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IDENTIFYING BARRIERS AND PROPOSING A ROADMAP TO DEVELOP INDUSTRIAL SYMBIOSIS PROJECTS

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ABSTRACT

This article identifies barriers for the implementation of industrial symbiosis projects in companies located in the Industrial and Port Complex of Pecém (CIPP). The concept of industrial symbiosis (IS) has become a well-recognized approach for environmental improvements at the regional level. Many technical solutions for waste and by-product material, water, and energy reuse between neighboring industries (so-called synergies) have been discovered and applied in the IS examples from all over the world. However, the potential uptake of new synergies in the regions is often limited by a range of nontechnical barriers. This study adopted a qualitative approach and conducted semi-structured interviews with managers of companies in operation at CIPP. The results showed that low levels of trust, communication, and cooperation prevent companies from establishing waste exchange initiatives. The research also confirms the existence of social, technological, financial, regulatory, and institutional barriers for the implementation of industrial symbiosis projects. Companies in the CIPP are in the initial stage of maturity, which means they do not recognize possible benefits from industrial symbioses. The research proposes ways for greater engagement among companies, in the sense of guiding the development of industrial symbiosis projects. It is necessary to pay attention to the barriers identified in the CIPP, because they are not easily removed in the social and economic context of the vast majority of Brazilian industrial complexes.

Keywords: industrial symbioses, maturity grid, barriers, eco-industrial park.

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RESUMO

O artigo identifica barreiras para a implantação de projetos de simbiose industrial em empresas instaladas no Complexo Industrial e Portuário do Pecém (CIPP). O conceito de simbiose industrial possibilita melhorias ambientais em nível regional, por meio da reutilização de resíduos, água e energia entre empresas vizinhas. A pesquisa adota uma abordagem qualitativa, por meio de entrevistas semi-estruturadas com gestores industriais. Os resultados indicam a existência de barreiras, que incluem: fraca fiscalização ambiental, baixa cooperação e confiança entre as empresas, elevadas barreiras econômicas, e ausência de compartilhamento de informações. As empresas do CIPP se encontram no estágio inicial de maturidade para a implantação de projetos de simbiose industrial, onde baixos níveis de confiança, comunicação e cooperação impedem as empresas de estabelecerem iniciativas preliminares de troca de resíduos sólidos. A pesquisa propõe caminhos para um maior engajamento entre as empresas, no sentido de guiar o desenvolvimento de projetos de simbiose industrial. O estudo reforça a necessidade de prestar atenção nas barreiras identificadas no CIPP e nos desafios para superá-las, os quais estão presentes na grande maioria dos complexos industriais brasileiros.

Palavras-chave: *simbiose industrial, maturidade organizacional, barreiras, eco-parque industrial*

1 INTRODUCTION

Industrial symbiosis (IS) is part of the field of industrial ecology. It describes the interaction of different companies, within a specific industrial complex, exchanging resources for economic and environmental benefits (CHERTOW, 2000). IS focuses on improving resource productivity and production eco-efficiency by transforming the waste from one firm into inputs for another. According to Chertow (2007), IS networks arise in different conditions. They can be "emergent or self-organizing networks," which develop in a decentralized way, even though a coordinating institution may manage them.

Another design for IS networks is the presence of an "anchor company," operating as a supplier of resources and knowledge to promote IS among companies in the same regions (KERHONEN, 2001). Companies may search for other companies or individuals to develop IS networks (BAASS; BOONS, 2004; HEWES; LYONS, 2008; MIRATA, 2004; SHI et al., 2010; VAN BEERS et al., 2007). Finally, "coordinating institutions" recruit companies to allocate services or exchange of by-products through industrial eco-parks (CHERTOW and EHRENFELD, 2012; GIBBS and DEUTZ, 2007).

IS systems are often referred to in the literature as 'industrial eco-parks' (CÔTÉ; COHEN-ROSENTHAL, 1998), 'eco-industrial development' (COHEN-ROSENTHAL, 2003), 'regional resource synergies' (VAN BEERS et al., 2007) and 'circular economy' (GENG; DOBERSTEIN, 2008). Examples of IS projects can be found in Kalundborg, Denmark (JACOBSEN, 2006), Puerto Rico, USA (CHERTOW; LOMBARDI, 2005), Industrial and Port complex of Rotterdam, Holland (BAAS, BOONS 2007), United Kingdom (MIRATA, 2004), Kwinana and Gladstone, Australia (VAN BEERS et al., 2007) and Guigang, China (ZHU et al., 2007).

An industrial eco-park is a group of companies that supply goods and services in a specific geographical area, gathered to improve the economic performance of the participating companies, while minimizing environmental impacts and contributing to better environmental and resource management (LOWE, 2001). The implementation of industrial eco-parks requires the adoption of IS principles, such as cleaner production, prevention of pollution, and energy efficiency. In an industrial eco-park, the reduction of environmental impacts and the cost of waste management is seen as a common goal based on shared values and norms (CHERTOW; EHRENFELD, 2012).

The emphasis in the development of industrial parks has usually been on the identification and overcoming of institutional, regulatory, technological, and financial barriers (GENE; HAWE; ZHU, 2007; KIM, 2007). Recently, Golev et al. (2014) observed other socially oriented barriers such

as information, cooperation, community, and commitment to sustainable development. Also, the essential elements for companies to participate in IS projects are the project's environmental management model, and its technological solutions for waste treatment and final disposal.

In Brazil, there are few IS projects and industrial eco-parks. There are initiatives in the State of Pará, coordinated by the cosmetics company Natura; the industrial eco-parks of Santa Cruz and Paracambi, in the state of Rio de Janeiro; and the Candiota Project in the State of Rio Grande do Sul. It is possible to observe, therefore, a lack of knowledge about the application of the concepts of IS, industrial ecology, and industrial eco-parks (ELABRAS VEIGA; MAGRINI, 2009). There is a need to change the company's mindset in developing countries in order to incorporate technologies able to reuse waste (LI et al., 2015).

In this national context of few industrial eco-parks, the Government of the State of Ceará established, in the municipality of São Gonçalo do Amarante, a conventional industrial complex. The Industrial and Port Complex of Pecém (CIPP) intended to strengthen the industrial park of Ceará, enabling the promotion of integrated industrial and port activities. The responsible management of the solid waste produced by companies operating in the CIPP is one of the challenges both for the state's government and for the companies since there is no adequate infrastructure for the collection, treatment, and disposal of industrial waste.

Against this backdrop, the research is inspired by the following question: *Are the barriers and the CIPP companies' level of maturity able to develop industrial symbiosis projects?* The study examines how barriers – inside and outside companies – prevent the adoption IS projects. These barriers are deeply present in the context of developing countries under specific economic, institutional, and social conditions. This study refers to an industrial and port complex in a stage of consolidation, and it confirms the need for a research agenda to identify the mechanisms and events that connect companies towards a more sustainable IS.

This article is organized into six sections. The next section presents the barriers and paths for the development of IS projects. The third section introduces the methodology adopted to carry out the semi-structured interviews with the industrial directors and environmental managers of companies established in the CIPP. The fourth and fifth sections present the results and discussions based on the results observed, showing an incipient scenario to implement proactive proposals regarding the management of industrial solid waste. Finally, the study suggests paths to expand the companies' engagement and identify potential synergies.

2 BARRIERS AND PATHS FOR IMPLEMENTATION OF INDUSTRIAL SYMBIOSIS PROJECTS

2.1 Understanding the diversity of barriers in the development of industrial symbiosis projects

Industry symbiosis (IS) involves the flows and cycle of materials and energy, as well as the synergistic interactions between the companies, through which waste is converted into inputs (AYRES; AYRES, 2002). When using waste as inputs, companies enhance production efficiency and reduce costs on waste disposal and input acquisition (FRACCASCIA; YAZAN, 2018). The companies' perception about IS is associated with the material provision, resources' reutilization, and financial advantage, which are factors related to the integration among companies in industrial parks to develop IS and close their materials loop (ORMAZABAL et al., 2018).

The analysis of the types of waste and identifying opportunities for reusing the waste in other industrial processes is a challenging task (BRAND; BRUIJN, 1999). The existence of a viable technical solution does not guarantee the implementation of an IS project. These projects also

rely on environmental policies, trust, and communication between companies, which may be significant obstacles to identify and develop an industrial eco-park (CEGLIA, ABREU, SILVA FILHO, 2017). Chopra and Khanna (2014) emphasize that industrial symbiotic networks are based on the principles of ecological systems, where waste is considered input in production systems.

The diversity of companies and the multi-functionality of processes are elements that increase the possibilities of developing and strengthening IS networks. Also, it is crucial to identify inter and intra-organizational aspects when establishing guidelines to develop IS (MADSEN et al., 2015). Cohen-Rosenthal (2000) argues that the development of IS is based more on interactions between people and organizations than on the mass and energy flow. IS projects require social interconnections between institutions and individuals that share values and are culturally aligned.

According to Golev et al. (2014), experiences of different IS projects are crucial to understand and describe the contexts that facilitate overcoming barriers of this type of interaction. The authors point out barriers such as lack of commitment to sustainable development, inconvenience in regulatory compliance (such as difficulties to obtain licenses for waste reuse), lack of cooperation, and lack of information (absence of detailed qualitative and quantitative data on production inputs and waste flow, which are considered the starting point for the development of synergies regarding the use of resources in a region). Golev et al. (2014) also point out as barriers the technical infeasibility and the lack of technical knowledge (the latter is a barrier that can be removed, for example, by involving a consulting firm).

Golev et al. (2014) observe the importance of the relationship with the community when implementing IS projects, since a lack of community awareness also represents a barrier. Therefore, well-established communication systems between businesses and the local community, as well as environmental education programs, help to ensure the local legitimacy of new synergies. Finally, Golev et al. (2014) stress the need to remove the economic infeasibility barrier. Economically, the IS project may result in increased revenues, lower production costs, lower operating costs, and diversification or assurance of water, energy, and material supplies.

2.2 Roadmaps to implement industrial symbiosis projects

Transforming a regular industrial complex into an industrial eco-park, with a focus on waste management, and industrial symbiosis (IS) requires close collaboration between companies (GOLEV and CORDER, 2012). Chertow and Ehrenfeld (2012) developed a theoretical IS model characterized by three stages (sprouting, uncovering, and embeddedness and institutionalization). The model proceeds from a random formative stage involving numerous actors engaging in material and energy exchanges, to conscious recognition and intentional pursuit of network benefits, to institutionalization of beliefs and norms enabling successful collaborative behavior. They tested it in the analysis of a practical model observed in literature “the build and recruit model”, and then compared and contrasted this model with four other models observed in the literature: “the planned eco-industrial park model,” “the self-organizing symbiosis model,” “the retrofit industrial park model,” and “the circular economy eco-industrial park model,” which gradually evolve regarding the level of collaboration and environmental protection.

Leigh and Li (2015) present another IS model, highlighting the critical role of retailers and distributors toward environmental sustainability in the supply chain. The model emphasizes the importance of initiatives associated with “reduced need of raw materials,” “improved product and process design,” and “more eco-friendly products.” These initiatives reflect the integration of the concepts of industrial ecology and IS into the supply chain in order to avoid the stage of “final disposal” in waste management.

Golev et al. (2014) proposed a five-stage maturity grid that describes and interprets the IS's progress. The maturity assessment aims to measure and codify the typical resources or behaviors that reflect best practices on solid waste management (FRASER et al., 2002; WENDLER, 2012). The IS's maturity grid reflects the progression in overcoming the barriers to synergy projects, as well as emphasizing the importance of the evolutionary changes toward a region's eco-industrial development.

Stage I ("not recognized") corresponds to the first and lowest level of IS's maturity. This stage means that the companies are unaware of the concept of IS. There are different economic, regulatory, communication, and trust barriers that prevent collaboration. Stage I usually results in no or only minimal synergies. However, it is possible to observe the potential for the development of eco-efficiency projects.

Stage II ("initial efforts") shows progress in developing environmental concern, and there is an understanding of the importance of collaboration in environmental efforts. Some synergy projects may be implemented or, at least, the companies recognize the benefits of reusing waste. However, there are still significant barriers to the development of these projects, unless practices of reusing waste are part of legal requirements.

Stage III ("active") represents significant advances in the development of industrial symbiosis. Companies show an increasing interest in collaboration in different sectors, there is inter-organizational communication, and it is possible to observe successful collaboration experiences. At this stage, the progress of IS development may have occurred over several years, and after the completion of different projects. Also, the companies at this stage are studying other opportunities for collaboration.

In stage IV ("proactive"), industrial symbiosis may be considered as mature. Detailed research for new synergy opportunities are often observed, and studies for new projects are considered the standard procedure. There is well-established and continuous communication and information between companies and stakeholders, as well as a regional industrial development strategy actively supported by the community, including long-term projects to reduce cumulative and synergistic environmental impacts. Finally, stage V ("forming the future") represents a high maturity level of IS. At this stage, companies and stakeholders establish a continuous trusting collaboration. Long-term prospects and benefits are the main drivers for regional industrial development.

In this sense, Notarnicola et al. (2016) identified the basic level at which symbiotic activities and spontaneous synergistic interactions occur among the largest companies in the industrial district of Taranto. The path toward establishing IS requires companies to expand the focus of the core business and does not consider that reusing waste is a diversion of human resources and capital. Jiao and Boons (2014) explain that IS is a dynamic process and involves several actors, as well as the significant intervention of public policies.

3 METHODOLOGY

This is a qualitative, descriptive, and exploratory study, based on field research. In 2002, the State of Ceará established the Industrial and Port Complex of Pecém (CIPP), which is an industrial complex with an export zone, aimed at attracting enterprises from the petrochemical and steel sectors. Currently, CIPP has companies in the sectors of wind power, concrete and cement production, machinery used in basic sanitation, steel, and cement industries, and power generation companies (INESP, 2013). There is a high consumption of water, energy, and materials in the CIPP, as well as significant generation of solid waste.

In 2015, there were thirteen manufacturing companies established and six in implementation in the complex. Four service companies were operating and five in implementation. The state government has been worked to attract the petrochemical industry, facilitating negotiations with countries such as China and South Korea.

Semi-structured interviews were conducted with managers from six companies and different industrial sectors. The companies with the greatest environmental impact and with the potential to carry out symbiotic exchanges were selected to participate in the research. Table 1 shows the companies and position of the interviewees. It is worth highlighting the participation of the steel industry, which is the company "anchor" of the complex, the thermoelectric power plant, manufacturer of wind turbine rotor blades, steel pipe manufacturer, and fuel distributor. The interviews took place in 2015 and were conducted in person. The pilot interview took place at the fuel distribution company (C1) and confirmed the suitability of the data collection instrument. Each interview took about an hour and was recorded for later audio transcription and content analysis.

Table 1 – Profile of companies and interviewees

Company	Industrial Activity	Position of Interviewee
C1	Fuel Distributor	Administrative Manager
C2	Manufacturer of wind turbine rotor blades	Industrial Director
C3	Thermoelectric power plant	Technician of security, environment, energy efficiency, and health
C4	Manufacturer of wind turbines and components	Integrated Management Analyst
C5	Steel pipes manufacturer	Controller
C6	Steel industry	General Manager of Sustainable Development
		Technical Support Manager
		Institutional Relations Manager

Source: Research data

The instrument of data collection was adapted from the model proposed by Golev et al. (2014). The interviews collected information on barriers and the company's maturity stage for the implementation of IS projects. The interviews included questions about the licensing process at the state environmental authority (SEMACE) and the participation of the company in the CIPP business association (AECIPP), as shown in Table 2.

The data was analyzed using content analysis, which is, according to Berelson (1984), "a research technique for the objective, systematic, and quantitative description of the manifest content of the communication." Based on the semi-structured interviews, the documentary research, and the observations, it was possible to collect the necessary data, focusing on the evidence's convergence and consolidation.

Table 2 – Details of the data collection instrument

Barriers	Questions asked
Commitment to sustainable development	How is environmental management of the company discussed between employees and management? How are environmental standards/procedures shared with employees? Are employees responsible to act within their job descriptions (in the environmental management system) or do they always have to consult a manager? What are the company's values, and how do these values influence the way the company runs? Does the company hold an international certification (GRI, *Global Compact*, ISO 14001, SA 8000)? If yes, how does this certification influence the way the company is run and how it deals with both other companies and its own employees? Based on your experience, how do you think the company participates in sustainable development in the region where the CIPP is located?
Information	Can you give a general overview of the company's production process? What are the waste products that derive from the production process? Are there local companies that are willing to exchange waste and input materials with your company? Which are these companies? How does the company exchange information (about materials, water, energy, production process) with other companies within the CIPP? If information exchange does not occur, how could the company exchange this information?
Cooperation	How does the company establish cooperation and trust relationships with other companies in the CIPP? Would the company start a partnership with other companies in the CIPP to exchange waste products? Is the company prepared to encourage other companies in the CIPP to get involved in a waste reuse program?
Technical	How does the company deal with waste reuse processes? Does the company participate in a waste reuse program in the CIPP? Is the company prepared to change its production process to offer its waste products as input material to other companies or to receive waste products from other companies as input material? How might this be possible?
Regulation	How does SEMACE (government authority) regulate the company's environmental practices? In your opinion, can legislation or regulatory agencies (environmental) impair or aid waste exchange among companies?
Community	How does the company relate to the government*?* And to the community? Does the community support a waste reuse project among the companies in the CIPP? How would be the involvement of the community?
Economic	What are the main reasons for a waste reuse project between companies? For example, cost reduction of input materials? Does the company think that a waste reuse program can contribute to its economic results? Would the company invest resources (money, people, time) in the development of a waste reuse program in the CIPP?

Source: Based on Golev et al. (2014).

The interviews were transcribed, and the standard combination logic was applied using the qualitative analysis software Nvivo 10, which allowed for a systematic and objective analysis of the content. The software counts themes or instances of a category in a qualitative database. The use of Nvivo 10 in the generation of categories helps in the interpretation of patterns during the analysis (BAZELEY, 2006).

The information collected in the interviews was compared to the patterns observed in the model by Golev et al. (2014). The categories were distributed into the following dimensions: "Commitment to Sustainable Development"; "Information"; "Cooperation"; "Technical," "Regulation," "Community," and "Economic." Each expression (represented by a word, a phrase, or paragraph) was transformed into a category (SALDAÑA, 2009) and then distributed in one of the seven dimensions. This procedure allowed to infer the messages captured from interviews

(BARDIN, 2011). The analysis of the categories was divided in two moments: (1) identification of barriers to the development of industrial symbiosis projects and the degree of maturity of the researched companies; and (2) identification of ways to remove these barriers.

4 RESULTS

4.1 Barriers to establish commitments to sustainable development

The main values of CIPP companies are based on a commitment to employees, meritocracy, and quality management. Their environmental management is oriented to promote environmental awareness and corporate social responsibility, which is considered a facilitator for industrial symbiosis (IS).

The interviewee in C2 declared to have environmental education programs. The company promotes daily meetings where managers talk to the personnel responsible for operational areas in order to address the issue of waste, disposal, and the need to maintain a clean and safe working environment. C3 has a contract with outsourced firms for solid waste management and air quality monitoring.

Four companies interviewed have environmental management systems (EMS) certified by ISO 14001. C4 also has the OHSAS 18001 certification of occupational health and safety. When recruited to work in C4, employees are trained and oriented to comply with the operating procedures defined in the EMS. As for community relationship, C3 invests in the community, adopting the guidelines of Agenda 21, as well as project "*Pescar*," in which the employees offer technical training classes for the community. When hiring new employees, residents of neighboring communities have priority in the recruitment and selection process.

C6 (steel industry), aware of the impacts of its activity on the territory, made grants to support actions of the local government and civil society to address social problems. The company runs a program to elaborate a governance model including CIPP companies, community, and state and municipal governments, so these actors are engaged in discussing the sustainable development of the CIPP (*Programa Interagir*).

C6 has a Regional Development Plan (PDR) to stimulate the sustainable and harmonious development of the region. The general manager of sustainable development stated that the company had made several efforts to think of the region as a whole and prepare the territory to deal with the impacts of industrial activities.

C2 has a focus on environmental impacts and regulatory issues. The interviewee stressed the commitment to sustainable development in the CIPP region, mainly by associating the image of the company as a supplier of an alternative source of clean energy.

4.2 ***Barriers to implement a continuing flow of information***

CIPP companies operate in different markets, and therefore, have different production and operation systems. C2, for example, uses rolls of fiberglass fabric, core kit, and balsa wood as its main production materials. Its main waste is rests of fiberglass, various polymers, packaging material, pallets, vacuum plastic, and resin. C3 uses liquefied natural gas (LNG) and biomass as the main inputs to generated power. The main waste products are contaminated cloths and cotton waste, used oil and lubricant cans, cylinders, and centrifuge fluids. "In both cases, the inputs and waste are very different from the materials used by the CIPP companies, which makes the engagement in waste exchange difficult."

As for waste exchange, most of the interviewees pointed out that the companies around them were not willing to engage in such a practice. The CIPP companies, in general, are working within their scope and do not share information. C4 never searched for or was asked by another company to carry out the waste exchange. C4 reinforced that sharing information about the production process may be a barrier. In the case of an IS project, some information could be disclosed, but details of the production process would not be available to other participants.

4.3 Barriers preventing the cooperation among companies

It was possible to observe coordination among some of the companies established in the complex, such as the creation of the CIPP business association (AECIPP). In the association, company representatives meet at least once a month to discuss common problems such as demands for infrastructure, public transportation, and waste treatment. According to the interviewee in C2, the company is starting to establish relationships of cooperation and trust and starting to exchange information. The interviewees in C4 and C5 both declared not to have relationships with other companies.

Some issues related to the operation of the CIPP require cooperation among companies, such as the fact that there is no contingency plan for mutual assistance. The interviewee in C5 reported that there is no fire department at the CIPP. If there is a fire in one company, the nearest fire brigade will come from the city of Fortaleza, which is 60km away. Another issue is the absence of public transportation in the region. The cost of transportation for workers is, in some cases, higher than the salaries paid. Similarly, there are no hospitals in the region to provide ambulatory services.

About the willingness to establish a partnership to exchange waste with other companies in the CIPP, even though there is no effective engagement in an initiative of this nature, most of the companies interviewed find this possibility of partnership interesting. The interviewee in C3 declared that the donation or possible sale of reusable waste is subject to board approval. For the interviewee in C2, establishing partnerships to exchange waste does not seem to be a problem, as long as it does not change the production process. The interviewee in C4 reported the need to build a relationship of trust between the CIPP companies in order to establish partnerships, and consequently exchange information on the type of waste involved in the potential IS project.

Currently, there are no IS projects, nor a demand from companies to exchange waste. However, companies recognize the need to improve the responsible disposal of solid waste. Although no company takes the lead in an IS project, the interviewees were open and interested in participating in this kind of initiative. For example, the interviewee in C1 declared that the company would be interested in publicizing its participation in an IS program within the CIPP.

4.4 Technological barriers to implement industrial symbiosis projects

The interviewees suggest that IS projects are based on technical aspects and that they do not influence the production process. CIPP companies are not willing to modify their production process to receive waste from another company as input material. The most mentioned reason is that a possible modification could influence the quality of the product.

In this sense, companies adopt solutions involving recycling, co-processing, or landfill disposal. The CIPP does not have an industrial landfill. C2 recycles its packaging. C3 separates the waste and disposes of it differently according to the type of waste. For example, recyclables are destined to a cooperative working with these materials, the non-recyclable goes to landfill, and

the waste contaminated with oil goes for co-processing in a cement plant.

C4 outsources the waste disposal to other companies, which separate waste, plastics, and cardboard and reuse 80% of the waste. C6 has its own solid waste disposal strategy and has developed a waste management plan that includes the recycling or sale of its waste or by-products from the production process. C5 hires a firm to collect and properly dispose of the waste. C2 studied the possibility of using fiberglass waste to produce cement. However, it was found that the material influences the quality of the cement, and the project was not continued. In another study, the company studied the possibility of generating energy with the burning of the polymer residues, but the project was not financially viable.

4.5 Barriers regarding compliance with environmental regulations

The companies that are installed in the CIPP require an operating license issued by the state government environmental authority (SEMACE). All the companies participating in this research have the operating license issued by SEMACE, with conditions to be followed and issuance of monitoring reports. As for SEMACE's inspections, the interviewee in C4 stated that inspections occur if there is an irregularity or if the community files a report. On the other hand, the interviewee in C1 said that the inspections of the National Petroleum Agency (ANP) and SEMACE are periodic.

According to the interviewees, SEMACE does not support companies participating in waste management programs. The relationship between SEMACE and companies is coercive. Companies operate on their own to optimize their environmental management. For example, C5 invested in a water treatment plant to reuse effluents because water is a scarce resource in the CIPP.

As for the influence of environmental legislation on environmental programs promoting IS, most interviewees stated that environmental standards do not pressurize. The interviewee in C3 said that regulatory agencies would not be opposed since there would be a significant environmental gain. However, SEMACE does not prevent or support waste exchange, i.e., the agency has an incipient role in encouraging proactive action by CIPP companies.

4.6 Barriers in the relationship with government and community

Most of the companies researched have an institutional relationship with the government, limited to complying with the legal requirements. The local governments of the municipalities of São Gonçalo and Caucaia act in a limited way in order to solve, together with the representatives of the companies, the demands of the region. The interviewee in C3 admitted having difficulty contacting the municipalities to schedule a meeting about the company's sustainable development program.

The interviewee in C4 reported a similar situation, confirming the effort to maintain a relationship with the local government. Despite the effort, the interviewee reveals the difficulty in scheduling meetings with the governments of Caucaia and São Gonçalo, saying that the relationship with the local government ends up limited to the compliance with the norms and legal requirements.

However, since it is a high-impact enterprise that counts on government support through tax exemption, C6 has a more extensive relationship with the state government of Ceará. This interaction is carried out particularly through the Secretariat for Economic Development (SDE), which supports the development of programs such as the Regional Development Program (RDP). As for the relationship of C6 with the community, the institutional relations manager said that there is a list of programs under development with the communities in the territory, aiming to mitigate social impacts and prepare the communities and the territory to deal with the impacts resulting from the steel industry.

The companies argued that the community is far from their facilities. Most of the companies affirmed that the relationship with the community occurs basically through hiring residents of the municipalities of São Gonçalo and Caucaia. In C2, the majority of the employees come from the local community, living in neighboring areas or nearby cities. C2 also promotes the "week of environmental awareness," in which environmental education activities are carried out. Examples of activities in this week are actions such as taking the employees to clean the beach of Pecém and offer environmental education lectures in local schools.

The interviewees mentioned that they believe the community would support a waste exchange program in the CIPP region. According to the interviewee in C4, the residents interested in the program could be involved, through the creation of a recycling association. C4 would be willing to promote an environmental education program for potential members. In this sense, C4 considers that the government plays a fundamental role in promoting the collection of recyclable material, a practice that does not exist in the CIPP nor neighboring municipalities.

4.7 Economic barriers to implement industrial symbiosis projects

There is an economic barrier to be removed regarding the companies' willingness to invest human, time, and financial resources to develop industrial symbiosis (IS) projects. The interviewee in C3 declared that the company would collaborate with symbiotic exchanges only if the project was legal, profitable, and had a strong technological foundation.

The interviewee in C5 exposed the intention to collaborate with the waste exchange, adding value, and giving a responsible destination to the company's reusable waste. Currently, the company has a significant cost with responsible waste disposal. The interviewee in C3 could have financial gain if the company manages to send the oil to be refined in another company. C4 has a monthly cost of about R$ 30,000 (thirty thousand reals) to perform the collection of recyclable materials, and the profit from the sale of some of this material is not significant.

Correct disposal and reduction of costs in the process of waste treatment and destination were the reasons more frequently mentioned for participating in an IS project. According to the interviewee in C3, the benefits to joining such an initiative are the reduction of waste and operational cost, as well as a more mindful use of the industrial landfill. These potential benefits, however, are not attractive enough for companies to start mobilizing for the development of IS projects.

5 DISCUSSION

The study assessed the barriers to the development of industrial symbiosis (IS) projects among companies established in the Industrial and Port Complex of Pecém (CIPP). The results show that companies in the CIPP do not recognize the need or usefulness of developing IS projects, and are at stage I ("not recognized") of the maturity grid for IS (Golev et al. 2014). Based on the barriers for IS observed in this case, Table 3 presents a roadmap to implement IS projects.

Table 3 – Barriers and roadmaps to implement IS projects

Barriers	Characteristic of the barriers in the CIPP	Roadmaps to IS projects
Commitment to sustainable development	There are values promoting sustainable development	Include in the EMS medium and long term planning the implementation of IS projects
	Employees are active in the operation of the companies' environmental policies	
	There are companies with environmental management systems (EMS), certified by ISO 14001	
Information	The flow of input materials and waste from production processes are known	Creation of an information system able to collect information on waste generated by the CIPP companies and identify possible opportunities for IS
	Low information sharing (about materials, water, energy, production process) among companies	
	Absence of an information system about materials input and output	
Cooperation	Low cooperation and trust among companies	Integration of CIPP companies through the AECIPP, creating a network exchanging waste, water, and energy guided by trust and collaboration
	There is a business association (AECIPP)	
	Uncertainties regarding partnerships with other companies to exchange waste	
	Low willingness to engage in mobilization for waste reutilization	
Technical	Elaboration of waste management programs in each company	Sign formal contracts and invest in R&D to design products, processes, and the cycle of materials, water, and energy
	Companies are not willing to change their production process to participate in a program to reuse waste	
Regulation	Low monitoring and control from environmental agencies	Improvement of coercive and normative pressures to develop IS
	Targets established by the National Solid Waste Policy	
	The environmental authority (SEMACE) does not stimulate the IS among companies	
Community	The relationship with the community is restricted to hiring personnel	Building relationships of trust between communities and companies of the CIPP
	Opportunity to involve the community in a recycling program	
Economic	Cost reduction as one of the main reasons to engage in waste exchange	Economic incentives and subsidies from state and municipal government for the development of IS projects
	Need to prove the economic feasibility of the IS projects	

Source: Developed from the field research

Although CIPP companies have a low level of IS maturity, they are committed to programs of environmental education and adopt environmental management systems. Thøgersen and Ölander (2002) confirm that environmental programs are important for the implementation of IS projects. Also, the certification ISO 14001, related to the implementation of environmental management systems, reinforces the importance of including the development of IS projects in the organization's strategic planning. Therefore, these two elements already presented by the CIPP companies may be the trigger to lead them toward IS projects in the future.

The exchange of information on materials and waste generated in the production processes is the starting point for the development of IS. However, CIPP companies do not share this type of information. In the CIPP, companies cannot develop interactions with each other, because they act in individually and have difficulty sharing information or developing projects involving waste exchange. Similar results were found by Li et al. (2015), in which the lack of information exchanged between companies, due to technological confidentiality and commercial issues, works as a barrier to IS projects.

For example, Abreu and Ceglia (2018) ratify the use of "Synergie," the platform that combines input-output created by the company International SL, as a source of information, where companies find opportunities to exchange waste. Halstenberg et al. (2017) confirmed that this online platform facilitated the exchange of by-products and allowed companies a safe and common platform to discuss synergies through IS.

The absence of information systems on inputs and outputs of materials limits the exchange of by-products between companies. The Federation of Industries of the State of Ceará tried to build this information system (called "*Bolsa de Resíduos*," or "Waste Exchange"). However, the initiative failed because companies do not feel confident to disclose data on their waste. In this sense, Fraccascia and Yazan (2018) have corroborated the use of online platforms as a tool to reduce uncertainties and implement reliable businesses. For Low et al. (2018), online platforms for the development of IS projects can support the transition from linear to a circular economy.

Currently, cooperation among CIPP companies is incipient. A coordinating body such as the CIPP Business Association (AECIPP) can make a significant contribution to improving the communication process. Following the example proposed by Liu et al. (2018), CIPP companies could establish an IS network to share by-products and waste in order to carry out actions to save energy, water, and materials, as well as mitigating greenhouse gas emissions. The AECIPP could coordinate, together with the government of the State of Ceará, the attraction of companies to join the IS network.

Similarly, CIPP companies have few relationships of trust and, therefore, do not cooperate. Elster (2007) confirmed that when companies trust one another, managers share information. Increasing trust could influence companies to become involved in environmental issues because the availability of information is also a driving force for the development of IS (HATEFIPOUR, 2012). According to Ceglia et al. (2017), cooperation and trust are fundamental factors for the realization of symbiotic exchanges.

Hewes and Lyons (2008) point out that trust between companies emerges through social relations developed by informal contacts. These contacts often occur under the influence of a leader, who believes that waste exchange can be a viable solution. Within the CIPP, there is a lack of social relations and both formal and informal leadership. Similar failure was also pointed out by Elabras Veiga and Magrini (2009), based on evidence from the experience of developing eco-industrial parks in the Brazilian state of Rio de Janeiro.

In the case of the CIPP, the companies do not have mechanisms to carry out investments in R&D to obtain technical solutions, such as workshops or seminars focused on developing solutions in waste management. These results were also found by Redmond, Walker, and Wang (2008) in a case study on waste management in Australian small business. The lack of action of managers to solve environmental problems occurs due to a "business as usual" mindset. As demonstrated by Hewes and Lyons (2008) and Chertow (2000), investments in waste treatment and disposal technologies require time and financial resources.

Although companies in the CIPP have stated that they do not receive institutional support, there are legal instruments, such as the National Solid Waste Policy (PNRS), which encourages symbiotic exchanges. Incentives for recycling and higher costs to send waste to landfills can work as driving forces for the development of IS projects. It is necessary to establish rigorous environmental standards, comprehensive resource utilization schemes, financial support, and environmental planning, as suggested by Yu et al. (2015) for the development of IS projects in China.

Relations between CIPP companies and the community are incipient. Issues related to "mental distance," "trust," "openness," and "communication" are determinants in social interactions. Ashton and Bain (2012) report that the pioneering IS experience in Kalundborg (Denmark) was influenced by the social relationships and norms shared among the actors in a network. Informal relationships are common in Brazil, as confirmed by Abreu et al. (2015). The authors demonstrate that Brazilian companies tend to build an organizational field on a relational basis. However, the approach often consists of short-term actions, only to deal with timely problems.

Finally, regarding the economic barrier, CIPP companies expect IS projects to be economically feasible, which may result in increased revenues or reducing production costs, guaran-

teeing water, energy, and materials. However, few actions for efficient solid waste management resulting in economic advantage are in place. Also, companies tend to over-monitor their partnerships related to selling waste for recycling. The absence of a "win-win" behavior has also been reported by Chertow (2012) as a barrier to IS experiences.

6 CONCLUSION

This research explored a perspective on the implementation of industrial symbiosis (IS) projects, based on the case of the Industrial and Port Complex of Pecém (CIPP), in Brazil, exploring the barriers faced by companies and the firms' degree of maturity. The research showed that building relationships of trust is vital in the coordination of working groups that provide satisfactory solutions for exchanging waste and by-products. Also, companies must recognize that solid waste is a resource to be used in a closed-cycle production system.

A company needs proactive vision, environmental awareness, and information sharing in order to develop IS projects. The strategies to remove the barriers observed in the case of the CIPP may contribute to the operation of industrial complexes. Based on the research, it is possible to conclude that initiatives of eco-industrial development must include public policies, laws, stricter regulations, and financial incentives. Also, further research is needed in order to obtain economically viable technological solutions of low environmental impact.

As for the limitations of this research, it is noteworthy that the low number of companies researched. This limitation was minimized both by the careful selection of interviewees, which represented the main actors of the CIPP and by the use of the in-depth interview. Another possible limitation is the fact that the CIPP is located in an economically underdeveloped region in Brazil, where social and economic issues receive more attention than environmental impacts. Finally, the period studied may represent a limitation, since the institutional changes occur slowly and are motivated by pressures external to the CIPP.

Despite the research limitations, the results provide initial insights to understand the enormous task of implementing IS projects in Brazilian industrial parks. Future research may involve identifying practices and instruments of pressure adopted by political actors and companies to facilitate processes of industrial symbiosis.

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Contribution	[Author 1]	[Author 2]	[Author 3]
1. Definition of research problem	√	√	√
2. Development of hypotheses or research questions (empirical studies)	√	√	√
3. Development of theoretical propositions (theoretical work)	√	√	
4. Theoretical foundation / Literature review	√		
5. Definition of methodological procedures	√	√	√
6. Data collection		√	√
7. Statistical analysis	NA	NA	NA
8. Analysis and interpretation of data	√	√	
9. Critical revision of the manuscript	√		
10. Manuscript writing	√		
11. Other (please specify)			