Economia circular e simbiose industrial: um indicador para tomada de decisões

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Circular economy and industrial symbiosis: an indicator for decision making

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Resumo

A economia linear,cuja cadeia produtiva baseia-se em extrair, produzir, usar e descartar está atingindo seu limite devido aos impactos ambientais e insuficiência de recursos. O modelo de produção circular surge com ideiasadversas ao modelo linear, com princípios baseados em eliminar poluição e desperdício, aumentar a vida útil dos materiais e recuperar os sistemas naturais.A simbiose industrial é uma prática totalmente alinhada para colocar em prática os princípios da economia circular, que propõe a criação de sinergias e cooperação entre as indústrias, onde as mesmas podem compartilhar recursos e reaproveitar os resíduos da produção. Para identificar lacunas e oportunidades de pesquisa foi realizada uma análise bibliométrica e identificou-se que existem poucos estudos abordando barreiras à simbiose industrial e indicadores para identificar e auxiliar na superação das mesmas. Visando identificar a relação entre economia circular e simbiose industrial, a pesquisa buscou identificar o grau de maturidade da simbiose industrial em uma empresa, com auxílio do indicador grau de maturidade da simbiose industrial, que contrapõe as sete barreiras da simbiose industrial contra os cinco estágios de maturidade. Para mensurar o grau de maturidade da simbiose industrial foi proposta uma Equação, que possibilitouidentificar o grau de maturidade da empresa, o qual equivale a 28,5% da simbiose perfeita, que serviu para indicar que mudanças e melhorias precisam ser implementadas, além disso o indicador mostrou-se uma grande aliado ao processo de tomada de decisão.

PALAVRAS CHAVE: Economia Circular, simbiose industrial, barreiras, indicador, maturidade

Resumen

La economía lineal, cuya cadena productiva se basa em extraer, producir, usar y desechar, está llegando a su limite por los impactos ambientales y la insuficiencia de recursos. El modelo de producción circular surge con ideas totalmente contrarias al modelo lineal, con princípios basados en la eliminación de la contaminación y los residuos, el aumento de la vida útil de los materiales y la recuperación de los sistemas naturales. La simbiosis industrial es uma práctica totalmente alineada para poner em práctica los principios de la economía circular, creando sinergias y cooperación entre industrias, donde pueden compartir recursos y reutilizar residuos de producción. Para identificar vacíos y oportunidades de investigación se realizó un análisis bibliométrico y se identificó que existen pocos estudios que aborden las barreras a la simbiosis industrial e indicadores para identificarlas y ayudar a superarlas. Para identificar la relación entre economía circular y simbiosis industrial, la investigación buscó identificar el grado de madurez de la simbiosis industrial em uma empresa, utilizando el indicador grado de madurez de la simbiosis industrial, que contrasta las siete barreras de la simbiosis industrial contra las cinco etapas de desarrollo madurez. Para medir el grado de madurez de la simbiosis industrial se planteó uma Ecuación, que permitió identificar el grado de madurez de la empresa, que equivale al 28,5% de la simbiosis perfecta, lo que sirvió para indicarlo al indicar que los cambios y es necessário implementar mejoras, además, el indicador demostró ser un gran aliado en la toma de decisiones.

PALABRAS CLAVE**:** Economía circular, simbiosis industrial, barreras, indicador, madurez

Abstract

The linear economy, whose production chain is based on extracting, producing, using and discarding, is reaching its limit due to environmental impacts and insufficient resources. The circular production model comes up with ideas that are totally contrary to the linear model, with principles based on eliminating pollution and waste, increasing the useful life of materials and recovering natural systems. Industrial symbiosis is a practice fully aligned to put into practice the principles of the circular economy, creating synergies and cooperation between industries, where they can share resources and reuse production waste. To identify gaps and research opportunities, a bibliometric analysis was carried out and it was identified that there are few studies addressing the barriers to industrial symbiosis and indicators to identify and help overcome them. Aiming to identify the relationship between circular economy and industrial symbiosis, the research sought to identify the degree of maturity of industrial symbiosis in a company, using the indicator degree of maturity of industrial symbiosis, which contrasts the seven barriers of industrial symbiosis against the five stages of development. maturity. To measure the degree of maturity of the industrial symbiosis, an Equation was proposed, which made it possible to identify the degree of maturity of the company, which is equivalent to 28.5% of the perfect symbiosis, which served to indicate that by indicating that changes and improvements need to be implemented, in addition, the indicator proved to be a great ally in the decision-making process.

KEYWORDS: Circular economy, industrial symbiosis, barriers, indicator, maturity

1. Introduction

Impacts on the environment the risk of depletion of environmental sources of resources arising from the current, linear production model, whose capacity is to extract, transform and alter the environment, as externalities to affect a more critical state are taken to the world at a time most critical from an environmental, economic and social point of view. This scenario is a recurring theme that has been the focus of international community concerns (Ellen Macarthur Foundation, 2012).

The European Commission has developed a document highlighting the need to improve production and recycling processes, through more sustainable production that moves towards a strategic transition towards a circular economy, which contributes to the achievement of the United Nations' sustainable development goals, contained in the 2030 agenda for sustainable development (DELGADO-AGUILAR *et al.*, 2020), whose focus is to eradicate poverty on the planet and unite economic, social and environmental development on a global scale (SHULLA *et al.*, 2019).

One of the circular economy proposals is about a more sustainable use of materials, through cycles, in which waste is reused as raw material (DELGADO-AGUILAR *et al.*, 2020). This circuit pattern is based on the concept of industrial symbiosis, which is a subfield of industrial ecology that deals with cooperation between industrial companies in managing resources, so that the waste of one company becomes the inputs for another (MULROW *et al.*, 2017).

Industrial symbiosis is based on an industrial systems integration approach (GENG *et al.*, 2014) with cooperative relationships between economically independent industries, usually with geographic proximity (CHERTOW, 2000) and involves the adoption of a collective approach between companies, where surplus materials, energy, water or by-products are shared and incorporated into processes.

The concept of industrial symbiosis is an analogy with the nature's symbiosis, imitating the natural ecosystem, with maximum use of available resources (HERZER; ROBINSON; FABIANO DE LIMA, 2017) and proposes cooperation between industrial companies in resource management, in so that one company's waste becomes another's input (MULROW *et al.*, 2017) following a systematic thinking for companies to integrate key elements in sustainability approaches (LEIGH; LI, 2015).

The principles of the circular economy aligns with industrial symbiosis, contributing to the regeneration of renewable resources and minimizing the extraction of finite resources (principle 1), taking advantage of the value of resources and optimizing processes (principle 3) and reducing negative externalities (principle 3). In this sense, it is recognized as an effective approach to support the transition from a linear economy to a circular model through the entry of materials into closed loops (ABREU; CEGLIA, 2018).

Regarding its implementation, industrial symbiosis is associated with development at the regional level, with cooperation and technical solutions for the reuse of waste and by-products, sharing of water, energy and materials between neighboring industries, which are usually configured in the form of arrangements in eco-industrial parks, such as Kalundborg, Denmark (GULIPAC, 2016), Gladstone, Queensland, Australia (GOLEV; CORDER; GIURCO, 2015), Suzhou, China (WEN; MENG, 2015).

According to published studies, it was noted that the potential for capturing synergies is often limited by a series of barriers such as environmental regulation, lack of cooperation and trust between industries in the area, economic barriers and lack of information sharing (GOLEV; CORDER; GIURCO, 2015)

In order to help overcome the barriers, a new tool was presented: the industrial symbiosis maturity grid, which aims to monitor and assess the level of regional industrial collaboration, in addition to indicating a path for improvement and development (GOLEV; CORDER; GIURCO, 2015). The tool was developed and applied in the industrial region of Gladstone in Queensland, Australia, and the results showed that Gladstone is in the third (active) stage, facing five stages of maturity, with cooperation between industries being the strongest characteristic and information barrier that needs to be improved.

In order to improve the assessment of the degree of maturity, this study suggests a quantitative assessment of the degree of maturity of the industrial symbiosis, which until then was only evaluated qualitatively, through an equation, facilitating the identification of the company's maturity stage, in addition to being a new instrument to assist in the decision-making process. The present work proposes to carry out an analysis of the degree of maturity of the industrial symbiosis in a flat glass production industry, through the indicator degree of maturity of the industrial symbiosis.

2. Materials and methods

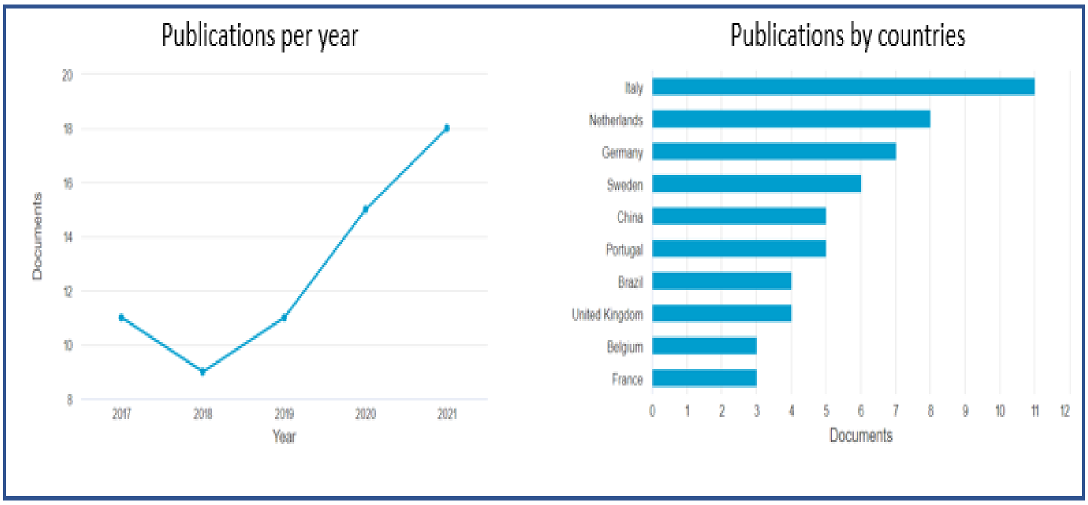
2.1 Bibliometric Analysis

To identify research opportunities, searches were carried out in the Scopus database, from 2017 to 2021. The first search was carried out only with the term industrial symbiosis, and 731 publications related to the topic were identified. The second search combined the terms industrial symbiosis and barriers and found 64 publications, representing 8.7% of industrial symbiosis publications.

In order to identify the gaps regarding he topic and possible research opportunities, an analysis of publications involving industrial symbiosis and barriers was carried out, identifying the evolution of publications per year, as well as the ten countries that publish the most on the themes and the main terms that relate to industrial symbiosis and barriers.

The analysis results can be seen in Figure 1.

Figure 1.Publications per year and Publications by countries



Analyzing the publications per year, from 2017 to 2021, it was noted that 2018 was the year with the lowest number of publications, with less than 10 publications, and 2021 the year with the highest number of publications. The analysis of publications by countries indicates that 80% of publications are concentrated in Europe and Brazil occupies the 7th position, with only 4 publications involving industrial symbiosis and barriers, which is an indication that there are gaps and possible research opportunities.

The articles published in Brasil, the authors and a brief comments on each, can be seen in Table 1.

Table 1. Brazilian articles about industrial symbiosis and barriers

Title	Authors	Coments
Nano and micro level circular economyindicators: Assistingdecision-makers in circularity assessments	1. Carla T. de Oliveira 2. Thales E. T. Dantas 3. Sebastião R. Soares	The study aimed to assist in the decision-making process, helping to choose the most appropriate indicator for circularity assessments, presenting a systematic review of the literature. As a proposal for future work, it wassuggestedtoanalyzetheintegrationoftheindicatorspresentedwithconsolidatedmethodologiestoovercomebarriersrelatedtocircularityandsustainability performance.
Barriers, drivers, and relationships in industrial symbiosis of a network of Brazilian manufacturing companies	1. Miguel A. Sellitto 2. Fábio K. Murakami 3. Maria A. Butturi 4. Simona Marinelli 5. Nelson Kadel 6. Bianca Rimini	The study aimed to identify barriers, opportunities and the structure of relationships that support industrial symbiosis initiatives in a network of Brazilian manufacturing companies. Different types of internal and external barriers were identified and improvement proposals were made to overcome the barriers.

Renewable energy in eco-industrial parks and urban-industrial symbiosis: A literature review and a conceptual synthesis	1. Maria A. Butturi 2. Francesco Lolli 3. Miguel A. Sellitto 4. Elia Bulugani 5. Rita Gamberini 6. Bianca Rimini	The study provided an overview of the scientific literature on energy synergies in eco-industrial parks, which facilitate the uptake of renewable energy sources at an industrial level, creating urban-industrial energy symbiosis. It also highlighted the barriers that make this process difficult.
Critical elements for eco-retrofitting a conventional industrial park: Social barriers to be overcome	1. Domenico Ceglia 2. Mônica C. S. de Abreu 3. José Carlos L. S. Filho	The study investigates the social barriers to be overcome in the promotion of opportunities for waste exchange and it was identified that social barriers are prerequisites for the engagement of companies in the establishment of technological and logistical solutions.

The analysis of the articles showed that there are few approaches involving industrial symbiosis and barriers and there is a lack of studies with indicators focused on industrial symbiosis. From this analysis, an opportunity was identified to carry out a study applying the indicator of the degree of maturity of the industrial symbiosis to a company producing flat glass in Brazil and, from it, create an equation capable of quantifying the degree of maturity of the industrial symbiosis.

2.2 Measuring the Industrial Symbiosis Maturity Degree

Through a systematic literature review, it was identified that the most pertinent and relevant barriers to industrial symbiosis can be summarized in a group with seven (GOLEV; CORDER; GIURCO, 2015) (Table 2).

Table 2. Industrial Symbiosis Barriers

Type of Barrier	Description
Commitment to Sustainable Development	Motivate for the creation of an organizational strategy, with the development of projects that contribute to regional sustainable development.
Information	Lack of data on industrial waste, materials, water and energy flows for the development of regional resource synergies.
Cooperation	Cooperation and trust between participants are crucially important factors for new synergy projects.
Technical	Lack of technical knowledge can be a barrier to a new project, which can be compensated by involving a business consultancy or research organization.
Regulatory	Difficulties in obtaining approvals for waste reuse projects are an obstacle to synergies, as well as legal requirements and higher taxes to eliminate waste are motivators for industrial symbiosis projects.

Community	Making the community aware of environmental and economic impacts can be a motivator to initiate project development. Well-established communication systems between industries and communities along with environmental education programs help ensure that new synergies emerge.
Economic	Investing in new projects can be a factor that discourages several companies, so it is expected that synergistic connections bring a positive economic result with environmental benefits, resulting in increased revenue, lower input and operating costs

One of the recommended ways to identify and overcome barriers within the industrial environment is through indicators, as they are capable of detecting trends and variations, in addition to serving as a basis for evaluating the impact of actions and assisting in the decision-making process (FELICIO *et al.*, 2016).

To determine the degree of maturity of industrial symbiosis, a questionnaire was designed, with questions related to each of the barriers of industrial symbiosis, which was sent to the person in charge of the company's environmental sector and discussed among team members to reach a consensus of the answers.

After applying the questionnaire, the answers were collected and analyzed in detail and, subsequently, the maturity matrix was created, based on the matrix of Golev, Corder and Giurco (2015), with some adaptations, identifying the degree of maturity of industrial symbiosis in where the company is, according to the definition of each stage.

a) Assembly of the Matrix

The maturity grid of this work was developed from the literature review carried out for the development of the research. The matrix was created listing each of the seven barriers against the five stages of maturity, based on the responses obtained in the questionnaire sent to the company. Each barrier was analyzed separately and allocated to the corresponding stage.

b) Elaboration of the Maturity Degree Equation

In order to quantify the degree of maturity of industrial symbiosis, the industrial symbiosis maturity degree equation was created, which is a new instrument aimed at measuring the degree of maturity of industrial symbiosis, whose logical-mathematical basis is the multiplication between the matrix stages and barriers to industrial symbiosis.

The score value of each barrier was multiplied by the total number of barriers present in each stage. The sum of the multiplications represents the value of the maturity degree referring to the company. Equation 1 represents the calculation of the degree of maturity (ISMG).

$$ISMG = \sum_{i=1}^{5} ai\ X\ ni\ , 0 \leq ai \leq 5\ ;\ 0 \leq ni \leq 7 \quad (1)$$

ISMG: Industrial Symbiosis Maturity Grid

ai: stage punctuation

ni: numbers of barriers in the stage

The values of ai are comprised in a range from 0 to 5, which correspond to the variation in the scores of the stages within the maturity grid.

3.4. Stages Analysis

Stage 1: in the equation it will be represented by ai = 0 and represents the situation in which there aren't industrial symbiosis practices. It corresponds to 0% of industrial symbiosis.

Stage 2: in the equation it will be represented by ai = 1,25 and represents the situation in which initial efforts are identified.

Stage 3: in the equation it will be represented by ai = 2,5 and represents the situation in which there are greater efforts and consolidated projects regarding industrial symbiosis.

Stage 4: in the equation it will be represented by ai = 3,75 and represents the situation in which industrial symbiosis is at an evolved degree, with standardized actions.

Stage 5: in the equation it will be represented by ai = 5 and represents the perfect symbiosis.

Table 3 identifies the percentage range corresponding to each stage of the maturity matrix.

Table 3.Percentage in termsof industrial symbiosis

Stage number	**Percentage in terms of industrial symbiosis**
1	ai = 0%
2	0% < ai < 50%
3	50% ≤ ai < 75 %
4	75% ≤ ai < 100%

5	ai = 100%

Through Table 3 it is possible to identify how much of the industrial symbiosis is reached at each stage, where 0% represents the absence and 100% the apex.

The values of ni correspond to the total number of barriers inserted in the same stage, ranging from 0 to 7, where the latter represents the total number of barriers to industrial symbiosis, as identified in Table 2.In addition to being a new indicator related to industrial symbiosis, the equation for the industrial symbiosis maturity degree of will be an instrument to assist the decision-making process.

3. Results and discussion

For a better analysis of the industrial symbiosis level of the company, three cases were considered:

• Case 1: all barriers of industrial symbiosis are in stage 5 – best case

• Case 2: all barriers of industrial symbiosis are in stage 1 – worst case

• Case 3: real company case

To identify the degree of industrial symbiosis of the company, all the answers to the questionnaire referring to each of the barriers mentioned were analyzed and the stage at which each one of the barriers was found was identified. Each of the barriers was assessed in isolation according to the responses provided by the company.

To calculate the maturity grid of industrial symbiosis indicator, grades from 1 to 5 were assigned to the stages, where a score of 1 represents stage 1, identified as the worst situation, and a score of 5 represents stage 5, which is the best situation. Table 4 shows each barrier, the stage in which it is inserted, the rationale and the assigned score.

Table 4. Assessment of industrial symbiosis barriers

Barriers	Stage	Justification	Punctuation
Commitment to Sustainable Development	3	Sustainable development exists in the company and indicators are used to measure actions, but without standardization	2,5
Information	2	There are reports available, but lack information of waste	1,25

Cooperation	2	The cooperation between occurs when they are facing some problem together	1,25
Technical	2	Opportunities to reuse waste arise, but only well-designed projects can be implemented	1,25
Regulatory	2	Recycling is highlighted as important, but there is no specific regulation	1,25
Community	1	The community is not recognized as an equal part in the negotiation of the industrial process	0
Economic	3	It is understood that resources can be valuable and there is information about costs and waste, but there is no investment in new projects	2,5

The analysis of Table 4 shows that none of the barriers are in stages 4 and 5; four of the seven barriers are in stage 2, two are in stage 3 and 1 is in stage 1. In addition, it was identified that the barrier that is at the worst stage is the community, that is, there are not enough efforts to indicate a relationship between the company and the community that is favorable to symbiosis.

To quantify the maturity degree, the value of the score of each barrier was multiplied by the total barriers in each stage and the sum of the multiplications of barriers represents the value of the degree of maturity, calculated using Equation 1.

In order to have reference values that identify the best and worst situation, the maturity level was calculated for the best and worst cases and, subsequently, the maturity level of the company's real case was calculated. From the results consolidated in Table 4, it was possible to calculate the degree of maturity for the three cases described.

Case 1 – best case: all barriers of industrial symbiosis are at stage 5

Case 1 represents the best case, that is, the perfect situation, where all barriers are at stage 5. Since there are a total of seven barriers, and if they are all at stage 5, the score for each of them is worth 5. The Equation 2 represents the best case.

$$ISMG = 7 * 5 = 35 \qquad (2)$$

It was identified that for the best case the value of the industrial symbiosis maturity degree should be equal to 35 and this value should be used as the best reference.

Case 2 – worst case: no use of resources and all barriers of industrial symbiosis are in stage 1.

Case 2 represents the worst case, that is, the worst situation, where all barriers are in stage 1. Since there are a total of seven barriers, and if they are all in stage 1, the score for each one of them is worth 1. The Equation 3 represents the worst case.

$$ISMG = 7 * 0 = 0 \quad (3)$$

It was identified that for the worst case the value of the industrial symbiosis maturity degree is equal to 7 and this value should be used as the worst reference.

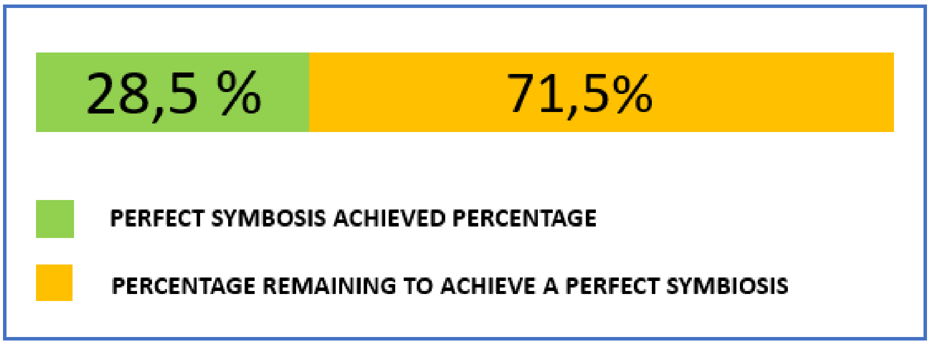
Case 3 – the company's actual situation

Case 3 represents the real situation of the company at the moment analyzed. The Equation 4 represents the best case.

$$ISMG = (1 * 0) + (4 * 1{,}25) + (2 * 2{,}5) + (0 * 4) + (0 * 5) = 10 \quad (4)$$

The percentage of the maturity degree of the company's industrial symbiosis and the percentage that is missing for the perfect symbiosis can be seen in Figure 2.

Figure 2. Industrial Symbiosis Maturity Degree Percentage



Analyzing Figure 2, it is clear that the company's maturity degree does not represent even half of the ideal value, indicating the need for improvements to move towards the perfect symbiosis.

According to the results, the need for improvements was identified, such as encouraging actions that bring the community and the company closer, standardizing activities, such as the regular publication of informative reports about the company and waste and what is done with them, in addition to the standardization of indicators aimed at waste.

Improvements can be implemented to increase the maturity level of the company's industrial symbiosis and achieve perfect symbiosis. In order to achieve these improvements, some actions that can be taken by the company were defined, as shown in Table 5.

Table5. Suggestions for barriers

Barriers	Strategic actions aimed at the degree of maturity of the symbiosis
Commitment to Sustainable Development	Standardize the types of indicators to be used and determine regularity in their use, create projects and actions to minimize present and future environmental impacts
Information	Make it a standard practice of the company to create and share periodic reports on actions to minimize environmental impacts and the benefits arising from such attitudes, such as creating reports on waste generated and what was done with each one of them
Cooperation	Search for more information about nearby companies that could become the company's partners, creating new synergies and joint efforts, with the objective of promoting improvements for the community, such as reducing costs and environmental impacts, through the sharing of materials and/or use waste.
Technical	Analyze with details the opportunities and actions to reuse waste and increase the company's commitment to the creation of new projects aimed at promoting this attitude
Regulatory	Implement ISO 14000, in order to ensure balance and environmental protection, through rules and guidelines to achieve the objective, in addition to having the reuse of waste as one of the main focuses
Community	Provide more information to the community through good communication channels, such as social networks, in addition to promoting a partnership between the company and the community, where the latter is active in the decision-making process for the present and future industrial development, being able to opine on the company's actions
Economic	Waste reuse projects have proven efficiency and new business opportunities are being investigated, seeing collaboration between industries as a competitive advantage

Table 5 presents some actions that can be chosen by the company in favor of improvements regarding each of the mentioned barriers. It is also suggested that actions seem to be glued together, trying to encompass all the barriers, or a good part of them, because in order to increase the degree of industrial symbiosis it is necessary that more barriers are minimized and fit into more advanced stages.

4. Conclusion

The analysis of the industrial symbiosis maturity degree indicator allowed to identify that four of the seven industrial symbiosis barriers are in stage 2, two are in stage 3, one is in stage 1 and there aren’t barriers in stages 4 and 5.

In order to quantify the industrial symbiosis maturity degree, an Equation (ISMG) was created, an original creation of this work, and the calculation of the indicator for the real scenario of the company resulted in a value equal to 10, which is equivalent to 28.5% of the perfect symbiosis, which is equivalent to 35. The result of the equation allowed us to verify that, in general, the company is inserted in stage 2, with initial efforts related to industrial symbiosis and less than 50% of perfect symbiosis.

The industrial symbiosis maturity degree equation is an instrument to help the decision-making process within the field of industrial ecology, and can expand its application to other companies or industrial parks, in addition to being a quantitative indicator that has proven to be effective in identifying how much symbiosis already exists in a given company and how much is lacking, serving as a guideline for the implementation of improvements.

As a proposal for future work, it is suggested to apply the equation and the industrial symbiosis maturity matrix in other scenarios and the union of them with other indicators directed to the circular economy and industrial ecology and it is suggested that the application of the indicator be carried out in a group of companies with geographic proximity or in an industrial park, in order to analyze how their relationship is in terms of industrial symbiosis.

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Recebido em: 21-08-2022
Aceito em: 13-02-2023

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