and the results for both the systems were compared and the final results can be seen in Table 3. The baseline scenario was used as a benchmark case for the comparisons with the new system. For this, it used a list of indicators provided by the United Nations (2015).

Table 3. Scoring matrix for determining whether the new system can support the SDGs.

SDG number and description	Indicators from the Agenda 2030	Contribution scores of the new system
SDG 4 - Quality Education	-Ensure that all customers acquire the knowledge and skills needed to promote sustainable consumption (through education for sustainable development and sustainable lifestyles). *Indicator based on the specific UN indicator number 4.7.*	+
SDG 7 - Affordable and Clean Energy	-Renewable energy shares in the total final energy consumption (including life cycle perspective). *Indicator based on the specific UN indicator number 7.2.1.*	+
SDG 12 - Responsible Consumption and Production	-Material footprint based on the MECO matrix and MN indicator results in a life cycle perspective. *Indicator based on the specific UN indicator number 12.2.2.*	+
SDG 13 - Climate Action	-Total life cycle greenhouse gas emissions per year. *Indicator based on the specific UN indicator number 13.2.2.*	++
SDG 17 - Partnerships for the Goals	Number of partners across the value chain with mechanisms in place to enhance policy coherence of sustainable development. *Indicator based on the specific UN indicator number 17.14.1.*	++

Source: Adapted from Laurent et al. (2020) and Life Cycle Initiative (2023).

It can be concluded that the suggested new system can be considered a positive contribution. No negative impacts were found, i.e., in none of the linked SDGs the target score was detrimental to the new system. The Life Cycle Initiative (2023) explains that when none of the linked indicators score as negative, and at least one linked indicator (or target) scores as a contribution, the overall score for that SDG should be considered as a positive contribution.

SDGs 4, 7, and 12 were scored as +, and SDGs 13 and 17 received ++. SDG 4 was a positive contribution to the new system because of the ecolabelling suggestion for communicating with sustainable consumers. SDG 7 tends to be higher in the new system due to the substitution of diesel with biodiesel, as well as looking for shorter routes for input transportation and briquette distribution.

For SDG 12, the proposed method suggested measuring material footprint based on the semi-quantitative tools - MECO matrix followed by MN indicator; the new production system tends to reduce chemical releases from diesel-burning for transportation, and as a result, it received a positive contribution.

Life cycle climate change impacts can be measured in SDG 13 by using the MECO matrix on the proposed method, and the lower energy consumption in the new system tends to minimize a lot (++) greenhouse gases released. The GHG Protocol (WRI, 2015) was used as a calculation tool for the comparison of air releases from transportation activities, and the results showed a comparison of the simulation of diesel vs. biodiesel used by light goods vehicles in the transportation of 100 km wood waste and 10 km for domestic distribution product. Only the effect of diesel/biodiesel substitution, with a reduction of over 50% in air emissions, reducing from 0.043 metric tonnes to 0.023 metric tonnes. Meanwhile, the effect of the optimizing the mode of transportation, where tricycles powered by biodiesel could be used to distribute the product since the distance covered is only 10 km – a reduction of 1% in fossil emissions could be achieved in this scenario.

SDG 17 can be highly improved (++) in the new system because of the use of Life Cycle Stakeholders in the EMS, before generating action plans. Lastly, the goal of this paper was achieved since the proposed step-by-step method was completely tested for the SME briquette case study in Brazil. The application of the proposed method took 04 months of application and the results are currently being implemented by the company to improve its EMS and guarantee fulfilment with the ISO 14001:2015 need to address LCT.

5 Research implications

What should be done to properly apply the proposed method in the context of waste management? Some relevant research implications can be summarized:

Technical and practical implications: The proposed model is qualitative and semi-quantitative, as most of the management tools suggested are user-friendly and do not require much quantitative data, making them easily applicable to SMEs. The model is particularly suitable for companies that are relatively new or less experienced in resource efficiency within LCT. Research by Bertassini et al. (2022) indicate that, for companies with limited knowledge in this area, the ideal approach is to initiate the transition towards more sustainable production through gradual but impactful changes in behaviours and culture. This is especially relevant for SMEs in emerging economies, which face various constraints in implementing extensive changes in terms of resources efficiency (Fatimah et al., 2020; Kayikci et al., 2022).

Political implications: Waste management is not only a requirement for SMEs with ISO 14001, but it is also a catalyst for accessing financial incentives. For instance, reverse logistics credits are instruments issued by the government or incentives offered to companies that adopt reverse logistics practices in order to incentive ‘zero waste’ (Pietzsch et al., 2017). These credits serve as a means to acknowledge and reward companies for their efforts in promoting the circular economy. Several countries and regions have implemented programs where these credits are applicable. The European Union, through Directive 2008/98/EC on waste, has established targets and requirements for waste management, including reverse logistics In the United States, various states have their own legislation and programs on reverse logistics. For instance, California operates the Container Deposit Program, which offers credits to liquor manufacturers participating in the bottle return system (Berck et al., 2021). In Canada, the province of Ontario has implemented the Recycling Credits Program, allowing businesses to purchase credits to fulfil their recycling obligations (CCME, 2019). In Brazil, the National Solid Waste Policy (Law No. 12,305/2010) establishes guidelines for reverse logistics and enables the implementation of reverse logistics credits in specific sectors. However, it is essential to raise awareness among SMEs in emerging economies like Brazil about the advantages of implementing LCT and complying with ISO 14001 requirements (Silva et al., 2019). Therefore, simple models like the one proposed in this paper can assist SMEs in mapping waste in their own processes and value chain.

6 Conclusions

In light of the challenges faced in implementing an EMS, in particular ISO 14001 which passes by a certification process, many SMEs face the challenge to expand their view from internal production processes to the whole product life cycle perspective. Meanwhile, SMEs are supposed to assume the commitment to the SDGs, since nations are engaging in the United Nations’ sustainable visions. Considering this, this research introduced a step-by-step method to include LCT into 14001:2015 clauses, by using simple activities and tools which can be easily understood by organizational managers of SMEs and also contribute to SDGs.

The results indicated that adopting the proposed method can increase the organization's environmental performance by adopting a life cycle perspective, without requiring much investment in hiring experts or training.

Considerations about LCT into EMS, in special ISO 14001 are essential for opening up opportunities for innovation and other tangible and intangible benefits as already presented in this article. Moreover, it is possible to expect that life cycle requirements become more stringent in a future new version of ISO 14001, demanding now the understanding and application of LCT activities and tools to avoid difficulties during the transition process.

As a limitation of this study, not all the proposed activities and tools were used in the case study since it was an illustrative application for an SME company in Brazil.

For future research, an Integrated Management System (IMS) focused on Life Cycle Sustainability Assessment (LCSA) assessing both environmental and social issues in order to meet more SDGs, could be developed.

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Authors contribution

Fabio Neves Puglieri, Mariane Bigarelli Ferreira, Antonio Carlos Farrapo Junior, Cassiano Moro Piekarski and Diogo Aparecido Lopes Silva worked together in the Conceptualization and theoretical-methodological approach, Theoretical review (literature survey), Data Collection, Data Analysis, Writing and Final revision of the manuscript.

Appendix 1. Tools Description.

PESTEL Analysis

PESTEL is a tool used to analyze and map the external environment trends that can influence the organization, providing support for decision-making with long-term objectives, and aiming to choose sustainable innovation and investment strategies. External trends analyzed comprehend six areas: Political, Economic, Social, Technical, Environmental, and Legal (Song et al., 2017).

SWOT Analysis

SWOT is a tool that allows a strategic assessment of internal and external factors in the organization, according to two positive points (Strengths and Opportunities) and two negative points (Weaknesses and Threats). 'S' and 'W' determine the internal factors, and 'O' and 'T' are the factors external to the organization (Pesce et al., 2018).

The organization’s decisions should be focused on maximizing Strengths and Opportunities while minimizing Weaknesses and Threats.

Climate SWOT (Pesonen & Horn, 2014)

Adapted from SWOT analysis, the Climate SWOT is a fast and economical tool to model the implications of climate change, dynamically including the life cycle perspective. Climate SWOT aims to identify how climate change will present opportunities for long-term strategies and planning (Pesonen & Horn, 2014).

Climate SWOT is based on six phases: i) identification of the product’s life cycle stages; ii) identification of climate impacts related to each life cycle stage. Those impacts should be positive and negative, in the current business and the future; iii) climate impacts are evaluated according to their significance for the environment, incomes, stakeholders, and legal requirements; iv) results are compiled into current impacts and future impacts, and then, v) strategies are defined to maximize strengths and opportunities while minimizing weaknesses and threats; vi) lastly, a strategic plan with objectives, responsibilities, budget, and a schedule is created.

Life Cycle Stakeholders (UNEP, 2017)

This tool aims to identify the stakeholders and their needs through the organization’s life cycle. Stakeholders are positioned in three categories: supply chain (e.g., suppliers of goods and services); customers (e.g., distributors, customers, and recyclers); professional interest (e.g., shareholders, workers, and banks); and personal interest (e.g., universities, nongovernmental organizations, and communities).

Streamlined LCA (S-LCA)

Many examples of simplified LCA tools are found in the body of literature. Ong et al. (1999) presented a tool called the Pre-LCA Tool (PLCAT) that can be used as a prelude to a full LCA or as a stand-alone tool by a quick-and-easy means, of assessing the environmental impacts of products. Sánchez (2020) developed an environmental impact methodology based on a magnitude impact indicator “MN”, which assesses impact categories according to their scope, relevancy, frequency, and reversibility of impacts. The eVerdEE is a Simplified LCA based on the VerdEE tool, originally developed by the Italian National Agency for New Technology, Energy, and Sustainable Economic Development (ENEA) (Arzoumanidis et al., 2013). More recently, Russo et al. (2015) showed an assessment tool based on an abridged LCA oriented to SMEs called TRIZ Eco-Guidelines.

The MECO matrix is one of the most spread S-LCA tools found in the literature. MECO refers to four factors, i.e. Materials, Energy, Chemicals, and Others, and it allows an LCA practitioner to get a concise overview of the environmental burdens through the evaluation of aspects that cause negative environmental impacts

(Volinová, 2011). “Materials” includes material consumption, waste generation, and material scarcity along the life cycle. “Energy” includes all energy sources that can be used during a product’s life cycle, while “Chemicals” refer to chemical’s substances used and their environmental hazard level, and finally, the “Others” category includes other environmental problems (e.g., noise, smells) (Volinová, 2011).

Environmental Impact & Aspect Matrix

Environmental Impact & Aspect Matrix is a tool commonly used as part of an EMS. It is an environmental assessment tool that is not limited to assessing the inputs and outputs of the life cycles of processes and products, but also assesses the danger of the materials involved in the analyzed process, allowing to assess the environmental consequences of organizational activities. Another important characteristic of this tool is related to the existing of a prioritization system, which allow to define a ‘risk score’ to any organization activity. Prioritization is calculated usually based on ‘severity’, ‘occurrence’ and ‘detection capacity’, serving as an important reference for decision-making.

5W2H

This is an important tool designed to define answers, such as deadlines, costs and responsibilities for an environmental action plan. 5W2H refers to the following questions: “What?”, “Why?”, “When?”, “Where?”, “Who?”, “How?” and “How much?”, contributing to investigate and report on different situations of pre-defined environmental management planning, aiming at the continuous improvement of processes and better visualization of the stages of an EMS.

Life Cycle Indicators and KPI (Key Performance Indicators)

Life Cycle Indicators and KPIs can be used as quantifiable metrics that reflect the environmental performance of an organization, assessing the achievement of its objectives and goals. The literature presents some environmental Life Cycle Indicators and KPIs, such as Material efficiency, Energy Efficiency, Water Management, Waste Management, Biodiversity, and Pollutant Emissions (Obradovic et al., 2016). These indicators can assess the achievement of goals related to the reduction of environmental impacts related to the life cycle of a product or service, allowing strategic execution in the points with the lowest environmental performance.

Appendix 2. MN indicator description and application.

Table 1A. Description of the Simplified LCA method proposed by Sánchez (2020).

Impact category	Classification	Weight factor	Description
Geographical coverage (Ab)	Point source	1	Environmental impact occurs only in the area directly affected by anthropic activity.
	Local (up to 100 km)	3	Environmental impact occurs locally, even in the area directly affected by anthropic activity.
	Regional (above 100 km)	5	Environmental impact occurs regionally, as an indirect result of the point source.
Relevance (R)	Moderate	3	The impact is verifiable or measurable without significant gains or losses in the environment quality for the geographical coverage.
	Relevant	5	The impact is verifiable or measurable with significant gains or losses in the environment quality for the geographical coverage.
Frequency (Fq)	Biannually or more	1	Environmental impact occurs rarely
	Monthly or more	2	Environmental impact occurs monthly or until six months.
	Weekly	3	Environmental impact occurs once a week at least.
	Daily	4	Environmental impact occurs daily (routinely).
Reversibility (Rv)	Reversible	1	Environmental impact is reversible if it is possible to reach a state of equilibrium with the environment quality.
	Irreversible	3	Environmental impact is not reversible anymore, even when control actions are performed to mitigate the impact.
Magnitude (MN)	Low	≤ 9	The sum of scores from Equation 1. MN results show a low magnitude of environmental impacts, and they are reversible if immediate action plans are prepared.
	Moderate	10 to 15	The sum of scores from Equation 1. MN results show a moderate magnitude of environmental impacts, and they are reversible if mitigate actions are properly performed.
	High	≥ 16	The sum of scores from Equation 1. MN results show high magnitudes of environmental impacts, and they are irreversible, even if mitigation actions are performed.

Source: Own authorship.

Table 2A. Degree of risk for MN results.

Impact category	Classification	Description
Degree of risk	Controllable	It is possible to control environmental impacts if mitigation actions are considered.
	Uncontrollable	Even when applying mitigating actions, environmental impacts are uncontrollable.

Source: Sánchez (2020).

Table 3A. MN results and risk degree classification.

Phase	Environmental aspect	Impact category (midpoint)	Ab	R	Fq	Rv	MN	Priority	Risk degree
RAW MATERIALS	Wood sawdust (50.0% moisture)	Resource consumption (renewable material)	5	3	4	1	13	Moderate	Controllable
	Raffia bag	Resource consumption (non-renewable)	5	3	4	3	15	Moderate	Controllable
TRANSPORTATION	Wood sawdust (50.0% moisture)	Resource consumption (renewable material)	5	3	4	1	13	Moderate	Controllable
	Raffia bag	Resource consumption (non-renewable material)	5	3	4	3	15	Moderate	Controllable
	Diesel	Resource consumption (non-renewable energy)	5	5	4	3	15	Moderate	Controllable
	CO	Air contamination	3	3	4	3	16	High	Uncontrollable
	Particulate matter	Air contamination	3	3	4	3	16	High	Uncontrollable
	CO_2	Air contamination	3	3	4	3	16	High	Uncontrollable
	NOx	Air contamination	3	3	4	3	16	High	Uncontrollable
	SO_2	Air contamination	3	3	4	3	16	High	Uncontrollable
BRIQUETTE PRODUCTION	Wood sawdust (50.0% moisture)	Resource consumption use (renewable material)	5	3	4	1	13	Moderate	Controllable
	Raffia bag	Resource consumption (non-renewable material)	5	3	4	3	15	Moderate	Controllable
	Electricity	Resource consumption (renewable/ non-renewable energy)	5	5	4	3	15	Moderate	Controllable
	Water vapor	Air contamination	3	3	4	1	11	Moderate	Uncontrollable
	VOCs*	Air contamination	3	3	4	1	11	Moderate	Uncontrollable

Table 3A Continued…

Phase	Environmental aspect	Impact category (midpoint)	Ab	R	Fq	Rv	MN	Priority	Risk degree
PRODUCT DISTRIBUTION	Wood sawdust (50.0% moisture)	Resource consumption (renewable material)	5	3	4	1	13	Moderate	Controllable
	Raffia bag	Resource consumption (non-renewable material)	5	3	4	3	15	Moderate	Controllable
	Diesel	Resource consumption (non-renewable energy)	5	5	4	3	15	Moderate	Controllable
	CO	Air contamination	3	3	4	3	16	High	Uncontrollable
	Particulate matter	Air contamination	3	3	4	3	16	High	Uncontrollable
	CO_2	Air contamination	3	3	4	3	16	High	Uncontrollable
	NOx	Air contamination	3	3	4	3	16	High	Uncontrollable
	SO_2	Air contamination	3	3	4	3	16	High	Uncontrollable
PRODUCT USE	CO	Air contamination	3	3	4	3	16	High	Uncontrollable
	Particulate matter	Air contamination	3	3	4	3	16	High	Uncontrollable
	CO_2	Air contamination	3	3	4	3	16	High	Uncontrollable
	Raffia bag	Resource consumption (non-renewable material)	5	3	4	3	16	High	Controllable
	Ash	Soil contamination	1	3	4	1	9	Low	Controllable

*VOC: volatile organic compound
Source: Own authorship.

Appendix 3. MECO application and results.

Table 4A. MECO matrix results.

	RAW MATERIALS		TRANSPORTATION		BRIQUETTE PRODUCTION		PRODUCT DISTRIBUTION		PRODUCT USE	
	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output
Materials	2.15 kg of sawdust (50.0% moisture)	2.15 kg of sawdust (50.0% moisture)	2.15 kg of sawdust (50.0% moisture)	2.15 kg of sawdust (50.0% moisture)	Screening process: 2.15 kg of sawdust (50.0% moisture)	Screening process: 1.95 kg of sawdust (50.0% moisture)	1kg packaged briquette	1 kg packaged briquette	1 kg of briquette	0.05 kg raffia bag
					Drying process: 1.95 kg of sawdust (50.0% moisture)	Drying process: 0.2 kg of dry sawdust for furnace			1 kg of briquette	1kg briquette-fired
						Drying process: 0.75 kg of water vapor				
						Drying process: 1 kg dry sawdust				
					Briquetting process: 1 kg of dry sawdust	Briquetting process: 1 kg of briquette				
	0.05 kg raffia sack	0.05 kg raffia sack	0.05 kg raffia sack	0.05 kg raffia sack	Packaging process: 0.05 kg raffia sack	Packaging process: 1 kg packaged briquette				
Energy			3.75E-03 kg of diesel		Drying process: 0.3 kg of dry sawdust		2.2×10^{-04} kg of diesel			4,600 kcal
					Briquetting process: 0.063 kWh of electricity					
Chemicals				1.1×10^{-02} kg of CO_2				6.5×10^{-04} kg of CO_2		1.65 kg of CO_2
				1.9E $\times 10^{-06}$ kg of CO				1.1×10^{-07} kg of CO		1.05×10^{-05} kg of CO
				4.45×10^{-07} kg of particulate matter				2.65×10^{-08} kg of particulate matter		
				4.8×10^{-05} kg of NOx				2.85×10^{-06} kg of NOx		
				7.5×10^{-08} kg of SO_2				4.4×10^{-08} kg of SO_2		
Others										

Source: Own authorship.