Life Cycle Assessment (LCA) applied in different scenarios of nutrient recovery in the form of struvite: systematic review

Avaliação do Ciclo de Vida (ACV) aplicada em diferentes cenários de recuperação de nutrientes na forma de estruvita: revisão sistemática

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ABSTRACT
The wastewater nutrients recovery in the form of struvite has been a trend due to the scarcity of phosphorus sources and the large energy expenditure for the production of nitrogen fertilizers. Another reason to replace the industrial fertilizers is directly related to the negative impacts on the environment, such as eutrophication of water bodies. Based on the aforementioned, the goal of the present paper is to perform a bibliometric analysis. Our work aims to review the main scientific articles published in the last five years based on the Life Cycle Assessment (LCA) tool to the evaluation of the sustainability of the processes used to obtain struvite from different types of wastewater. In this way, a survey was carried out followed by a systematic literature analysis using the ProKnow - C method, since it is a descriptive research. Based on the ProKnow - C method, data collection follows pre-established procedures, from the selection of the keywords to the filtering phase. These steps allow the selection of a quality bibliographic portfolio. The bibliometric analysis of data was performed using Microsoft Excel 2016 and statistical charts. Few publications were found on the subject. The results indicate that the environmental aspects are considered favorable to nutrient recovery. However, the need to formulate standardized guidelines to guarantee the quality to the application of LCA methodology in studies of systems for nutrient recovery it is evident.
Key words: Life Cycle Assessment, Sustainability, Nutrient recovery, Struvite.

RESUMO
A recuperação de nutrientes das águas residuais na forma de estruvita tem sido uma tendência devido à escassez de fontes de fósforo e ao grande gasto energético na produção de fertilizantes nitrogenados. Outro motivo para substituir os fertilizantes industriais está diretamente relacionado aos impactos negativos ao meio ambiente, como a eutrofização dos corpos d'água. Com base no exposto, o objetivo do presente artigo é realizar uma análise bibliométrica. Nosso trabalho tem como objetivo revisar os principais artigos científicos publicados nos últimos cinco anos, com base na ferramenta de Avaliação do Ciclo de Vida (ACV), para avaliar a sustentabilidade dos processos utilizados para obter estruvita a partir de diferentes tipos de águas residuais. Dessa forma, foi realizada uma pesquisa seguida de uma análise sistemática da literatura pelo método ProKnow - C, por se tratar de uma pesquisa descritiva. Com base no método ProKnow - C, a coleta de dados segue procedimentos pré-estabelecidos, desde a seleção das palavras-chave até a fase de filtragem. Essas etapas permitem a seleção de um portfólio bibliográfico de qualidade. A análise bibliométrica dos dados foi realizada no Microsoft Excel 2016 e gráficos estatísticos. Poucas publicações foram encontradas sobre o assunto. Os resultados indicam que os aspectos ambientais são considerados favoráveis à recuperação de nutrientes. No entanto, é evidente a necessidade de formular diretrizes padronizadas para garantir a qualidade da aplicação da metodologia LCA em estudos de sistemas para recuperação de nutrientes.

Palavras-chave: Avaliação do Ciclo de Vida, Sustentabilidade, Recuperação de Nutrientes, Struvita.

1 INTRODUCTION
The use of waste from environmental sanitation for the production of alternative fertilizers presents itself as a great opportunity to generate new products, such as struvite (MgNH4PO4 · 6H2O). Another factor that corroborates with the replacement of industrial fertilizers is their direct relationship with negative impacts on the environment, such as eutrophication of water.

According to ZHOU et al. (2018), the recovery of nutrients through the chemical precipitation of struvite has proven to be an economically viable technique, being proven by more than 40 large plants worldwide. However, little is known about the environmental impacts caused by the implementation of these technologies. Many environmental impact assessment tools are available, such as the Environmental Impact Assessment (EIA), the Material Flow Accounting and the Environmental Auditing, in addition to the Life Cycle Assessment (LCA) that may be an integral part of the EIA. The EIA is a tool used to assess the impacts of a project and it is specific to a location and time and in this way, it identifies the environmental effects of an activity in a given location and time period. The Material Flow Accounting, on the other hand, is a family of methods in which the accounting for the total required materials, the quantity of material per unit and the substance flow analysis is inserted. All of these methodologies focus on the flow of materials, especially those inserted in the production chain (FINNVEDEN; MOBERG, 2005).

However, a way used by the Brazilian agribusinesses to quantify and qualify the environmental impacts of the various stages of production, consumption and final destination of the
industrial and agricultural products or services is through the Life Cycle Assessment (CLAUDINO; TALAMINI, 2013). Thus, it is recommended that studies of Life Cycle Assessments should be carried out before the implementation of any techniques in new and/or existing areas (ADAMSSON; BAN; DAVE, 2003).

The Life Cycle Assessment consists of an assessment of the production systems or products from the “cradle to the grave”. In this sense, the evaluation begins in obtaining the raw materials and ends with the disposal of all materials. LCA differs from the traditional methods that estimate environmental impacts, since it allows estimating the cumulative environmental impacts resulting from all phases of the product's life cycle and/or processes that are generally disregarded, such as: the extraction of raw materials, the transportation and final disposal of the product. With the inclusion of the impacts of the entire life cycle of the product and/or system, LCA provides a broad view of the environmental aspects of the product or process so that an analysis of the pros and cons is performed (WILLERS; RODRIGUES; SILVA, 2013).

According to BAITZ et al. (2012), the Life Cycle Assessment is recognized for addressing the environmental impacts triggered by human activities in a reliable, understandable and scientific way. The estimates generated through the use of the LCA tool lead us to obtain more accurate results than the studies with more limited scopes. LCA is a useful support in decision making (MATTHEWS, HENDRICKSON AND MATTHEWS, 2015).

The life cycle assessment has been establishing itself as a “gold standard” for the study of the environmental impacts generated by services, a system or a product. In this way, a systematic survey of the studies that applied the LCA tool in the assessment of sustainability in different scenarios of nutrient recovery in the form of struvite was carried out. This study analyzed the bibliometric and methodological aspects, as well as the main results observed in the literature.

2 METHODOLOGY

This study was carried out by applying a systematic literature review using the Proknow-C-Knowledge Development Process - Constructivist methodology (ENSSLIN et al., 2010). This methodology was developed at the Laboratory of Multicriteria Methodologies in Decision Support (LabMCDA) of the Federal University of Santa Catarina – UFSC, Brazil (ENSSLIN, ENSSLIN and PACHECO, 2012), and it has proved to be an important tool in the construction of knowledge in the most varied research areas (AFONSO et al., 2011), in which it is divided into 4 stages: (I) selection of the bibliographic portfolio; (II) bibliometric analysis of the bibliographic portfolio; (III) systemic analysis of the bibliographic portfolio and (IV) elaboration of the research objectives (REINA et al., 2014).
In the stage of selection of the bibliographic portfolio, scientific articles were selected by searching the database using keywords defined according to the research theme. The “Scopus” database was adopted at this stage because it is based on bibliometric methods (FERENHOF et al., 2014; PINHEIRO; BARTH, 2014). The authors AFONSO et al. (2011) affirm that it is important to carry out different combinations among the keywords when searching the databases. Further, so that the documents found are appropriate to the proposed theme, the reading of at least two articles among those found is suggested.

A filtering process was carried out to select the articles used in the bibliographic review, in which criteria were defined for inclusion and exclusion of articles, thus obtaining a reduced portfolio with information on the topic of scientific interest and importance. The keywords chosen, combined and used in the search for the articles were: “Struvite” and “Life cycle assessment” or “LCA”. Only articles published between the years 2013 to 2018 were selected. The impact factor applied in the selection of articles was ≥1.27, which is one of the criteria established by Qualis Capes, brazilian journal evaluation system, for the article to receive the classification A1 in the area of Engineering I.

In the bibliometric analysis stage of the portfolio, it is crucial to collect indicators on the research. Among the main indicators, the following stand out: the countries that most published on the subject addressed, the institutions and their respective authors, the type of document, the increase or decrease in the number of works published on the subject. The main objective of this analysis is to demonstrate quantitatively the information regarding the bibliographic portfolio obtained (ensslin et al., 2010). All data collected were analyzed using the microsoft excel 2016.

The bibliographic portfolio was analyzed in a systematic way, through a complete reading of the selected articles, in order to raise important issues on the studied subject and, thus, to point out gaps to be studied. To facilitate the organization of the data and consequently of the analysis, tables were used in Microsoft Excel 2016 (AFONSO et al., 2011).

3 RESULTS AND DISCUSSION

In the selection of works in the Scopus database, the combination of the keywords “struvite” and “life cycle assessment” or “LCA” was inserted at the beginning of August 2018. Initially, 16 documents were found, being reduced to 14 after the application of the filter in relation to the desired period, 2013-2018. After the filtering process, only 12 articles were selected. Then, the 12 pre-selected articles in the previous step were submitted to stages 2 and 3, and finally, to a careful reading; thus, the set of articles remained unchanged (Figure 1).
The first publication that presented the combination of keywords in their context was “Nutrients in urine: Energetic aspects of removal and recovery” (MAURER, SCHWEGLER and LARSEN, 2003), published by the magazine Water Science and Technology with 136 citations in the analyzed period. It is possible to observe, as shown in Graph 1, that a new work was published only in 2012, which contained the analyzed keywords, with the title “Life cycle assessment of phosphorus alternatives for Swedish agriculture” (LINDERHOLM; TILLMAN; MATTSSON, 2012).

**Graph 1.** Total publications per year among the works found in Scopus when the keywords “Struvite” and “Life cycle assessment” or “LCA” are combined.

Source: Adapted from Viegas et al. (2016)
When considering the evaluated period, it is observed that the year 2013 did not present any publication. In 2014 there were 2 publications, in 2015 the number of publications doubled. However, in 2016 and 2017, the number of publications decreased and remained stable until 2018, when the publications increased again, thus showing the growing interest in the subject under analysis.

Among the documents published in the period from 2013 to 2018, all were scientific articles, 14 in digital and 1 in printed form. Of this total, 12 were published in journals with an impact factor greater than 1.27 and had an A1 rating simultaneously. The journals with impact factor above 1.27 and classification A1, with the largest number of publications related to the research topic, were the magazine Water Research (40%), followed by the magazine Environmental Science and Technology (17%). The other journals: Journal of Environmental Management, Journal of Cleaner Production, Science of the Total Environment, Resources, Conservation and Recycling, International Journal of Environmental Science and Technology and Waste Management, contributed with one publication each (8%) (Graph 2).

**Graph 2.** Number of publications in A1 magazines according to Engeneering I Qualis Capes Classification and with an impact factor greater than 1.5 in the period 2013-2018.

Another bibliometric data obtained was the number of citations for works published in the journals, in which the sum of all works published by Water Research totaled 56 citations (Graph 3). The most cited article until the beginning of August 2018 was “Evaluation of new alternatives in wastewater treatment plants based on dynamic modeling and life cycle assessment (DM-LCA)” (BISINELLA DE FARIA et al., 2015) with 23 citations, followed by the article “Life cycle comparison of centralized wastewater treatment and urine source separation with struvite precipitation: Focus on urine nutrient management” (BRADFORD-HARTKE et al., 2015) with 22 citations, both published by that magazine.
New processes must comply with the principles of sustainability where the benefits generated outweigh the costs of implementation. The Life Cycle Assessment (LCA) methodology governed by ISO 14040/44 (2006) was used by several authors to compare environmental performance in different scenarios for nutrient recovery (IGOS et al. 2017). Regarding the research analyzed, the functional unit used by most of the authors in their research was 1 m³ of raw wastewater to be treated (BISINELLA DE FARIA, et al., 2015; MBAYA; DAI; CHEN, 2016; IGOS et al., 2017). The volume of urine was also used as a functional unit (ISHII; BOYER, 2015; LANDRY; BOYER, 2016), as well as the removal of 1 kg phosphate eq. removed. (RODRIGUEZ-GARCIA et al., 2014), the recovery of 1 kg of phosphorus (BRADFORD-HARTKE et al., 2015), the management 1 annual per capita load of food waste, black water and gray water (KJERSTADIUS et al., 2017), treatment and disposal of annual load sludge in the AirPrex ® system at the Wassmannsdorf (WMD) WWTP (39,127 t TS / a) (ZHOU et al., 2018), handling 1 m³ of liquid digestive (LD) waste (STYLES et al., 2018) and 274 tons per day of animal manure (PEDIZZI et al, 2018).

The Life Cycle Assessment (LCA) was applied in different scenarios, such as in conventional wastewater systems compared to black water separation systems (THIBODEAU; MONETTE; GLAUS, 2014). LCA was performed in conjunction with dynamic modeling (DM) in different wastewater stations to quantify the energy and environmental advantages of urine separation (BISINELLA DE FARIA et al., 2015), a conventional scenario without urine separation compared to scenarios with urine separation (ISHII; BOYER, 2015; LANDRY; BOYER, 2016; MBAYA; DAI; CHEN, 2016; IGOS et al., 2017 and KJERSTADIUS et al., 2017). The environmental profile of different types of treatments for supernatants resulting from the anaerobic digestion of sludge generated in sewage treatment plants (STP) was carried out by Rodriguez-Garcia et al. (2014) using the LCA tool. BRADFORD-HARTKE et al. (2015) evaluated in terms of cumulative energy demand, global warming potential and acidification potential by applying LCA in different technologies for phosphorus recovery. PEDIZZI et al. (2018) evaluated the environmental performance of different
treatment arrangements aimed at recovering energy and nutrients from a mixture of animal manures, concluding that strategies that seek the recovery of P as high-quality struvite are environmentally interesting alternatives.

ISHII and BOYER (2015) quantified the environmental impacts of managing urine Nitrogen and Phosphor in different scenarios. The environmental impacts of the life cycle were quantified according to ISO 14040 (2006), considering a centralized treatment system without urine separation (Scenario A), systems with urine separation and addition of magnesium oxide (MgO) (Scenario B) for maximum recovery of P as struvite, and addition of MgO and sodium phosphate (Na3 PO4) for maximum recovery of P and N as struvite (Scenario C). The environmental impact of Scenario A was mainly related to the high consumption of electricity in the central wastewater treatment plant due to the large volume of influencers to be treated and the expenditure of electricity in the drinking water treatment plant used in the waste water. Although the struvite precipitation method addressed in Scenario C allows to recover high amounts of P and N as fertilizers, there are major impacts for the production of Na3 PO4 and MgO, necessary for precipitation. The LCA of this study and the corresponding results show the benefits generated by water savings in other communities that require advanced water treatment for the discharge of urine and the need to evaluate other methods for N.

The environmental profile of different types of treatments for supernatants resulting from the anaerobic digestion of the sludge generated in sewage treatment plants (STP) was carried out by RODRIGUEZ-GARCIA et al. (2014), who demonstrated that (i) the technologies for removing N, (ii) the complete autotrophic removal of nitrogen on nitrite (CARNON) and (iii) the complete autotrophic removal of nitrogen on nitrite (NSC), have less impact on the environment compared to struvite crystallization (SCP). This is due to the high consumption of electricity by the SCP for each kg of P removed. When including the individual technologies in a STS plant, it was highlighted that the differences between the individual treatments are not relevant when integrated into a STS. The environmental impacts associated with a STS were few in all evaluated categories, except for eutrophication, where there was a considerable reduction by applying the NSC process, and the SCP process and especially when CARNON and SCP were combined (RODRIGUEZ-GARCIA et al. 2014).

A study on the environmental impacts, fresh water savings and potential amounts for nutrient recovery through the struvite precipitation from urine separation in buildings was carried out by MBAYA, DAI and CHEN (2016). The results obtained through the Life Cycle Assessment (LCA) showed that the net production of struvite in a dense and typical city can cover the consumption of diamonium phosphate fertilizers (DAP) in many countries and obtained favorable net savings of freshwater. KJERSTADIUS et al. (2017) also took the separation into account by applying LCA to
investigate the carbon footprint and the potential for nutrient recovery in a conventional sanitation system and a possible source separation system with increased nutrient recovery in Sweden. They concluded for the carbon footprint and the nutrient recovery (phosphorus and nitrogen) that the source separation system could increase the nutrient recovery, mainly through the struvite precipitation and the ammonium removal at the wastewater station, and reduce the carbon footprint. In view of the studies presented, the environmental aspects are favorable in the recovery of nutrients through the chemical precipitation of struvite.

4 CONCLUSION

A systematic review of the literature is presented on the application of the Life Cycle Assessment (LCA) in systems designed to recover nutrients from the sanitation through the chemical precipitation of struvite, in order to verify the sustainability of the process. Few studies have been found applying LCA to these systems. The results shown in the selected articles demonstrated that the environmental aspects are favorable to the recovery of nutrients. However, there was a variability in the parameters adopted in the literature, such as the definitions of the functional unit, the system limits, in the choice of the impact assessment methodology and in the procedure used for the impact interpretation defined by the ISO 14040 (2006) and 14044 (2006). In view of this, the need to formulate standardized guidelines to guarantee the quality of the application of the LCA methodology in studies of the systems aimed at the recovery of nutrients in the sewage treatment stations is evident.

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