UNIDADE DE SANEAMENTO INTEGRADO PARA TRATAMENTO DE ÁGUAS RESIDUAIS URBANAS COM WETLANDS CONSTRUÍDOS: UMA ANÁLISE BIBLIOMÉTRICA

Gustavo Stolzenberg Colares - gustavoscolares@gmail.com
Universidade de Santa Cruz do Sul - UNISC, Programa de pós-graduação em Tecnologia Ambiental – PPGTA
Av. Independência, 2293 - Universitário, 96815-900, Santa Cruz do Sul – RS.

Carine Baggiotto – cbaggiotto@unisc.br
Universidade de Santa Cruz do Sul - UNISC, Programa de pós-graduação em Tecnologia Ambiental - PPGTA
Av. Independência, 2293 - Universitário, 96815-900, Santa Cruz do Sul – RS.

Salatiel Wohlmuth da Silva - salatiel.silva@ufrgs.br
Universidade Federal do Rio Grande do Sul – UFRG, Departamento de Obras Hidráulicas
Av. Bento Gonçalves, 9500, 91501-970 - Porto Alegre - RS

Adriane de Assis Lawisch Rodriguez - adriane@unisc.br
Universidade de Santa Cruz do Sul - UNISC, Programa de pós-graduação em Tecnologia Ambiental - PPGTA
Av. Independência, 2293 - Universitário, 96815-900, Santa Cruz do Sul – RS.

Ênio Leandro Machado - enio@unisc.br
Universidade de Santa Cruz do Sul - UNISC, Programa de pós-graduação em Tecnologia Ambiental - PPGTA
Av. Independência, 2293 - Universitário, 96815-900, Santa Cruz do Sul – RS.

Resumo:
Neste trabalho, unidades de saneamento foram investigadas dentro de um sistema combinado de tratamento de águas residuais, consistindo de reatores anaeróbicos (ARs), wetlands construídos híbridos (CWs) e uma unidade de ozonização (O3), tratando águas residuais de um campus universitário no sul do Brasil. Uma análise bibliométrica detalhada foi conduzida usando o software VOSviewer para explorar tendências de pesquisa emergentes e os termos mais conectados relacionados ao tratamento de águas residuais e sustentabilidade ambiental. A análise bibliométrica envolveu a busca no banco de dados Web of Science usando palavras-chave como "tratamento de águas residuais", "wetlands construídos" e "sustentabilidade". Os dados foram processados no VOSviewer, que gerou mapas ilustrando a frequência e a coocorrência de termos na literatura. Esta análise destacou termos-chave como "energia", "custo", "impactos ambientais" e "sustentabilidade", indicando seu papel central no cenário de pesquisa. A análise também identificou grupos de tópicos relacionados, com "energia" sendo um dos mais proeminentes, refletindo sua importância nos aspectos ambientais e econômicos dos sistemas de tratamento de águas residuais. Os insights obtidos a partir da análise bibliométrica ressaltam a importância das considerações energéticas na pesquisa sobre tratamento de águas residuais e destacam áreas nas quais estudos futuros podem se concentrar, particularmente na otimização do uso de energia e na exploração de tecnologias sustentáveis para o gerenciamento de águas residuais.

Palavras-chave: *Tecnologias limpas; Wetlands construídos; Ozonização; Saneamento rural; Sustentabilidade.*

INTEGRATED SANITATION UNIT FOR URBAN WASTEWATER TREATMENT WITH CONSTRUCTED WETLANDS: A BIBLIOMETRIC ANALYSIS

Abstract:
In this work, sanitation unit were investigated within a combined wastewater treatment system, consisting of anaerobic reactors (ARs), hybrid constructed wetlands (CWs), and an ozonation (O_3) unit, treating wastewater from a university campus in southern Brazil. A detailed bibliometric analysis was conducted using VOSviewer software to explore emerging research trends and the most connected terms related to wastewater treatment and environmental sustainability. The bibliometric analysis involved searching the Web of Science database using keywords such as "wastewater treatment," "constructed wetlands," and "sustainability." The data was processed in VOSviewer, which generated maps illustrating the frequency and co-occurrence of terms in the literature. This analysis highlighted key terms like "energy," "cost," "environmental impacts," and "sustainability," indicating their central role in the research landscape. The analysis also identified clusters of related topics, with "energy" being one of the most prominent, reflecting its significance in both the environmental and economic aspects of wastewater treatment systems. The insights gained from the bibliometric analysis underscore the importance of energy considerations in wastewater treatment research and highlight areas where future studies could focus, particularly in optimizing energy use and exploring sustainable technologies for wastewater management.

Keywords: *Clean technologies; Constructed Wetlands; Ozonation; Rural Sanitation; Sustainability.*

1. INTRODUCTION

Regarding the current water scarcity crisis, several technologies aiming for local treatment and wastewater reuse are becoming attractive, mostly when the main objective is the non-potable reuse of water (Jabri et al. 2019). In this context, studies are focusing on minimizing resources waste, energy consumption and potable water demand, as well as reducing waste generation and possibly providing nutrient recovery and even energy generation from wastewater (Dell'Osbel et al. 2020). Centralized and decentralized wastewater treatment plants have large differences concerning the process scheme, but one of the main aspects regarding the latter is the greatest potential of recovering resources, such as reusing reclaiming water (Arias et al. 2020; Albornoz et al., 2019; Albornoz et al., 2020).

Constructed wetlands (CWs) have proven to be an interesting alternative for decentralized wastewater treatment plants, due to their simple construction, maintenance, and their high treatment efficiency (Flores et al., 2020). In addition, CWs systems are emerging as an interesting option when basic sanitation in developing countries is lacking, mainly when applied after a primary treatment, such as septic tanks, which are very common for more isolated residences, avoiding the collection and transport of wastewater to a central treatment plant (De Souza Celente et al. 2020). Besides treating wastewater, CWs have a high potential to deliver a wide range of ecosystem services, such as providing water for reuse, nutrients cycling, and enhance biodiversity (Wang et al. 2017; Calheiros et al. 2021).

In rural areas, integrating CWs systems with anaerobic reactors (ARs) is a tendency, allowing the recovery of materials, energy and nutrients, less environmental pressure (Lutterbeck et al. 2017), simplified maintenance and operation, and good integration with the natural environment (Pelissari et al. 2017).

Although there are many environmental and economic benefits obtained with the use of CWs, for wastewater containing high loads of pollutants, especially organic matter, ammonium ion and soluble phosphorus (P), a large surface area is required, in order to promote the integration of these systems with other pre-treatment operations and final polishing processes, necessary to meet

legal and regulatory requirements. In these cases, the integration between constructed wetlands and microalgae can exemplify gain for higher load factors in the wastewaters to be treated in terms of total nitrogen and total phosphorus (ZHAO, et al., 2023).

When the topic of integration involves detoxification and disinfection of effluents, integrating CWs with advanced oxidation processes can be an option (Horn et al. 2014). Nevertheless, depending on legal requirements, the reuse of treated wastewaters may obey strict safety standards. So, the use of a post-treatment technology after the CWs system such as chlorination, ozonation or ultraviolet (UV) radiation, may be required to achieve disinfection guarantee. Besides disinfection, the integration of an ozonation unit after a CWs system can also promote color removal of the water, which is a fundamental aspect when aiming for water reuse (Colares et al. 2019). Several researchers investigated different CWs configurations, ranging from very simple systems to more complex and sophisticated ones, such as forced aeration CWs (Wu et al. 2014), CWs and algae for post treatment (De Souza Celente et al. 2019), CWs and ozonation (Tripathi and Tripathi 2011; Horn et al. 2014), and CWs with UV disinfection (Álvarez et al. 2017).

The objective of this study is to use the bibliometric tools to evaluate an integrated system for wastewater treatment and non-potable reuse, aiming to diagnose the environmental sustainability and economic viability of the treatment processes.

2. MATERIAL AND METHODS

The bibliometric analysis was performed aiming to identify emerging research aspects and the most linked terms to wastewater treatment and environmental sustainability, by using the Web of Science database. This platform was chosen due to the database with a large coverage, quality and availability of the research material related to the study subject. The search terms used for the database information were: "wastewater" and "life cycle assessment", and. for the second bibliometric map, "constructed wetlands" and "life cycle assessment", both on March 2023.

The bibliometric mapping was performed with the information, accessed from the database, by using the VOSviewer software (version 1.6.19). Records from all periods were considered (for 30 years), and the methodology adopted was similar to the ones recommended by De Souza et al. (2018) and Dell'Osbel et al. (2020). The VOSviewer software then generates maps, considering the number of times a term is cited in the database and the connections between each of the terms. In addition, the software groups the items in clusters according to connections with other terms.

In the network view category, some labels may not be displayed to avoid overlapping with other extracted terms, and the size of each circle is determined by the occurrence of the item. The color of each term determines to which cluster an item is added. Lines simulate connections between items, and the distance between two items indicates affinity, i.e., items closer to each other are more connected than items farther apart. (Eck and Waltman, 2019).

The main steps of the VOSviewer application were to insert the downloaded database into the software, create a co-occurrence term based on the textual data, considering the words in the title and abstract fields. The software extracted terms using the "full count" method (when a term can be read multiple times in the same article), and the minimum number of occurrences of a term was set to 3.

Lastly, a selection of the terms was performed to identify the most relevant terms to the research topic and exclude terms such as measurement units, repeated and irrelevant items. The software then generated maps considering the number of times each term is cited, the connections between each of the terms, and also groups the items in clusters according to their links. As a normalization method "association strength" was chosen, which is the standard recommendation of the program.

3. RESULTS AND DISCUSSIONS

By using "life cycle assessment" and "wastewater" as keywords on the Web of Science platform, 719 articles were found. Their data was downloaded and analysed by the VOSviewer software, resulting in a bibliometric map (Figure 1). The terms were grouped according to their links, generating 5 clusters. The blue cluster was mostly related to water treatment technologies, sustainability and wastewater pollutants, while the red cluster is associated to the environmental impacts and LCA aspects, and the green was mainly related to biofuels and energy generation. The yellow cluster, on the other hand, is related to energy and energy efficiency and environmental impacts assessment. Finally, the purple cluster represents anaerobic digestion, waste, food waste and sewage. The items "energy" and "cost" also were highlighted in the bibliometric analysis.

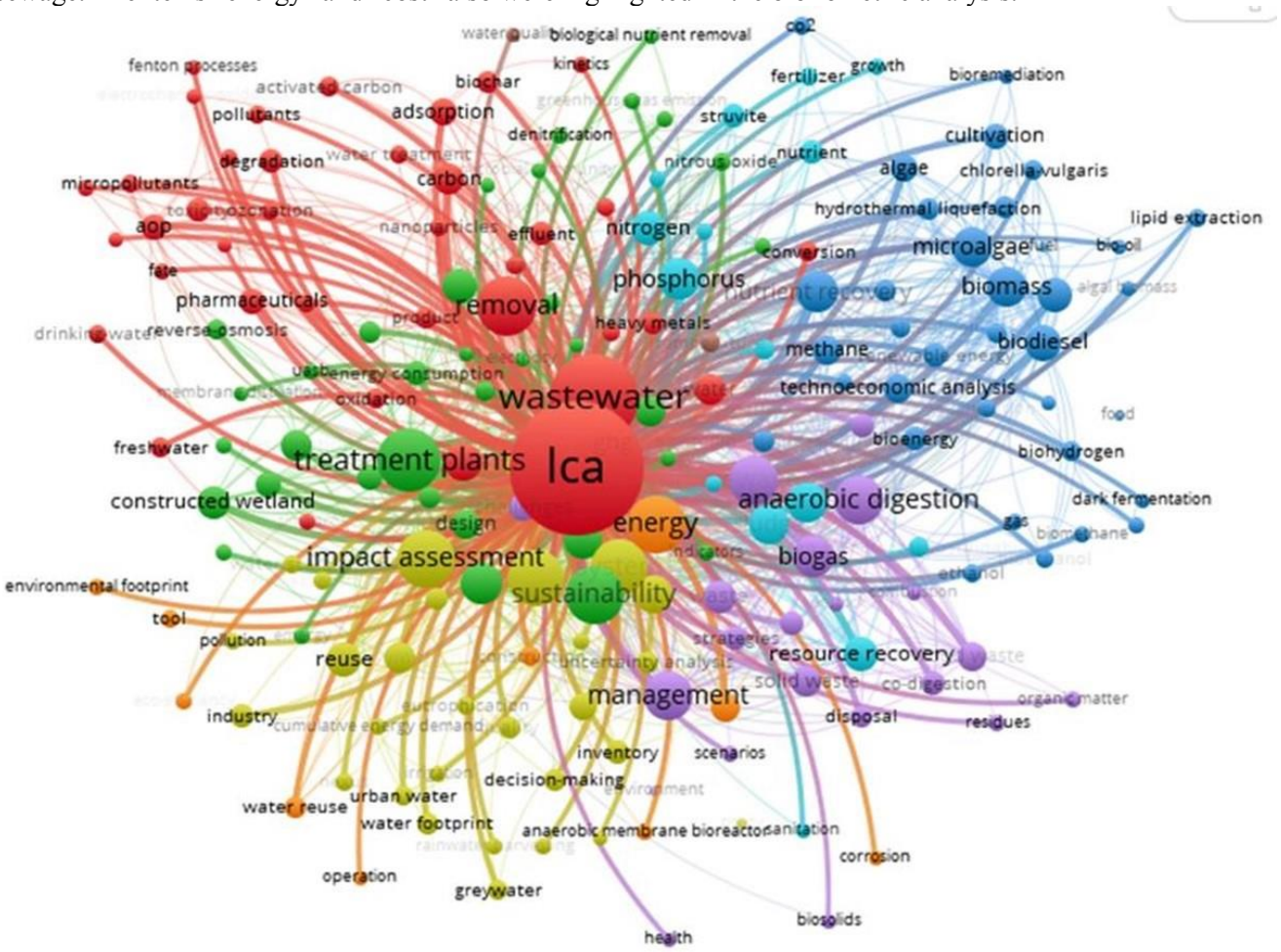


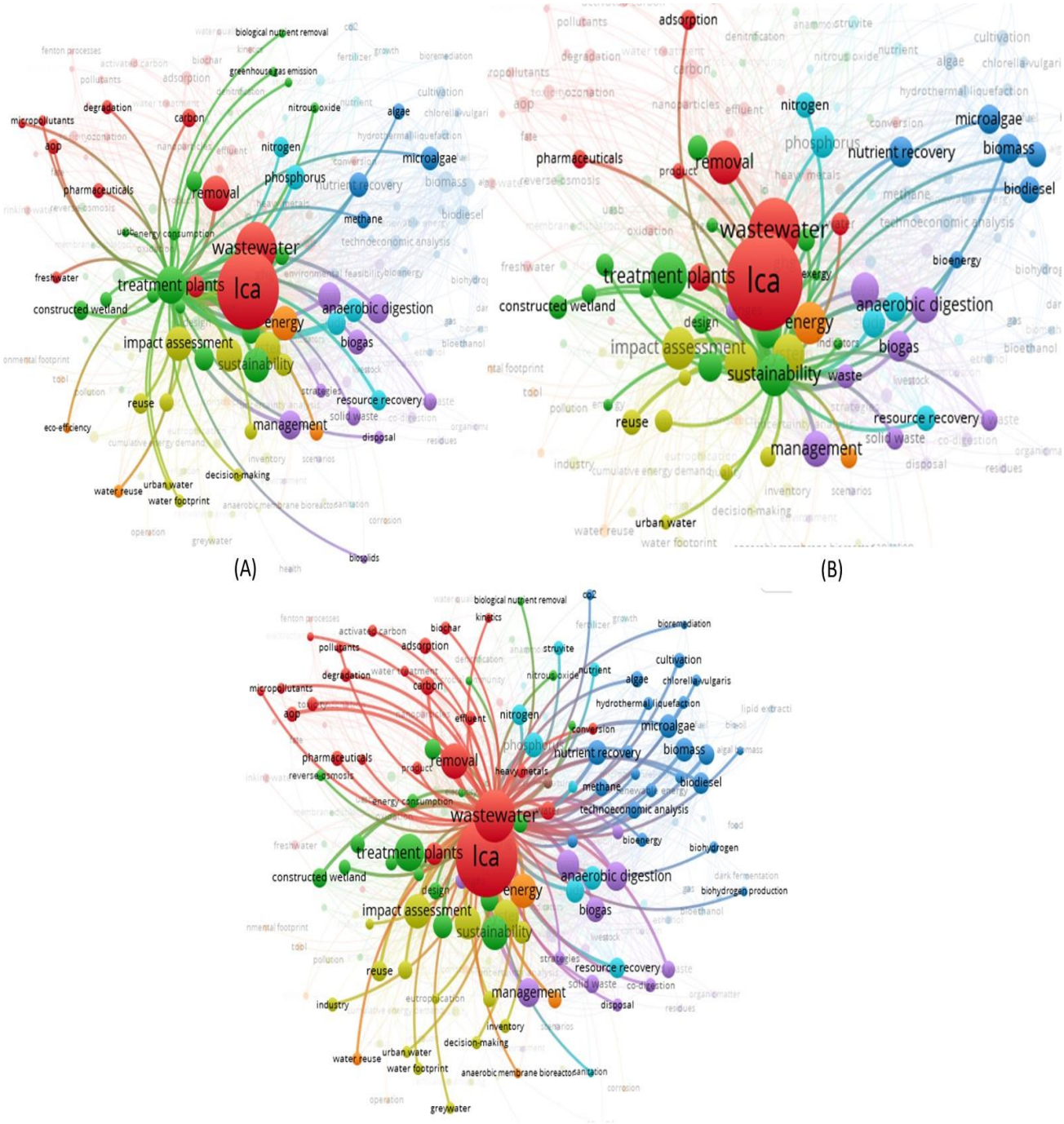
Fig. 1 Bibliometric mapping produced in VOSviewer software using "life cycle assessment" and "wastewater" as searching terms in the Web of Science database

From the bibliometric map, it was possible to verify that some of the most cited terms were LCA, environmental impact, cost, energy, sludge, reuse, climate change, biomass, product, industry, sustainability and treatment plants. It is interesting to highlight how the terms “microalgae” and “biomass” were located close to “nutrient recovery” and “biogas”, indicating the potential relations between these items.

“Wetland” was a term that presented significant citations, and was located close to important items such as: “treatment plants”, “freshwater”, “membrane bioreactor”, “LCC” (life cycle cost), “industrial wastewater”, “energy consumption” and “UASB”. Later, similarly to Figure 1,

another bibliometric analysis was conducted by using as searching terms “constructed wetlands” and “life cycle assessment” in the Web of Science platform (Figure 2).

Figure 2 Bibliometric mapping produced in VOSviewer software using "life cycle assessment" and "constructed wetlands" as searching terms in the Web of Science database. (A) Featured for “Treatment plants”, (B) Featured for “LCA” e (C) Featured for “Wastewater”.



As shown in Figure 2, it is interesting to highlight that the software grouped the terms in 5 clusters representing different aspects of CWs applications. The blue one, consisted of terms regarding management, with terms such as recovery, technologies, and environmental impact. The red one is more related to systems, with terms such as energy, reuse, activated sludge, membrane bioreactor and wastewater treatment. The green cluster is more related to the LCA, containing terms such as removal, treatment systems and denitrification. The purple one is associated with efficiency and phosphorus. And the yellow cluster is related with constructed wetland, nitrogen removal and anaerobic digestion.

Based on the bibliometric analysis, some topics that should be more studied in the future are: the integration of treatment technologies with biofuel production, processes with lower energy demand or energy generation, and, mostly, systems with low environmental impacts. For Flores et al. (2019), more studies should be developed involving decentralized treatment units, such as constructed wetlands, with their economic assessments. According to the authors, this would allow to test the economic feasibility of these systems and thus promote the dissemination of these technologies.

De Souza et al. (2019), after conducting a bibliometric analysis and literature review on microalgae for wastewater treatment, indicated that clean technologies should be investigated in order to reduce environmental impacts and costs, especially those associated with the energy balance. The authors also suggest adopting a treatment that can result in biomass generation, which can be converted into several bioproducts, such as animal ration, biochar, pigments, and biofuels. In this context, the bibliometric analysis showed a lack of studies for LCA applied to integrated systems with CWs, since “LCA” term is not presented in Figure 2, but only associated with “environmental impacts”.

4. CONCLUSIONS

The bibliometric analysis was in accordance with the obtained results, since the terms "energy", "cost" and sludge" were highlighted in the maps. However, given the limitations associated with available data from the pilot scale system, further investigations should focus in up-scaling this treatment system to a real scale application, as well as conducting assessments regarding also social and landscape aspects of the wastewater treatment and reuse with the proposed system.

Acknowledgments

Ao National Council for Scientific and Technological Development/CNPq of Brazil - 311531/2021-0, FAPERGS PqG – 2021; FAPERGS/CNPq 07/2022 - Programa de Apoio à Fixação de Jovens Doutores no Brasil; Edital Fapergs 02/2022 - Clusters Tecnológicos – CLUSTER MEMPOA and CAPES. À CAPES (Número do pós-doc estratégico: 88881.691616/202201) pelo pagamento da inscrição no evento.

REFERÊNCIAS

Albornoz, L.L., Centurião, T.C., Giacobbo, A. Zoppas-Ferreira J., Bernardes, A.M. (2020). Influence of rain events on the efficiency of a compact wastewater treatment plant: a case study on a university campus aiming water reuse for agriculture. Environ Sci Pollut Res 27, 41350–41360

Albornoz, L.L., Marder, L., Benvenuti, T., Bernardes, A. M. (2019). Electrodialysis applied to the treatment of an university sewage for water recovery, Journal of Environmental Chemical Engineering, Volume 7, Issue 2.

Álvarez, J. A., Ávila, C., Otter, P., Kilian, R., Istenič, D., Rolletschek, M. & Jorgensen, C. (2017). Constructed wetlands and solar-driven disinfection technologies for sustainable wastewater treatment and reclamation in rural India: SWINGS project. Water Sci. Technol., 76(6), 1474-1489.

Arias, A., Rama, M., González-García, S., Feijoo, G., & Moreira, M. T. (2020). Environmental analysis of servicing centralised and decentralised wastewater treatment for population living in neighbourhoods. Journal of Water Process Engineering, 37, 101469.

Calheiros C. S. C., Almeida C. M. R., Mucha A. M. (2018). Chapter 8. Multiservices and Functions of Constructed Wetlands. In: Wetland Function, Services, Importance and Threats. Editor: Wojciech Halicki. Published by Nova Science Publishers, Inc. New York. Pages 269-298. ISBN: 978-1-53613-562-6. https://novapublishers.com/shop/wetland-function-services-importance-and-threats/

Colares, G. S., De Souza Celente, G., Da Silva, F. P., De Loreto, A. C., Lutterbeck, C. A., Kist, L. T., & Machado, Ê. L. (2019). Combined system for the treatment and reuse of urban wastewater: the efficiency of anaerobic reactors+ hybrid constructed wetlands+ ozonation. Water Sci. Technol. 80(2), 254-264.

Dell'Osbel, N., Colares, G. S., de Oliveira, G. A., de Souza, M. P., Barbosa, C. V., & Machado, Ê. L. (2020). Bibliometric Analysis of Phosphorous Removal Through Constructed Wetlands. Water Air Soil Poll. 231(3), 1-18.

De Souza Celente, G., Colares, G. S., da Silva Araújo, P., Machado, Ê. L., & Lobo, E. A. (2020). Acute ecotoxicity and genotoxicity assessment of two wastewater treatment units. Environ. Sci. Pollut. R. 1-8.

De Souza, M. P., Hoeltz, M., Benitez, L. B., Machado, Ê. L., & de Souza Schneider, R. D. C. (2019). Microalgae and Clean Technologies: A Review. CLEAN - Soil Air Water. 47(11), 1800380.

De Souza, M. P., Hoeltz, M., Gressler, P. D., Benitez, L. B., & Schneider, R. C. (2018). Potential of microalgal bioproducts: general perspectives and main challenges. Waste Biomass Valori. 1-18.

Eck, N. J. V.; Waltman, L. Manual for VOSviewer version 1.6.10. Uninversiteit Leiden, CWTS Meaningful metrics. 10 January 2019.

Flores, L., García, J., Pena, R., & Garfí, M. (2020). Carbon footprint of constructed wetlands for winery wastewater treatment, Ecological Engineering, Volume 156.

Flores, L., García, J., Pena, R., & Garfí, M. (2019). Constructed wetlands for winery wastewater treatment: A comparative Life Cycle Assessment. Sci. Total. Environ. 659, 1567-1576.

Horn, T. B., Zerwes, F. V., Kist, L. T., Machado, Ê. L. (2014). Constructed wetland and photocatalytic ozonation for university sewage treatment, Ecological Engineering, Volume 63, , Pages 134-141.

Jabri, K. M., Fiedler, T., Saidi, A., Nolde, E., Ogurek, M., Geissen, S. U., & Bousselmi, L. (2019). Steady-state modeling of the biodegradation performance of a multistage moving bed biofilm reactor (MBBR) used for on-site greywater treatment. Environ. Sci. Pollut. R, 26(19), 19047-19062.

Pelissari, C., Ávila, C., Trein, C. M., García, J., de Armas, R. D., & Sezerino, P. H. (2017). Nitrogen transforming bacteria within a full-scale partially saturated vertical subsurface flow constructed wetland treating urban wastewater. Sci. Total. Environ. 574, 390-399.

Tripathi, S. & Tripathi, B. D. Efficiency of combined process of ozone and bio-filtration in the treatment of secondary effluent. Bioresource Technol. 102 (13), 6850–6856.

Wang, M., Zhang, D. Q., Dong, J. W., & Tan, S. K. (2017). Constructed wetlands for wastewater treatment in cold climate—A review. J. Environ. Sci. 57, 293-311.

Wu, S., Kuschk, P., Brix, H., Vymazal, J., & Dong, R. (2014). Development of constructed wetlands in performance intensifications for wastewater treatment: a nitrogen and organic matter targeted review. Water Res., 57, 40-55.

Zhao, X., Meng, X., Dang, B., Zhang, T., Shi, W., Hou, N., Yan, Q., Li, C. (2023). Succession dynamics of microbial communities responding to the exogenous microalgae ZM-5 and analysis of the environmental sustainability of a constructed wetland system, Bioresource Technology, Volume 371.