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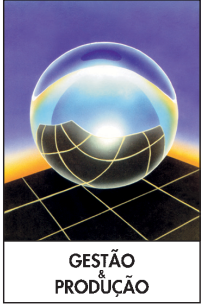

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Pressures from the context and institutional capacity building to develop industrial symbiosis networks

Pressões do contexto e a construção da capacidade institucional na formação de uma rede de simbiose industrial

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Abstract: This research analyzes the importance of the institutional and economic context and the institutional capacity building to develop an industrial symbiosis networks through the "Programa Mineiro de Simbiose Industrial" (PMSI). The research is qualitative, exploratory and descriptive, using content analysis techniques. Interviews were conducted with managers and government actors with active PMSI participation. The institutional and economic contexts and the current knowledge, mobilization and relational capacities were identified. The results indicate that the industrial symbiosis network is not dense and there are few waste exchanges among companies. There is an effort among actors who participate in the PMSI to build knowledge, mobilization and relationship capacities. However, the institutional context is unfavorable to the development of industrial symbiosis. This study article reinforces the need to invest in eco-innovative solutions and institutional environment improvements to develop efficient natural resources and waste management, and thus allow the development of eco-industrial parks.

Keywords: Waste management; Industrial network; Environmental management; Sustainability; Eco-industrial park; Industrial symbiosis; Industrial ecology.

Resumo: *O artigo analisa a importância do contexto institucional e econômico, e da construção da capacidade institucional para o desenvolvimento de uma rede de simbiose industrial. A pesquisa caracteriza-se como qualitativa, exploratória e descritiva, utilizando a técnica análise de conteúdo. Foram realizadas entrevistas com gestores de empresas e atores institucionais que participam do Programa Mineiro de Simbiose Industrial (PMSI). Foram identificadas as pressões do contexto institucional e econômico, o estágio atual das capacidades de conhecimento, mobilização e relacionamento capazes de gerar interações na rede de empresas. Os resultados da pesquisa indicam a existência de uma rede de simbiose industrial pouco densa e com trocas isoladas de resíduos entre empresas. Existe um esforço dos atores que participam do programa mineiro de simbiose industrial na construção de capacidades de conhecimento, mobilização e relacionamento. No entanto, o contexto é desfavorável ao desenvolvimento da rede de simbiose industrial. As conclusões da pesquisa reforçam a necessidade de investir em soluções eco-inovadoras e a melhoria do ambiente institucional e econômico para a gestão eficiente dos recursos naturais e dos resíduos, e que possibilitem a criação de eco-parques industriais.*

Palavras-chave: *Gestão de resíduos; Rede de empresas; Gestão ambiental; Sustentabilidade; Eco-parque industrial; Simbiose industrial; Ecologia industrial.*

1 Introduction

Industrial parks have problems related to waste management. Ceglia et al. (2017) warn that in Brazil these problems include a limited database on industrial waste, the absence of recycling plants, and lack of treatment plants able to guarantee responsible disposal. Transforming industrial waste into raw material can represent an alternative to managing environmental impact with economic and social benefits, and this involves developing a network of companies able to use the material produced. According to Ayres

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& Ayres (2002), business networks can emerge as eco-industrial parks. Côté & Hall (1995, p. 44) defined eco-industrial parks as a

> […] community of manufacturing and services businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues, including energy, water, and materials.

Li et al. (2015) state that the objectives of eco-parks include balancing environmental protection with economic development through energy conservation, reduction of greenhouse gas emissions and the development of green supply chains. The transformation of a traditional industrial park into an eco-industrial park requires that companies located in the same region, exchange resources, share information, facilities, and services (Chertow, 2000).

Companies working based on the concept of eco-industrial parks have common interests, operate in an environment of cooperation and mutual trust as well as, according to Li et al. (2015), incorporating environmental technologies. Ceglia et al. (2017) identified the existence of social, institutional, financial, regulatory and technological barriers. Social barriers include lack of trust among companies, lack of values related to benevolence and universalism, fragile environmental engagement, and weak cognitive domain on reusing waste materials.

In this sense, Chertow & Park (2016) reinforce the importance of the industrial symbiosis (IS) network, which is a subfield of industrial ecology and involves companies in a collaborative approach sharing resources, benefiting the environment and generating economic advantages. Industrial symbiosis consists of the use of by-products, waste, and energy, water and material flow as a means of promoting sustainable industrial development (Wang et al., 2017).

The Federation of Industries of the State of Minas Gerais (FIEMG) coordinates the "Industrial Symbiosis Program of the State of Minas Gerais" (PMSI). The PMSI emerged from the "National Industrial Symbiosis Programme" (NISP), developed in the United Kingdom. NISP was created in 2002 with the aim of facilitating symbiotic links between companies (Wang et al., 2017). Through the company International Synergies Ltd, NISP's experience has been transferred to Brazil, and to other countries such as Romania, Hungary, Turkey, Mexico, South Africa, and China.

Institutional capacity building is crucial for the development of an industrial symbiosis network. Healey (1998) defines "institutional capacity" as the ability of a community (a group of people who interact directly, often and in a variety of ways) to engage in solving everyday problems. Institutional capacity is related to the opportunities of individual actors to participate in collective action.

This research was conducted based on the following question: *Does the context, the institutional capacities and the interactions created within the Industrial Symbiosis Program of the State of Minas Gerais (PMSI) make it possible to develop eco-industrial parks*? The objective is to identify the institutional and economic contexts that influence the regional industrial system where actors of the industrial symbiosis program work. The interaction between companies and institutional actors enables institutional capacity building, relationship, and mobilization.

The relevance of this study is based on the need for innovative solutions for the efficient management of industrial parks. The study offers some lessons learned that expand the understanding of the skills needed to engage companies and other actors, as well as the usual business relationships, for joint reuse of resources. Understanding the operation of the PMSI through the development of institutional capacities can induce the creation of sustainable regional industrial systems such as eco-industrial parks or sustainable industrial clusters.

Therefore, the next section addresses the concepts and resources necessary for industrial symbiosis and the development of eco-parks, and presents the conceptual framework of this research. Then, the article offers the methodological procedures applied to collect eleven semi-structured interviews with PMSI participants. The results are described, followed by the discussion about the importance of context, institutional capacities, and interaction among the actors for the development of industrial symbiosis networks. Finally, strategies to move from PMSI to an eco-industrial park is discussed.

2 Understanding the concept of industrial symbiosis

The term "symbiosis" is based on the notion of biology where two different species exchange materials, energy, or information in a mutually beneficial way (Ehrenfeld, 1997). The analogy with ecology involves concepts of community and diversity and their contribution to the system's resilience and stability. The fundamental characteristics of ecosystems point to alternative models of industrial activities. These dimensions mainly involve the use of ecosystem ecology concepts, with emphasis on flows and the cycle of resources (Graedel & Allenby, 2011).

"Industrial Symbiosis" (IS) is defined as the optimization of collective resources, based on the exchange of by-products, and the sharing of benefits among different companies (Jacobsen, 2006). Industrial symbiosis is a mutualistic interaction of different companies in the beneficial reuse of waste, water or

energy, which results in a more efficient production regarding the use of natural resources, and a lower environmental impact (Grant et al., 2010).

Chertow (2000) explains that industrial symbiosis requires collaboration and geographical proximity between companies. Ehrenfeld & Gertler (1997) reinforce the need for this geographic proximity for the exchange of materials, water, and energy. Doménech & Davies (2011) explain that IS has emerged as a body of interchange structures to move towards a more eco-efficient industrial system by establishing a collaborative network for the exchange of knowledge, materials, water, and energy.

Industrial symbiosis connects companies in a system of collaboration and inter-organizational alliances to reduce environmental impact in an economically rational way (Doménech & Davies, 2011). Mirata & Pearce (2006) explain that the gains of the network (or alliance) are higher than the individual benefits of each company. Lombardi et al. (2012) affirm that an industrial symbiosis is a strategic tool for the economic development, innovation, and efficiency of the use of natural and residual resources.

The resources exchange can occur through reuse or by-product exchanges; of sharing infrastructure; and the joint provision of services (Chertow et al., 2008). By-product reuse occurs through the use of traditionally discarded materials or waste as substitutes for commercial products or raw materials. By-product exchanges can improve efficiency in the use of resources and better recognize their economic value, which is fundamental for the transition from a linear flow of materials, water, and energy to a circular flow.

Infrastructure sharing takes place through the collective use and management of steam, electricity, water, and wastewater. Joint service provision involves companies collectively assembled to address their ancillary needs, which has to do with materials and services not directly related to their core business. Fire suppression, safety, cleaning, restoration, and waste management are examples of ancillary services, which have environmental implications (Chertow et al., 2008).

Chopra & Khanna (2014) argue that SI's main feature lies in a group of companies that jointly assume responsibility for the provision of utilities or infrastructure. These services include water, energy or heat supply systems, as well as wastewater treatment plants. For example, industrial symbiosis (IS) in Kalundborg, Denmark, has created a network for the exchange of waste, water, and energy between companies, based on the contractual relationship of dependence.

Chertow (2007) defines the planned model and IS self-organized model. The planned model includes a conscious effort to identify companies from different industries and locate them together so that they can share resources with each other. This model assumes the participation of a governmental body that encourages the formation of an eco-industrial park. In the IS self-organized model, an industrial ecosystem emerges from decisions made by private actors motivated by the exchange of resources to achieve goals, such as cost reduction, revenue growth, and business expansion.

2.1 Elements needed to create eco-industrial parks

The development of an eco-industrial park requires close social interconnections based on individuals, organizations, culture, values, and institutions. Cohen-Rosenthal (2000) confirms that the exchange of materials is based more on interactions between people and organizations than on mass flow. It is crucial to change managers' attitudes about waste disposal and build a greater awareness of the need to manage them (Tudor et al., 2007).

The development of industrial symbiosis networks can be considered as a starting point for the transformation of a traditional industrial park into an eco-industrial park. According to Spekkink (2015), industrial symbiosis occurs on two levels. The first is the "regional industrial system" that involves companies located geographically close to each other, where social, material and energy connections may occur. This level is where institutional capacities of knowledge, relationship, and mobilization are built.

Relational capacity refers to the network of relationships that reduce transaction costs between companies by increasing trust and mutual understanding (Boons & Spekkink, 2012). It is related to the capacity of collective action, based on the quality of the actors' relationships, such as the number and variety of actors involved in the community, and the level of trust between them (Healey, 1998). Knowledge capacity refers to the ability to acquire and use information that enables companies and other actors to shape their exchanges in such a way as to reduce their environmental impact. Finally, mobilization capacity refers to the ability of actors within the industrial park to mobilize firms and other actors to develop connections of industrial symbiosis (Boons & Spekkink, 2012).

The development of institutional capacities is observed in the number and diversity of actors involved, in the changes in the definitions of problems and solutions, and in the establishment of strategic vision. Spekkink (2015) explains that a larger and more diverse group of actors generally have access to a range of resources (waste) that consequently increase the possibilities for these actors to engage

and foster interactions. However, a large number of actors may present coordination problems.

At the second level are the interactions between other actors. These actors are encouraged to share beliefs, desires, and opportunities, to embark on the transformation of a traditional industrial park into an eco-industrial park. For Spekkink (2015), these interactions occur in the form of guidance, planning, feasibility studies, implementation, influence of other actors, agreements (contracts), establishment of new organizations, and the companies' strategic vision. These interactions result in a symbiosis network, which effectively composes the exchanges between these actors. The type of interaction also impacts contexts and institutional capacities.

Hedstrom & Bearman (2009) argue that the level of trust between community members is established as they see opportunities to engage in industrial symbiosis projects. Trust reduces the risk of failure in cooperative relationships. In the long run, actors understand that their problems and interests as interrelated, and they reevaluate individual goals, so they are aligned with collective ones. This process of social learning can lead to the development of shared strategic visions, in which actors articulate common interests and objectives (Elster, 2007).

Spekkink (2015) explains that the opportunities that the actors observe are not only defined by the dynamics of institutional capacity-building, and several events can influence this process, such as changes in policies and regulations, and in the economic context. It is observed, however, that when actors have built institutional capacity in the regional industrial system, they can work together to influence the context. Symbiotic exchanges can be developed autonomously from each other based on independent projects, but over time, they may become increasingly interconnected, contributing to the development of a network of symbiotic exchanges within the regional industrial system.

According to Liu et al. (2018), eco-industrial parks worldwide have developed in countries such as Australia, Denmark, the USA, Japan, China, South Korea, and Taiwan. In the UK, Lombardi et al. (2012) estimate that NISP significantly reduced the amount of waste diverted from the industrial landfill, created economic benefits for individual companies and local governments, and reduced greenhouse gas emissions. In Brazil, there are some eco-industrial park initiatives, such as the one coordinated by the company 'Natura' in the State of Pará; the eco-industrial parks of Santa Cruz and Paracambi in Rio de Janeiro; and the "*Projeto Candiota*" in the state of Rio Grande do Sul. Elabras Veiga & Magrini (2009) evaluate that, in Brazil, eco-park initiatives fail due to lack of institutional support, common interests, cooperation and trust between companies.

The success of the development of eco-industrial parks is usually attributed to the identification and overcoming of institutional, regulatory, technological and financial barriers (Geng et al., 2007; Kim, 2007). More recently, Golev et al. (2015) identified barriers related to social aspects including information, cooperation, community and commitment to sustainable development. Social elements that are essential for companies to participate in the development of an eco-industrial park involve trust, the cognitive domain on the importance of waste, environmental engagement and company values (Ceglia et al., 2017).

3 Methodology

This study is a qualitative, descriptive, exploratory and field research using semi-structured interviews for data collection. The interviewees were managers of the following organizations/initiatives: the Industrial Symbiosis Program of the State of Minas Gerais, an initiative coordinated by the FIEMG; *Fundação Estadual do Meio Ambiente* (FEAM) (state foundation for environmental protection); the *Associação de Catadores de Papel, Papelão e Material Reaproveitável* (membership organization formed by collectors of recyclable materials); the *Sindicato das Indústrias de Explosivos do Estado de Minas Gerais* (SINDIEMG) (union of fireworks companies of the state), as presented in Table 1.

Table 1. Institutions participating in the Industrial Symbiosis Program of the State of Minas Gerais interviewed for the study.

Characteristic	Actors	Interviewees' position in the organization
Promoter	Federation of Industries of the State of Minas Gerais – FIEMG	Superintendent of Industrial Development Environmental Manager Environmental Analyst
Supervisor	State foundation for environmental protection – FEAM	Manager of Residuals, and Mining and Industrial Solids Waste
Expectator	membership organization formed by collectors of recyclable materials – ASMARE	Vice-President
Mobilizer	Union of fireworks companies of the state of Minas Gerais – SINDIEMG	President

Source: Elaborated by the authors.

Also, managers of companies participating in the PMSI were interviewed, which totaled seven companies interviewed and visited at different phases of industrial symbiosis (e.g., completed IS; IS in progress; or IS in negotiation phase) and of various industrial sectors, as shown in Table 2. Finally, we interviewed companies that participated in the industrial symbiosis workshops but did not carry out any exchange of by-products or waste.

The questionnaires were formulated considering the specific contribution of each key actor to the development of the industrial symbiosis networks. The interviewees were asked about the conditions of the institutional and economic contexts, about the institutional capacities generated in the scope of the PMSI, in addition to the interactions between the institutional actors and the companies.

The interviews were conducted in 2014, were recorded and lasted an average of 45 minutes, totaling 9 hours of recording. For the analysis, they were transcribed, and the content was analyzed using the software Nvivo 10. This software works by counting themes, or instances of a category (nodes) in a qualitative database. The use of the software in the generation of categories helps in the interpretation of patterns during the process of analysis of the industrial symbiosis network (Bazeley, 2006). The coding and categorization were performed using Spekkink's (2015) conceptual framework.

The categories were divided into 'nodes' that include PMSI design", "context"; "institutional capacities" and "interactions between the actors and the industrial symbiosis network". Codes were developed to identify the design and the first steps of the PMSI, the influences of the institutional environment and economic context; to evaluate the capacity building in terms of mobilization, relationship, and knowledge; verify the articulation and interaction between the actors, and to identify the opportunities and feasibility of industrial symbiosis projects. After the codification stage and categorization of the interviews, a model for evaluating the strategies to advance the PMSI to an eco-industrial park was proposed.

4 Results

4.1 Conception and first steps of the Industrial Symbiosis Program of the State of Minas Gerais

The first steps towards the development of an industrial symbiosis network in Minas Gerais began in 2009. Consultants from the company International Synergies Ltd. (ISL), through the British embassy, presented the methodology of the National Industrial Symbiosis Program (NISP) to the FEAM. According to the FEAM interviewee, the institution did not show interest in coordinating the implementation of an industrial symbiosis program. Next, the ISL consultants presented the initiative to FIEMG, who became interested in coordinating the implementation of the program.

According to the FIEMG environmental analyst, the beginning of the PMSI was coordinated by FIEMG's Environment Management area, with the participation of FEAM, the *Centro Mineiro de Referência em Resíduos* (reference center for waste disposal of the state of Minas Gerais) and the non-profit *Serviço Social Autônomo* (SERVAS), which works with people in vulnerability with no access to fundamental rights, such as drinking water, education, employment and income opportunities.

FIEMG and partners were trained by the NISP team, and in 2009, the first Workshop on Industrial Symbiosis was held in the city of Divinópolis. According to FIEMG's environmental analyst interviewed, the Midwest region of the state of Minas Gerais has several types of companies – fireworks manufacturers, dairy products, footwear, clothing – increasing the likelihood of a connection between companies. In this pilot-workshop, 45 companies participated, and it was possible to identify 149 residual resources that could contribute to creating an industrial synergy.

According to FIEMG's superintendent of industrial development, the discussion about Brazil's solid waste policy (PNRS) again brought to the agenda the problem of solid waste management. The FIEMG environmental manager pointed out that the federation took the lead in this process, and decided to create

Table 2. Companies participating in the Industrial Symbiosis Program of the State of Minas Gerais interviewed for the study.

Companies	Industry sector	Interviewees' position in the company
Z	Chemical	Commercial Manager and Environmental Analyst
#2	Paint	Environmental Supervisor
X	Cosmetics	Commercial Manager
# 3	Cement	Commercial Manager
Y	Furniture	Company's owner
# 6	Fireworks	Company's owner
# 7	Eco-technology	Executive director

Source: Elaborated by the authors.

an Integrated Waste Exchange System. Through an electronic page, FIEMG offers the opportunity of real-time trading of various waste, adding value and avoiding expenses with final disposal.

According to the FIEMG environmental analyst, in 2010, with the help of the NISP team, the FIEMG continued to develop the workshops in Minas Gerais. At the end of 2010, the coordination of PMSI, through the sponsorship of AL-INVEST and in partnership with FIEMG's International Business Center, created the Brazilian Industrial Symbiosis Program (PBSI). The program's objective was: to train the federations of the industries in the Brazilian states that were interested in adopting the method of industrial symbiosis developed by NISP. FIEMG's superintendent of industrial development explained that, in 2011, professionals from the federations of the industries of the states of Paraná, Rio Grande do Sul and Alagoas were trained by the teams of NISP and FIEMG. In 2012, the Brazilian Industrial Symbiosis Program (PBSI) was sponsored by the Brazilian Service of Support for Micro and Small Enterprises (SEBRAE).

With the end of the sponsorship, in 2013, PBSI shut down its activities. The interviewee (superintendent of industrial development) also informed that, in addition to FIEMG, only the Federation of Industries of Rio Grande do Sul (FIERGS) continues to apply the method of industrial symbiosis, developed by ISL. FIERGS adopts the NISP methodology within its local productive arrangements (APL). By the end of 2014, the PMSI continued to be coordinated by the FIEMG, but it operated without the partnerships with FEAM, the reference center, and the nonprofit SERVAS.

4.2 Institutional and economic contexts, institutional capacities, and interactions in the Industrial Symbiosis Program of the State of Minas Gerais

The research shows the effort of the PMSI in the promotion of interactions between companies for symbiotic exchanges. Figure 1 presents the elements of the PMSI, based on the framework developed by Spekkink (2015). In general, the initiatives of industrial symbiosis are weakly influenced by institutional and economic contexts. It is observed the absence of public policies that promote the insertion of IS in the corporate strategy, either through coercive pressures or fiscal incentives.

The institutional capacities of relationship, mobilization, and knowledge are built within PMSI, through strong leadership of FIEMG, as the leading promoter of the interactions between companies. In this process, it is interesting to emphasize the existence of an instrumental vision of the companies and the absence of formal agreements in the process of waste exchange. At the level of the Regional Industrial System, a shared strategic vision is still incipient among companies and actors when it comes to industrial symbiosis for the development of eco-industrial parks.

4.2.1 Evaluation of the institutional and economic contexts

The institutional context was made explicit in the interviews by the representatives of FIEMG, FEAM and the companies, which highlighted the influence of

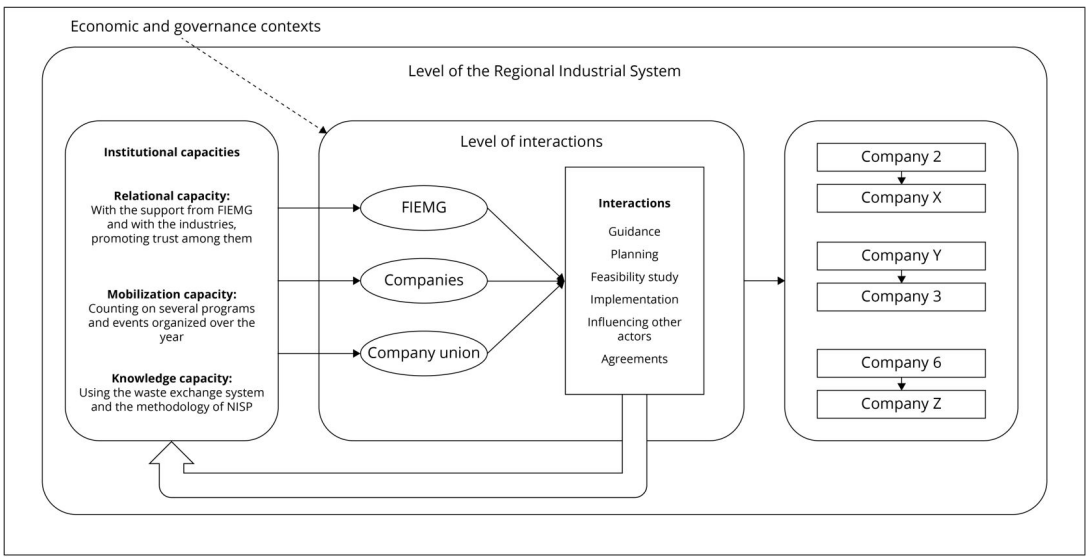

Figure 1. Industrial Symbiosis Network promoted by FIEMG in the PMSI. Source: Developed from field research, based on Spekkink (2015).

the National Solid Waste Policy (PNRS) and state Solid Waste Policy (PERS). The interview with FEAM's manager of residuals, and mining and industrial solid waste reveals that, despite the policy's extent and importance, the PNRS was still not unfolded in plans, programs, actions, and activities to reuse waste, which would allow its full operation. According to the interviewee, industrial symbiosis is indirectly contemplated in the PNRS, by the provisions that encourage the development of environmental and business management systems aimed at improving production processes and the reuse of solid waste, including energy recovery and use.

The FEAM interviewee reinforces that state policy PERS (Law 18031/2009) is still waiting for the State Solid Waste Plan to be finished. Launched on 25 July 2014, the deadline for the plan to be delivered was 14 months, counted from the signing of the contract. According to documents of the Ministry of the Environment (MMA) (Brasil, 2018), the State Plan for Solid Waste is still being drafted. The FIEMG environmental analyst stated that the companies did not incorporate PNRS or PERS actions into their environmental management models. However, the owner of company Y believes that PNRS or PERS may require greater control over waste disposal.

The state of Minas Gerais has 419 municipalities that deposit their urban solid waste inappropriately, and there is a limitation regarding infrastructure, based on the number of landfills available in the state. According to data from FEAM (2016), there are 17 landfills in Minas Gerais, serving 31 municipalities, and 54 sorting and composting plants, used by 56 municipalities. As for industrial landfills, the number is reduced to eight industrial waste landfills of Class II A and two industrial landfills for waste Class I. There are also nine cement plants licensed for co-processing, two blend units for co-processing and three incinerators for industrial waste (ABETRE, 2013).

FIEMG's environmental analyst says that, in the economic aspect, the issue of sustainability is observed from an instrumental perspective. It means that companies adopt environmental management with the intention of reducing costs with the acquisition of materials and waste disposal. According to the company's Environment Supervisor (#2), reducing logistical and operational costs was essential to integrate the PMSI. The interviewee reports that company #2 had to store a large amount of waste, to reduce transportation costs to the industrial landfill. This storage consumed physical space and increased the risk of fire.

4.2.2 Institutional capacity building in the Industrial Symbiosis Program of the State of Minas Gerais

Regarding institutional capacities, the interviews reveal that the knowledge capacity is manifested through FIEMG's experience with the "Waste Exchange," and courses in the environmental area, following the methodology transferred from NISP to PMSI. The "Waste Exchange" is an online platform for effective and free-of-charge negotiation of waste. FIEMG's expertise with the "Waste Exchange" facilitated the understanding of the industrial symbiosis methodology developed in the NISP.

The consultants of the International Synergies Ltd., trained the FIEMG technicians to conduct the workshops, raise awareness in the companies and create synergy among companies regarding the waste produced, helping FIEMG to be able to coordinate the industrial symbiosis program in Minas Gerais. FIEMG's mobilization capacity when it comes to the environmental issue was built through various programs and events. The FIEMG environmental analyst and PMSI coordinator explained that the workshops are held once a year in each FIEMG regional headquarter, which means that there are eight workshops throughout the year.

The guidelines on the operation of the PMSI start from the invitation sent by email to participate in the workshop on Industrial Symbiosis. During the workshop, FIEMG's team explains the concept of IS and the operation of the PMSI, as well as providing practical examples of symbiosis. Then, the companies participating in the workshop receive a card to complete with data on supply and demand of waste and resources (services and idle equipment). These workshops are characterized as "business roundtables," where companies share information.

The coordination of the PMSI upload the data collected during the workshop on the information system, developed by NISP, and generates the possible combinations between companies. The PMSI coordination facilitates the connection of companies through providing contact information for those interested in a particular type of waste or resource. According to the FIEMG environmental analyst, it is the responsibility of companies to negotiate, implement and monitor synergies.

As far as planning is concerned, FIEMG's superintendent of industrial development emphasizes that each company works with another to look for opportunities for symbioses. This planning involves the purchase, sale or donation of waste, the duration of the cooperation, the amount of waste and supply logistics. Other actors, such as company unions, technology companies, the National Industrial Apprenticeship Service (SENAI) and environmental agencies are

involved in the workshops. In cases of negotiations between several companies in the same sector, the development of technology, feasibility studies, and legal restrictions are also discussed. The companies are responsible for assessing the feasibility of IS in the economic, technological and logistic spheres. The implementation phase is carried out entirely in companies.

According to the executive director of company #7, relational capacity is one of the strengths of PMSI. FIEMG environmental consultants have strong capillarity between companies of different sizes. The environmental supervisor of company #2 reinforces that the relational capacity is observed through the support offered by FIEMG to the companies. The manager of residuals, and mining and industrial solids w of FEAM believes that industrial symbiosis is a good solution to reduce the shipment of solid waste to landfill. However, the promotion of IS is not part of the scope of FEAM activities.

The president of the union of fireworks companies SINDIEMG emphasizes that trust in FIEMG's actions enhances the credibility of the PMSI and promotes trust among the actors. The companies' unions related to FIEMG are important partners in the development of the PMSI. They work by mobilizing affiliated companies to participate in the IS network. For example, the President of SINDIEMG hopes that the industrial symbiosis will grow in MG, contributing with positive results for all actors involved.

On the other hand, the vice-president of ASMARE does not consider the organization as an ally of the PMSI. ASMARE was founded on 1st May 1990, as a consequence of intense mobilization through public demonstrations, the occupation of recyclables sorting locations and protests directed to the City Council of Belo Horizonte, the capital of the state of Minas Gerais (Gonçalves et al., 2008). Headquartered in the central region of Belo Horizonte, ASMARE is responsible for collecting, sorting, pressing and selling 421 tons of waste per month. This amount is added to an average of 52 tons coming from the monthly collection made by the Superintendence of Urban Cleaning (SLU) of the city, totaling 473 tons of recyclable materials processed.

Despite its strong performance in the collection of household waste, ASMARE's work is still incipient when it comes to serving the needs of the industry. This finding is evidenced in the interview with the organization's vice-president, from the point of view of the beliefs, desires, and opportunities. ASMARE believes that PMSI will reduce the volume of waste available to the nonprofit and that companies would only donate waste that has no commercial value.

4.2.3 Interactions among companies to develop the industrial symbiosis network

The interactions between the companies participating in the PMSI were evaluated based on guidance, planning, feasibility study, influencing other actors, agreements (contracts), new companies, strategic vision and influencing the context. In general, the research identified that the economic gains from waste exchanges represent the primary motivation for companies to join industrial symbiosis projects. Table 3 presents the interactions found in the PMSI.

Waste exchanges are identified as a sporadic opportunity to reduce operational and logistical costs. In the view of all companies interviewed and participating in the PMSI, solid waste should be disposed of responsibly, at the lowest possible cost. The interviewees of companies Z and #2 reinforce the concern with having an updated environmental license, as a condition for the companies to be able to engage in the symbiotic exchanges. In general, building an industrial symbiosis network is not part of the environmental management strategy of the

Table 3. Interactions between companies in the PMSI.

Type of interaction	How does it happen?
Guidance	FIEMG provides, with exclusivity, guidance to the companies.
Planning	FIEMG is responsible for planning regional workshops.
Feasibility study	The feasibility phase (technical, economic, or organizational) is carried out by the companies. Company unions help in the development of feasibility studies.
Implementation	Companies implement IS solutions, according to the findings of the feasibility studies.
Influencing other actors	FIEMG and the company unions try to influence other unions to integrate the PMSI.
Agreements (contracts)	There are signed formal contracts (waste buying and selling contracts) and the establishment of waste exchange informal agreements (donation).
New companies	No new company emerges from the PMSI.
Strategic vision	Actors engaged in the IS do not manage to establish strategic visions around which common interests and objectives are coordinated.
Influencing the context	PMSI has limited influence in institutional and economic contexts.

Source: Developed from field research, based on Spekkink (2015).

companies interviewed. These companies also do not influence others to participate in the PMSI.

Three cases of symbiotic exchanges promoted under the PMSI were identified. The first case involves a company in the paint industry (# 2) and a company in the cosmetic industry (X). It is a symbiosis that occurs in the central-west region of Minas Gerais state. The environmental analyst of company #2 pointed out that the residues of acetone, isopentyl acetate, and methyl ethyl ketone were destined for another company (located on the border of Minas Gerais with the state of Rio de Janeiro). In 2009, company #2 participated in the first industrial symbiosis workshop of PMSI and began negotiating an average of 300 kg per month of waste to Company X, a paint manufacturer located near company #2.

This symbiosis is carried out through donation, and there is no formal agreement such as a sales contract. The interviewee of company #2 says that the gains from this symbiosis involve cost reduction with disposal in an industrial landfill or co-processing. According to the interviewee, the main limitation of this industrial symbiosis was the need to issue an invoice, that is, the accounting part of the process.

Another example involves the industrial symbiosis between company #3 and company Y. The Company's Commercial Manager (#3) explained that it uses wood shavings (residue) produced by company Y in the composition of the blend of residuals, which will then be incinerated in the cement industry. The interviewee says that with this symbiosis, company #3 had a 5% reduction in the cost of acquisition of wood shavings and pays only the transportation of the waste produced by company Y. The interviewee stresses the intention to extend this symbiosis with the union of wood furniture companies to increase the volume of residuals received and reduce costs. In this sense, a partnership is being established with the furniture cluster of Carmo de Cajuru, a city located 120 km from Company #3 and the relationship is supported by the PMSI coordination.

Another symbiosis is carried out between 53 companies producing fireworks and company Z of the chemical industry. The president of SINDIEMG, owner of Company #6 (one of the 53 companies) explained that there had been several attempts to take advantage of the paper dust residue from the fireworks tubes. The first attempt involved a sugar plant, but there were problems with the contract. The second attempt was to transform paper dust into a new product, an ecological block of paper, but for technical reasons, this product was not financially viable. Finally, in a PMSI workshop, a chemical industry (company Z) showed interest in this residue for the manufacture of a liquid effluent solidifier.

This symbiosis is in the initial phase of implementation and, according to the interviewees of companies #6 and Z, the aim is to process 20 tons per month of waste. An exclusivity contract has been put in place to ensure that this partnership is perpetuated. Company Z made investments in its industrial plant to absorb the raw material from waste paper dust. Considered an environmental liability for fireworks companies, company #6 interviewee reinforces the importance of industrial symbiosis for the correct disposal of waste and economic benefit.

5 Discussion

Advances in the PMSI towards the implementation of eco-parks require changes in the context, in building institutional capacities, and in expanding business-to-business interactions. The isolated action of FIEMG will not be enough to guarantee the development of eco-industrial parks. The proposed strategies require the expansion of the networks of symbiotic relationships, as shown in Table 4.

The research reveals that the institutional and economic context put considerable pressure on the development of eco-industrial parks. The PMSI operates in a current environment that pressures only at the final disposal of waste. It is, therefore, necessary to establish rigorous environmental standards, comprehensive resource utilization frameworks, financial support, and environmental policy guidance, as suggested by Yu et al. (2015). In the economic context, research indicates the need to reduce operational, logistics and transaction costs. Notarnicola et al. (2016) reinforce the need to have a coordinator/promoter of the industrial symbiosis network and government financial support to drive companies towards an eco-industrial park.

In this sense, FIEMG's role as coordinator/promoter of the industrial symbiosis network must be strengthened. Following the suggestions proposed by Behera et al. (2012), the key issue for the development of any network of industrial symbiosis includes the identification of economic and environmental benefits. In the industrial complexes of Ulsan (South Korea), government support (central and local) played an important role. The companies were motivated by public policies that provided targets for waste reduction, measures to combat climate change, to promote "green growth" and other similar environmental policies.

The building of institutional capacities is crucial for the development of eco-industrial parks. The mobilization capacity of FIEMG and the company unions related to the federation such as SINDIEMG, confirm the need to develop a sense of trust between companies. It means that it is important to reinforce the existence of a shared vision, successful cooperation experiences and relationships characterized by the development of a common language. Ceglia et al. (2017) identified that the absence of environmental engagement and

Table 4. Strategies proposed to develop eco-industrial parks based on PMSI.

Elements	Components	Strategies	
		Based on PMSI	Developing Eco-Industrial Parks
Context	Institutional	Coercive pressure focused on final waste disposal and weak monitoring mechanisms	Provide better coercive and normative pressures to promote industrial symbiosis
	Economic	Focus on reducing operational, logistics and transactional costs	Economic incentives and subsidies to develop industrial symbiosis network
Institutional capacity building	Mobilization	Restricted to a group of self-organized companies	Developing networks with effective communication channels between companies
	Relational	Short term relationships and sporadic solutions between companies	Integration of companies in networks based on trust and collaboration
	Knowledge	Dissemination of information with an emphasis on the flow of materials, water, energy, and waste	Research and development to redesign products, processes, and cycling of materials, water, and energy
Interaction between companies	Guidance	Operational and bottom up	Strategic, top down and bottom up
	Planning	Short term planning limited to workshops	Long-term planning to develop the eco-industrial park
	Feasibility study	Short-term economic benefits	Long-term economic and environmental benefits
	Influencing other actors	Identification of possibilities and synergies	Building networks and relationships of mutual trust between companies
	Agreements (contracts)	Informal and sporadic relationships, with low financial support	Formal contracts and investment in technology to change processes and products

Source: Elaborated based on field research.

trust represent social barriers to transforming a traditional industrial park into an eco-industrial park.

PMSI has emerged as a self-organized business strategy among companies willing to cooperate to improve their economic and environmental performance. The workshops represent an essential "arena" where companies interacted. The research results show that the methodology adopted could go beyond the demand and supply of waste. The PMSI should take a more systematic approach and be implemented throughout the production system. Following Braungart et al. (2007), an eco-industrial park requires formal agreement among stakeholders, sharing of information on using the material, and development of resource and infrastructure sharing strategies.

Advances in PMSI require more significant interaction between companies and other institutional actors. Corroborating the recommendations proposed by Jiao & Boons (2017), an active process of participation of the actors is necessary to materialize ideas into practices. China's coordinated effort towards the development of eco-industrial parks could be adopted in Brazil. According to the recommendations of UNIDO (2017), it is fundamental the reinterpretation and redesign of public policies (i.e., PNRS and PERS); to promote efficient management of traditional industrial parks; to ensure infrastructure improvements to facilitate symbiotic exchanges and the involvement of companies and institutional actors.

6 Conclusion

This research shows that the industrial symbiosis network implemented in Minas Gerais is a result of an effort of institutional capacity building. FIEMG acts in the transfer of knowledge about industrial symbiosis, in the mobilization and articulation of companies and trade unions. In general, interactions between companies fail to create new organizations, do not influence other actors (such as membership organizations formed by collectors of recyclable materials, companies, and media) and, finally, the interactions cannot affect institutional and economic contexts.

Regarding the institutional context, companies do not face significant pressures from regulatory and environmental enforcement agencies to seek

innovative solutions to the waste issue. There are several waste disposal areas (not necessarily for responsible disposal) which limit the development of innovative solutions and the adoption of entrepreneurial behavior. In the economic context, companies do not envisage significant gains in developing symbiosis networks, and therefore do not allocate resources to break the social, financial, technological, institutional and regulatory barriers to change from traditional industrial parks to eco-industrial parks.

It is important to acknowledge the limitations of this research. First, it involves a single case of industrial symbiosis, fostered under the PMSI. Despite the methodological rigor in identifying the actors interviewed, the results obtained cannot be generalized. The second limitation is that this is a static study, i.e., it is not possible to capture changes in the practices adopted, the influence of the actors and the benefits achieved over time.

However, the study reinforces the importance of national and state policies that include mechanisms of industrial symbiosis. It is necessary to invest in eco-innovative solutions and in the improvement of the institutional and economic environment for the development of institutional capacities that result in efficient environmental management of natural resources and waste. The translation of public policies in the development of industrial parks requires a reflexive deliberation and adjustments in the processes of creation and evolution of symbiotic relationships, which are being neglected by governments, companies and other institutional actors.

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