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Article

"By-product Synergy" Dynamic Evolution at the Altamira-Tampico Industrial Corridor: 20 Years of Industrial Ecology in Mexico

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Abstract

The normative question "what's the impact of historical firm's decisions and network position in the embeddedness and performance of actors in a collaborative platform like the Industrial Symbiosis?" has received attention of researchers. This paper provides an overview of the Industrial Symbiosis (IS) process, offering an historical analysis of its evolution as the only current and life example of industrial collaborative network system which provides a novel setting of insights with which to inform and refine our understanding of these organizational theories more broadly. The results show the historical outline of Altamira-Tampico IS and set the three different stages – regional efficiency, regional learning, sustainable industrial district - proposed by Baas and Boons (2004), relating them to an underpinning motivation and industrial symbiosis network (ISN). So, the dynamic evolution of industrial symbiosis started with *Emergence* (1997), then *Regional efficiency* (2007) *Regional learning* (2011) and finishing with *Sustainable Industrial District* (2016) on a wider industrial symbiosis outlook. We consider that the IS project at Altamira-Tampico has been a dynamic example of socio-technical and environmental model, embodying one of the most successful biophysical, social and economic symbiotic case studies in Mexico and abroad. Building on this view, the managerial strategy and willingness of the stakeholders to encompass a compelling interactive learning process in Altamira is supported by the findings that identifies successful mechanisms heightening learning and innovation while decreasing transaction costs and increasing flexibility.

Keywords: historical analysis, industrial symbiosis, system dynamics, learning process, embeddedness.

Introduction

Within the framework of industrial ecology, the study and promotion of industrial symbiosis have generated a large amount of research (Chertow, 2000, Dannequin, Diemer, Petit, Vivien, 2000, Chertow, 2007, Beaurain, Brullot, 2011, Boons, Chertow e& al., 2016; Diemer & al, 2017). Based on the concept of biophysical symbiotic exchanges, industrial symbiosis engages "separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products" (Chertow, 2000, p. 314) for mutual economic and environmental benefits (Christensen, 2006. p. 3). Industrial symbiosis closes cycles by turning wastes into valuable materials that substitute raw materials in an industrial system, to reach a natural closed ecosystem (van Berkel, 2010). More recently, Diemer and Morales (2016) defined Industrial Symbiosis (IS) as a subfield of industrial ecology driven by "strong sustainability" expectations (Diemer, 2017). The idea that symbiosis can embody a model of strong sustainability refers to the interaction of four pillars: eco-efficiency, cooperation, proximity and resilience. From these considerations, industrial symbiosis can be presented as "the process of cooperation developed by networked actors in a common geographical, organizational and institutional environment. Voluntary involvement of local authorities, firms and NGO must promote synergies aimed at improving eco-efficiency and resilience of the dynamic system" (Diemer, Morales, 2017).

If industrial symbiosis has often been associated with metabolism studies (material and energy flows, input / output models, life cycle analysis) or efficient benefits, much attention is focused today on the social and dynamic learning process. The connection between biophysical exchanges and social interactions has been successively analyzed by Sterr and Ott (2004), Gibbs and Deuz (2005, 2007, 2008), Hewes and Lyons (2008), Shi, Chertow and Song (2009), Boons and Howard-Grenville (2009), Domenech and Davis (2011). These authors prefer to highlight the social dynamics within a symbiosis rather than the economic benefits or technological issues. Trust and community embeddedness, coordination mechanisms, norms, values, routines, rules and close relationships strengthen the sustainability of the symbiosis and explore the social context of industrial ecology. These perspectives were presented as a matter of evidence at the 2011 Industrial Symbiosis Research Symposium (ISRS) in San Francisco, which was organized by the International Society of Industrial Ecology (ISIE) section of the Yale School of Forestry and Environmental Studies. The emergence of the dynamic learning process introduced a new focus on industrial symbiosis studies. It considers that industrial symbiosis can be easily conceptualized as a process rather than a state of affairs. So, Lambert and Boons (2002, p. 473) described sustainable development (of industrial parks) as "social process in which the principles of sustainable development are taken as a starting point for assessing ecological, social, and economic aspects of decisions in an integrated way through interactive learning processes among societal actors". Boons, Spekkink and Mouzakitis (2011, p. 907) proposed to provide a theoretical basis for understanding the dynamics through which regional industrial systems change their connectiveness in their pursuit of reduced ecological impact. They distinguished two levels of analysis: the level of the regional industrial system (collection of firms located in proximity to one another) and the societal level (diffusion of industrial symbiosis, including philosophy and practice). More recently, Boons, Chertow, Park, Spekkink and Shi (2016, p. 4) specified seven types of industrial symbiosis dynamics, characterized by initial actors, their motivation, overall storyline and typical outcomes.

The aim of the paper is to explore the social context and the learning process of the Industrial Symbiosis (IS) to offer insights into the complex interactions between actors and organizations. The fact that industrial symbiosis seeks to optimize the material, energy and waste flows by acting on biophysical and economic dimensions of sustainability, should not make us forget that there are social key drivers that facilitate this pathway. We will refer to an empirical case study, the By-Product Synergy (BPS) project at Altamira-Tampico (Mexico). We argue that the IS is more than a simple group of stakeholders taking managerial decisions in a collaborative platform, this network involves the will of firms connected to events and historical commitments. The interactive learning process documented in Altamira suggests that embeddedness in the IS can heighten learning and innovative while decreasing transaction costs and increasing flexibility.

Three questions served as a guideline: What is the social context in which material and energy flows are produced and exchanged? How this social context affects the functioning, the organization and the future of the IS? What recommendations should be made to business companies or public actors to facilitate the transfer and learning process? To challenge them, we will outline the paper in four sections. First, we will provide a literature review on the dynamics of industrial symbiosis. Second, we will present the context and the history of industrial symbiosis at Altamira. Third, we will introduce the methodology of the case study. Fourth, we will analyze the results and the discussion of the industrial symbiosis dynamic at Altamira.

Literature review on Industrial Symbiosis Dynamics (ISD)

In a recent paper titled "Industrial Symbiosis Dynamics and the problem of Equivalence, proposal for a Comparative Framework", Boons, Chertow, Park, Spekkink and Shi (2016) used collective experiences of collaborative research efforts in North America, Europe and Asia to propose a theoretical framework to drive a comparative analysis to a global level. What they called the *problem of equivalence* would reflect the difficulty of finding concepts that identify equivalent empirical phenomena in different countries. Their research lead them to consider that industrial symbiosis has to be conceived as a process, a sequence of events which can be viewed as social mechanisms. This approach of industrial symbiosis dynamics tries to understand how the process of industrial symbiosis unfolds and spreads within a network of actors.

This question is central, Lambert and Boons (2002, p. 473) had put forward the hypothesis that the process (of sustainable development) consisted of a continuous stream of smaller co-operative efforts through which a group of actors advanced its understanding of how to assess social, economic and ecological aspects of their decisions in an integrated way. If ideally, each of the co-operative efforts contributed to the further development of the group of actors towards sustainability, Lambert and Boons noted that in practice, two problems prevented the materialization of the process: (i) If it's relatively easy to initiate in the short-term, social changes often come back into their old patterns. The embeddedness in an institutional and rigid context would explain this situation and the actors need to be involved in the changing process. (ii) Change is often incremental and is more linked to system optimization rather than system change, so, it's important to find the leverage points able to balance the existing system. For Lambert and Boons, industrial symbiosis would offer the opportunity of implementing these insights. Few elements could drive the system: (1) the goal, is not only to reach environmental targets, it's necessary to improve social, ecological and economic dimensions of sustainability (Diemer, 2013). (2) If the continuous appraisal of the system is important, a strategic vision to match operational implementation is essential. We could summarize this idea by the phrase "thinking global, acting local" commonly used in the jargon of sustainability. (3) There is a need to connect social and technological issues. Trust, commitments, collaboration and communication must be compatible with technological frontiers (each individual firm has to identify and follow his own technological pathway, there is no global strategy for all the actors of the global system). Lambert and Boons (2002) insisted in their conclusion setting two major types of industrial park: mixed industrial parks and industrial complexes (where industrial symbiosis belongs to), focused on the optimization of material and energy flows, however connection between biophysical exchanges and social relations is a necessary but not sufficient condition to improve the dynamic evolutive process of the symbiosis.

Boons and Berends (2001), Baas and Boons (2004) presented an interesting theoretical perspective suggesting how the emergence of industrial symbioses based on win-win situations between firms could lead to an organization strategy embracing industrial development (Diemer, 2017). The analytical framework begins by a static approach to system boundaries (sector of industry, product chain, regional industrial system) and proposes to focus on changes that influence the system. In dynamics issues, the authors argue that regional system "may be forced to grow in terms of activity numbers, and actor's diversity" (2004, p. 1075). Life cycle (network's evolution), learning network, collective facilities outsourcing, community development or innovations justify the adoption of changes which can follow the three following stages. The first stage, *regional efficiency*, is described as autonomous decision-making by firms and coordination with local firms to decrease inefficiencies (utility sharing). The second stage, *regional learning*, is based on mutual recognition and trust: firms and other partners exchange knowledge and broaden the definition of sustainability on which they act. The third stage, *sustainable industrial districts*, shows further evolution towards a strategic vision and collaborative action rooted in sustainability[1].

This analytical framework helps to analyze regional industrial systems (Boons, 2008) cases and to figure out the different alternatives to close loops (central planning, governmental agencies or self-organization market), without disregarding the structure, function and evolution of the regional industry. Ashton (2009) integrated insights from industrial ecology and economic geography with complex system theory to identify external forces and interactions among different actors. Ashton (2009) introduced economic geography to examines the reasons for the concentration of industries in certain regions, the organizational dynamics among businesses and the advantages for companies and human population. Using Porter's typology (1990), he insists on four sets of forces driven the success of a region: (1) *company strategy, structure and rivalry*, which determine how companies operate and interact with each other; (2) local market demands, which influence the quality of goods and services produced; (3) *the availability of factors of production*, as natural resources, labor, capital and infrastructure to meet supply needs and (4) the existence of related industries and institutions that support the core industries. The organizational structure of the regional industry results from these economic forces but also from social forces that define what are the acceptable norms and practices. Complex system theory is useful to consider interactions between actors at multiple levels and to examine how those interactions shape and change system structure and functions (Holling, 1987, 2001). Thus, Ashton considers that regional industrial ecosystem may be conceptualized as complex adaptive systems with diverse self-organized subsystems (including firms at one level and managers at another), with multiple connections among them and the ability to learn and adapt to external or internal changes. His case study – Barceloneta, Puerto Rico – integrates economic and ecological attributes that characterize the structures and functions in a regional industrial ecosystem. Industrial symbiosis is introduced as a strategy from managers in response to changing regulations, awareness of common problems and economic feasibility. All these arrangements provided collective strategy for treatment of wastewater or solvent recycling. The evolution of the industrial symbiosis is conceptualized within an adaptive cycle in complex system, resilience is a key driver to fight against perturbations and disturbances. This framework is interesting but we identified two limits:

(1) Study the evolution of industrial symbiosis doesn't mean representing its dynamism. We need to use here another form of complexity, a methodology introduced by Forrester (1961), *Industrial Dynamics* (or *System dynamics)*. System Dynamics is a form of computer simulation modeling which uses the concepts of information feedback and state variables to model social systems and to explore the link between system structure and time-evolutionary behavior (Forrester, 1968). To model the dynamic behavior of a system, Forrester (1969, p. 12) proposed to recognize four structural features: (i) Closed boundary around the system; (ii) Feedback loops as the basic structural elements within the boundary; (iii) Level (state) variables representing accumulations within the feedback loops; (iv) Rate (flow) variables representing activity within the feedback loops. The system dynamics purpose is to explain behavior by providing a causal theory, and then to use that theory as the basis for modeling and designing intervention policies into the system's structure, which then attempts to change behavior and improve performance (Lane, 2008). Thus, the evolution of industrial symbiosis may work out the reinforcing or balancing loops in the system (Sterman, 2000; Coelho, Morales, Diemer, 2017).

(2) If resilience assumed that industrial symbiosis is part of a system of ecological and economical interactions, Ashton (2009) used the first definition of resilience (Holling, 1996). This definition refers to stability close to equilibrium, resistance to disturbance and time taken

[1] Chertow (2007, p. 23) notes that it's not clear that the third stage sustainable industrial district is coming any time soon as nor that a strongly collective orientation will ever fully fit with the other imperatives of firms.

by a system to return to the equilibrium area. Holling (1996, p. 33) called it "Engineering resilience". There is a second definition of resilience which highlights conditions far away from any equilibrium. Instabilities can move the system towards another behavioral regime, that is, in another domain of stability (Holling, 1973). Thus, resilience is measured by the maximum intensity of disturbances the system can absorb without changing structure, behavior or regulatory process. Holling refers to this as "ecological resilience". This last definition implies analyzing the maximum disturbance one symbiosis can bear to without changing its operating system or organizational structure. For us, it's a pillar of strong sustainability (no substitution between natural capital and artificial capital, which reinforces the concept of industrial district).

More recently, Boons, Spekkins and Mouzakitis (2011) proposed to conceptualize industrial symbiosis as a process, even if that typology has changed afterwards (Boons, Spekkink, Muzakitis, 2011; Boons, Chertow, Park, Spekkink, Shi, 2016), we consider it relevant for this study, because dynamics is analyzed through two levels of analysis. At the first level, they insisted on the proximity of industrial relationships (Jensen and alii, 2011). They used the concept of regional industrial system (RIS) defined as "a more or less stable collection of firms located in proximity to one another, where firms in principle can develop social and material/energy connections as a result of that proximity" (2011, p. 907). Local authorities and other actors (consumers, citizens, NGOs…) can get involved in the symbiosis project and increase the viability of the regional industrial system. Industrial symbiosis is connected to eco-industrial parks or industrial clusters. They pointed out that, although geographic proximity is important to industrial symbiosis (Ehrenfeld, Chertow, 2002), it is not the only condition of resource exchanges (Wu, Qi, Wang, 2016). The industry success also depends on trust and social network developed by the agents' community. Boons, Spekkins and Mouzakitis (2011) introduced the concept of *institutional capacity building*, developed by Innes and Booher (1999). Institutional capacity building is "*an array of practices in which stakeholders, representing different interests, come together for face to face, long term dialogue to address a common concern issue*" (1999, p. 412). Three forms of institutional capital may reinforce the industrial symbiosis: (i) knowledge resources (availability and sharing of knowledge), (ii) relational resources (embeddedness of agents in social networks), (iii) mobilization capacity (structure and means to induce knowledge resources and relational resources). At the second level, they tried to understand how industrial symbiosis spreads in society, this dissemination is the result of innovation's transmission and its underpinning effect in the social context, which highlights the ability of the system to adapt to its environment and at the same time change its environment. Boons, Spekkings and Mouzakitis (2011) proposed a list of transmission mechanisms that are responsible for the diffusion of industrial symbiosis : (1) constraint, an organization is forced to adopt the routine rules of another organization that holds power within the symbiosis process; (2) imitation, an organization may adopt routines and operating procedures as a result of observing the practices of other organizations, for statutory reasons or because the practices provide a response to uncertain situations; (3) governance of private interests, organizations may choose to collectively adopt a rule or routine due to the threat of legislation; (4) public initiatives, political actors can initiate experiences and practices and then disseminate the results in the form of "good practices" to accelerate public acceptance; (5) training and professionalization, from training, people can learn new concepts and techniques; (6) altering the conditions of boundaries, actions are intended to stimulate the actors of regional industrial systems in a self-organizing way. These mechanisms seem to play a key role in the conception and the diffusion of the industrial symbiosis, they open a very large research field as the historical transition of socio-relational, organizational and cultural issues.

Firstly, these mechanisms may update the definition of industrial symbiosis in a social approach (Lombardi and Laybourn, 2012) by stipulating that "Industrial symbiosis engages diverse organizations in a network to foster eco-innovation and long-term cultural change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs and improved business and technical processes" (2012, p. 32). Organizational sociology examines how social forces drive structure and forces the interactions among groups (Scott, 2004). Studies in that area are focused on how shared beliefs, values and norms develop a social system and how these, in turn, influence the organization's behavior and function. So, the industrial ecosystem may constitute a new organizational field, where new norms will emerge, including communicational structures among different industries, considering traditional wastes as potential raw materials through the institutionalization of mechanisms for collaboratively resources management (Jacobsen, 2005). Social structure patterns induce repeated interaction among actors, usually symbolized as networks, where actors are represented by nodes and ties depicts connections between them (Ashton, 2008).

Secondly, these mechanisms enounced in the Table 1 may help us to build a typology of Industrial symbiosis dynamics, characterized by initial actors, actors' motivations, overall stories and typical outcomes. Boons, Chertow, Park, Spekkink, Shi (2016) introduce seven categories that could generate a symbiotic network: the self-organization, the organizational boundary change, the facilitation-brokerage, the facilitation collective learning, the pilot facilitation and dissemination, the government planning, and the Eco-cluster development.

Table 1: Seven types of industrial symbiosis dynamics

Dynamics **Typology**	**Initial actor(s)**	**Motivation of the initial actor(s)**	**Following actions/overall storyline**	**Typical outcomes**
Self-organization	Industrial actor	See economic and/or environmental benefits from IS	Industrial actors expect benefits in developing symbiotic linkages→ industrial actors search for suitable partners (existing partners in vicinity or new partners attracted from further away) → after finding a suitable partner, contracts are negotiated→ linkage becomes operative→ [repeat]	Agglomeration Hub-and-spoke network Decentralized network
Organizational boundary change	Industrial actor	Eco-efficiency and business strategy	An industrial actor expands its activities through vertical integration and develops internal exchanges→ the industrial actor changes its strategy from vertical integration into outsourcing→ the linkages remain and the system evolves into an interorganizational network	
Facilitation-brokerage	A public or private third-party organization	Enable firms to develop tacit knowledge and exchange experiences	A facilitator picks up the concept of industrial symbiosis from existing examples → the concept is translated into specific regional context→ industrial actor and facilitator engage in collaborative learning to develop symbiotic networks.	One-off network of symbiotic exchanges
Facilitation collective learning	A public or private third-party organization	Enable firms to develop tacit knowledge and exchange experiences.	A facilitator picks up the concept of industrial symbiosis from existing examples → the concept is translated into specific regional context→ industrial actor and facilitator engage in collaborative learning to develop symbiotic network	
Pilot facilitation and dissemination	A public or private third-party organization	Learn from nonlocal existing IS cases and experiment in a local context	A facilitator picks up the concept of industrial symbiosis from existing examples → the concept is translated into specific national/regional context→ groups of colocated industrial actors are selected to serve as exemplary cases→ further refinement of the concept occurs through learning in pilot projects→ the experiences from pilot projects are transmitted by the facilitator to other groups of collocated industrial actors.	Diffusion of IS concept among clusters
Government planning	Governmental actor(s)	Learn from existing IS cases and implement	A governmental actor picks up the concept of industrial symbiosis from existing examples → the concept is included in policies and translated to the specific national/regional context→ the governmental actor develops a plan for the development of linkages through stimulating and/or enforcing policy instruments→ the progress of implementation is monitored→ the results of evaluations are fed back into the policy to realize continuation/renewal/closure	
Eco-cluster development	Governmental and/or industrial actors	Innovation, economic development	Local governments and/or industrial actors develop a strategy for the development of an eco-cluster→ symbiotic linkages are developed through participatory process among multiple stakeholders as part of the broader eco-innovative strategies.	Redevelopment Brownfield development Greenfield development Innovation cluster

Source: Boons, Chertow, Park, Spekkink, Shi (2016, p. 5)

Every category has its own dynamic. For example, the dynamic of self-organization describes the development of symbiotic activities because of the self-motivated strategies of industrial actors. These actions are driven by individual industrial actors and occurred within an institutional context (level of trust, social norms, regulation's policy…). Kalundborg and its forty years of improving the synergies, is a good example. The dynamic of Eco-cluster development describes cases where different local actors (local government, firms and interest organizations) come together around the goal of achieving economic development and/or technological innovation, and IS is implemented as part of that developmental strategy (Boons and Alii, 2016). A participatory process seems essential to resolve any problem, conflict or discussion between actors and to engage them into a cluster of companies.

Taddeo, Simboli, Morgante and Erkman (2017) compared the dynamics of industrial symbiosis and the main characteristics of (regional) industrial clusters. Three study cases (chemical, automotive and agri-food industries) located in the Italian Region of Abruzzo were described. The authors considered that the most significant factors influencing the development of an industrial symbiosis arise from different life-cycle stages. The design of the framework refers to three stages: (i) current state of the context (structural factors as the nature and the characteristics of the processes and the material and energy flows); (ii) previous state of the context (factors and forces that are embedded in people and organizations: culture, experiences, knowledge, roles, rules, routines); (iii) future potential state of the context (perception of the local stakeholders, on future effects/potentials benefits). From the three previous study cases by Taddeo et al. (2017), the following key drivers are settled as geographical and technical requirements (strategic location, resources availability and the utilities presence in the industrial site); homogeneity / heterogeneity of industries (number industries and processes involved in the industrial symbiosis); active participation of stakeholders (local governments, agencies, key actors, communities); regulatory system (environmental legislation and standards). In summary, the structural factors that play the more relevant role in the industrial symbiosis development are: proximity of production plants, infrastructure, utility and service's availability, the wastes' volume and homogeneity, the limited presence of hazardous materials and the willingness of companies and stakeholders (Taddeo, Simboli, Morgante, Erkman, 2017).

To conclude on this part, we will say that the dynamic process of industrial symbiosis reviewed in this paper attempts to extend the works of Baas and Boons (2004), Boons and Grenville (2009), Boons, Spekkink and Mouzakitis (2011), Boons, Chertow, Park, Spekkink and Shi (2016), Taddeo, Simboli, Morgante and Erkman (2017). We identify stages of construction, type of actors and underpinning motivations in the industrial symbiosis, supporting our results through the evidence found in the Altamira case study. The stages that we present as a conceptual framework are those proposed by Baas and Boons (2004): Regional efficiency, Regional learning and Sustainability of industrial districts. However, we included another stage just before the Regional efficiency, called Emergence. We have sought to re-embed biophysical exchanges (stocks and flows of materials and energy) in the social system (Diemer, 2012, 2017). The *Social Embeddedness of Industrial Symbiosis* (Boons and Grenville, 2009) may be useful to address some key questions: how is the social context in which exchanges of material and energy flows are produced? Why does this social context enable or constrain transformation in production, exchange and consumption? What role do local and public authorities (municipalities), citizens and other organizations play in the occurrence and performance of industrial symbiosis? We introduced the two levels of social process in the evolution of industrial symbiosis – level of regional industrial system (RIS) and societal level (SL) – proposed by Boons, Spekkink and Mouzakitis (2011), even if the analysis of routines and norms was not completely done. We suggested that social mechanisms introduced by Boons, Chertow, Park, Spekkink and Shi (2016) to provide a typology of Industrial Symbiosis Dynamics could be helpful to illuminate our comprehensive overview of the Industrial symbiosis (IS) process, offering an historical analysis of its evolution.

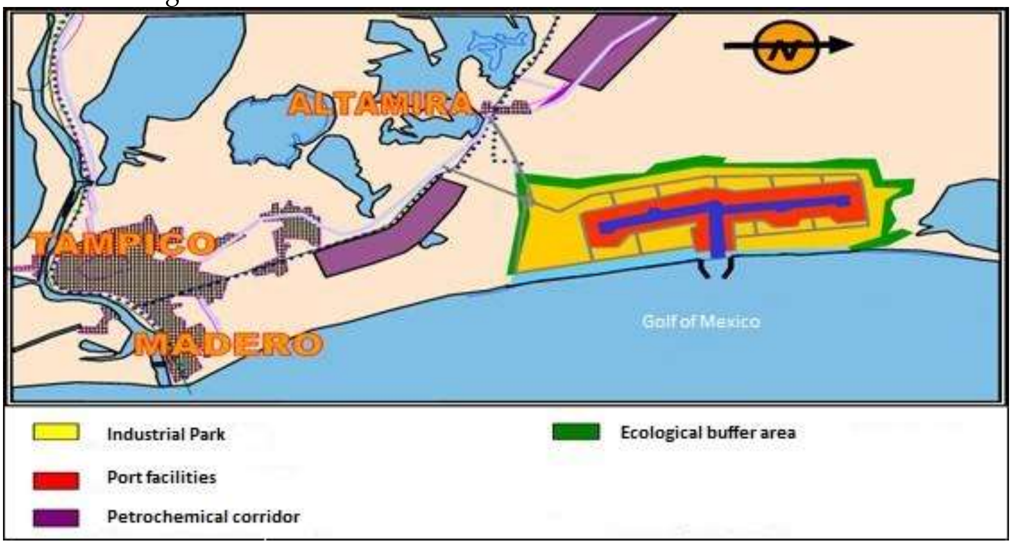
Case study context and history

The example of Kalundborg (Denmark) started in the 1960's, is often described as the success story of industrial symbiosis (Branson, 2016, Jacobsen, 2006), after this uncovering industrial symbiosis example other symbiotic projects emerged in the 1990's like the by-product synergy (BPS) project in Altamira (Mexico), started in 1997 by the Business Council for Sustainable Development for the Gulf of Mexico (BCSDGM[2]). From Mangan and Olivetti (2010), BPS is the matching point of undervalued waste or by-product streams from one facility with potential users to another facility, to create new revenues or savings with potential social and environmental benefits. The BPS process aims to provide manufacturing facilities with opportunities to reduce pollution and save money and energy by working with other plants, companies and communities to reuse and recycle waste materials.

Altamira-Tampico, Industrial Corridor Framework

Because of its strategic location, the Altamira-Tampico area in the state of Tamaulipas is one of the most important coastal commercial zones in Mexico. It has more than 30 companies with international links to more than 55 countries worldwide. The largest entities that foster the region's economy as presented in Figure 1 are the Madero Refinery, Altamira Industrial Park, the Altamira Industrial Port, the Petrochemical corridor and the Industrial Association of Southern Tamaulipas (AISTAC). For Altamira, the goal of the BPS project was "to promote joint commercial development among economic sectors so that one industry's wastes became another industry's input" (Young, Baker, 1999, p. 459). Promoted by the BCSDGM the Altamira BPS project aimed at its early stages to identify a minimum of five synergies, foster greater understanding of eco-efficiency, and create a new community of companies with greater industrial leadership.

Figure 1. Location of the Altamira Industrial Port Cluster



Source: Altamira Industrial Port (2005)

The Madero Refinery is one of the industrial complex's vital organs, with an annual capacity of 7.5 million tons of crude oil and refined products. The refinery is adding catalytic gasoline

[2] From Mangan and Olivetti (2010), the BCSDGM was subsequently established in 1993, comprising a non-profit organization of business leaders sharing the belief that businesses success is measured increasingly by their contribution to economic, social and environmental sustainability.

desulfurization plants, amine regeneration units and utilities. The refinery was upgraded and modernized between 1999 & 2002 to substantially reduce air and liquid emissions and surface water consumption. It also helped satisfy growing regional demand for unleaded gasoline to meet Mexican environmental regulations, assisted Mexico's electric sector in shifting consumption to natural gas, increasing light fuel production and expanding refining capacity. The project was supported by EX-IM bank in the United States.

The Altamira Industrial Park represents the strategic integration hub in the region. The cost-benefit ration overwhelmingly favors large scale production companies and long-term investment. Approximately 500 hectares have been prepared with all basic services, such as water, electricity, gas and roadways and they were made available. The Altamira Industrial Park contains around 20 large private companies (BASF Mexicana, Biofilm, Flex America, Absormex, Dypack, la Esperanza, Fletes Marroquin, MASISA, Iberdrola, Kaltex Fibers, Mexichem, Polioles, Posco Mexico, Sabic Innovative Plastics Mexico).

Altamira Industrial Port, is one of Mexico’s preferred trading port, built in 1980, its strategic location, only 500 km from the US border, as well as from the main economic centers in Mexico, allows for speedy access to any market in the world. The port uses only 30% of its total area of 3,000 ha and moves more than 6 million tons through the port every year.

Altamira Petrochemical Corridor counts several multinational corporations that represent nearly 25% of private petrochemical industry in Mexico and produce almost 60% of all exports in basic petrochemical products (CRYOINFRA, INDELPRO, M&G Polimeros Mexico, Chemtura, McMillan, DUPONT, DYNASOL, CABOT, Enertek and Petrotemex). The starting point of the petrochemical corridor was in the 1970´s with the establishment of the firms Dupont, PETROCEL and Hules Mexicanos. Furtherly stimulated by the construction of the Altamira trading port.

The Southern Industrial Association of Tamaulipas (AISTAC), is an organization funded at the beginning of the 1980´s, it represents some of the largest companies of the South of Tamaulipas state area and acts as a link between industry, community and local authorities. The AISTAC’s origin is strongly linked to the Altamira Petrochemical Corridor´s development.

As pointed out by Frosch and Gallopoulous (1992), the analogy between industrial and biological ecosystems is not perfect, much could be gained if the industrial system emulated the best characteristics of the biological analogy. Altamira’s industrial corridor operates as an open system subject to the entrance of energy: the petrochemical industry that processes a high flow of non-renewable fossil fuels, when they start to sough for a recovery and recycling strategy. Nevertheless, the economic, social and environmental benefits, according to some analyses, are still limited.

Historical outline at BPS Altamira - phases and typologies

The historical understanding of industrial symbiosis is based on combined biophysical, social and economic dimensions which are associated with four different phases and typologies of industrial symbiosis depicted in Table 2.

The first phase - the emergence phase - (1997-2006) is linked to the starting point of the By-product Synergy (BPS) Project represented in the Industrial symbiosis typology of “Facilitator – brokerage” (Boons et al., 2016) because at that moment most key petrochemical companies in the area were associated with/members of AISTAC. Of the 21 companies that participated in this project, 18 were members. The motivation of the stakeholders was the tipping point for organizational improvements and synergies development between firms. The BPS project was perceived as a high potential opportunity mainly because of the geographical proximity. Other positive factors like the existence of the AISTAC with its over 20 years of experience, the common environmental concerns shared by the companies, the companies' collective interest in identifying cleaner and more efficient processes, and the leadership of Mr. Prieto among the business members pushed the companies through the creation of high quality "commodity" and cost reduction processes, looking for collaborative efficiency improvement. Because of the first phase, the BPS identified a total of 373 material flows, the atmosphere of trust was strengthened and great enthusiasm was generated to cooperate in the project. From the output fluxes 120 were wastes from 78 different materials and 54 were final products, semi-finished products and by-products. The wastewater, CO_2 and CO represented the larger amount with 44820, 44400 and 26720 ton / year respectively (Carrillo, 2007). In the first stage, the WBCSD-GM did not go deep into the social dimension, even though the key actors' roles were underlined in the emergence of industrial symbiosis.

The second phase is the Regional efficiency (2007-2010) of industrial symbiosis, maintaining the "Facilitator –brokerage" type of industrial symbiosis practically without relevant changes, except by the fact that the main motivation of initial actors was the eco-efficiency instead of the transparency and the willingness for coordination in the form of inter-firm cooperation. This phase was characterized by the participation of 18 founding firms (members of the AISTAC), the research and education institutions as the Analysis and Socioeconomic Management Organization (AGSEO) at the Metropolitan Autonomous University and the Industrial Ecology Research group (GIEI) by the National Polytechnic Institute. The supporting role of the research educational institute heighten to reproduce the number of synergistic exchanges in the IS project and foster the innovation, technological, communicational and organizational skills necessary to enhance the performance of the network. On this phase the main outcome was the industrial metabolism analysis developed in the Altamira group, where 29 material fluxes were identified, together with 63 potential symbiotic exchanges. After a technical and economic viability study only 13 of those proposed exchanges were undertaken, attending efficiency gains of 44820 wastewater, 44400 carbon dioxides and 26720 carbon tons a year (Carrillo, 2005; BCSD-GM, 1999). Other sources of development were the regulation pressures implemented by public agencies and other side institutions which fostered Mexico's environmental policy and the adoption of more developed environmental strategies. Some of the research questions formulated during this period time were: Which factors assure the good performance of a byproduct strategy? What kind of firm can participate in a symbiosis strategy? What are the current firms' incentives to integrate this material and energy synergic dynamic?

The third phase was the Regional learning (2011-2015), where the evidence suggested a turning point of industrial symbiosis typology throw "Facilitator collective learning" where six of the firms become engaged in a collaborative learning process to develop a more symbiotic network dealing with the two main problems in the sought for sustainability. First, firms discovered that it is relatively easy to achieve superficial, short-term social change, but social actors tend to fall back into their old patterns of behavior over the long term due to their embeddedness in an institutional context. Second, firms found that to ensure the system's structural change rather than system optimization, changes need to emerge from the current system. Thus, every actor needs to be involved in the changing process, role that has been performed by AISTAC (as a facilitator on inter firm negotiations and agreements). The self-adaptive changing processes has led to a permanent state of learning, facilitated by the AISTAC communication and couching skills developed. The material flow synergies were reduced to 241 seeking to determine the conditions to establish a resilient industrial symbiosis, stressing the feeling that the main motivation in the Industrial symbiosis at that phase was the resilience of the system, because even with a decreasing number synergy (in volume and transaction value), the resilience sought to be improved in the process through the diversity and redundancy of activities and actors involved in the BPS network. A change toward sustainability is difficult to achieve in Altamira petrochemical BPS due to actor's divergence of interests, contending technologies and by products, which makes companies' synergies particularly difficult. The fact that Altamira's synergies are restricted mainly to ancillary process, is one of the evidence of the vulnerability of the industrial symbiosis, supported also by Rotterdam IS analysis by Baas et al. (2004).

Finally, the current phase (2016 up to present), is under construction, with the commitment of 15 firms fostering the engagement of new participants in the network even if they don't belong to the AISTAC. The decision is between maintaining a shrinking Regional learning or to endeavor an overarching industrial symbiosis outlook known as the Sustainability of Industrial District (2016). This decision relies on the managerial decisions and willingness of the stakeholders to extend the scope of the ISN to a larger scale (local or even regional) through the Eco-Cluster development, encouraged by a declining current situation in the volume and transaction value of synergies, partially attributed to the decreasing marginal efficiency of environmental actions detailed by Boiral (2005). Even when the adaptability and flexibility motivation are collectively attended in the final phase; at one moment, the ISN cannot be restricted to biophysical flows (313 material flow synergies) because of the global and interconnected dimension that industrial symbiosis brings to the social dimensions of industry's ecosystem. In this phase, the importance of social dimensions and qualitative data is undeniable. Altamira municipal government contribution is necessary to develop a strategy for the development of an eco-cluster with a broader scope of firms including small and medium firms as potential stakeholders of the Eco-innovative strategies.

Table 2. Four phases of dynamic evolution at BPS Altamira, characterized by typology, motivations, initial actors and overall the storyline

Dynamic Phase	IS type	Motivations	Initial actors	Overall storyline and outcomes
Emergence (1997-2006)	Facilitator - brokerage	Interfirm organizations and transparency	Business Council for Sustainable Development for the Gulf of Mexico (BCSDGM)	- The early stages of a market for industrial symbiosis development - 21 companies engaged in the project identifying 373 potential material flows: 199 inputs and 174 outputs, the atmosphere of trust was strengthened and great enthusiasm was generated to cooperate in the project.
Regional efficiency (2007-2010)	Facilitator collective learning	Eco-efficiency and environmentally friendly practices	The BPS 21 firms at Altamira project and the AISTAC	-63 more potential synergies identified by the research groups and stakeholders. -Inclusion of the research community -Increasing of environmental pressures and regulations from government. -By-product reutilization and decreasing wastes expected.
Regional learning (2011-2015)	Facilitator collective learning	Resilience	The six most engaged firms in the BPS Altamira project and the AISTAC	-Decreasing number of biophysical exchanges and in the value of this transactions. Only two new byproduct exchange projects developed by INDELPRO and CABOT. - Industrial symbiosis limited to ancillary products and not related to core activities and processes.
In an early phase of definition of the Sustainability of industrial district (2016 up to now)	Eco-Cluster development	Adaptability and flexibility	BPS Altamira current members, AISTAC, external participants and local authorities	-Decreasing marginal efficiency of environmental investments. -Altamira municipal government contribution necessary to develop a strategy for the development of an eco-cluster with a broader scope of firms including small and medium firms as potential stakeholders of the Eco-innovative strategies.

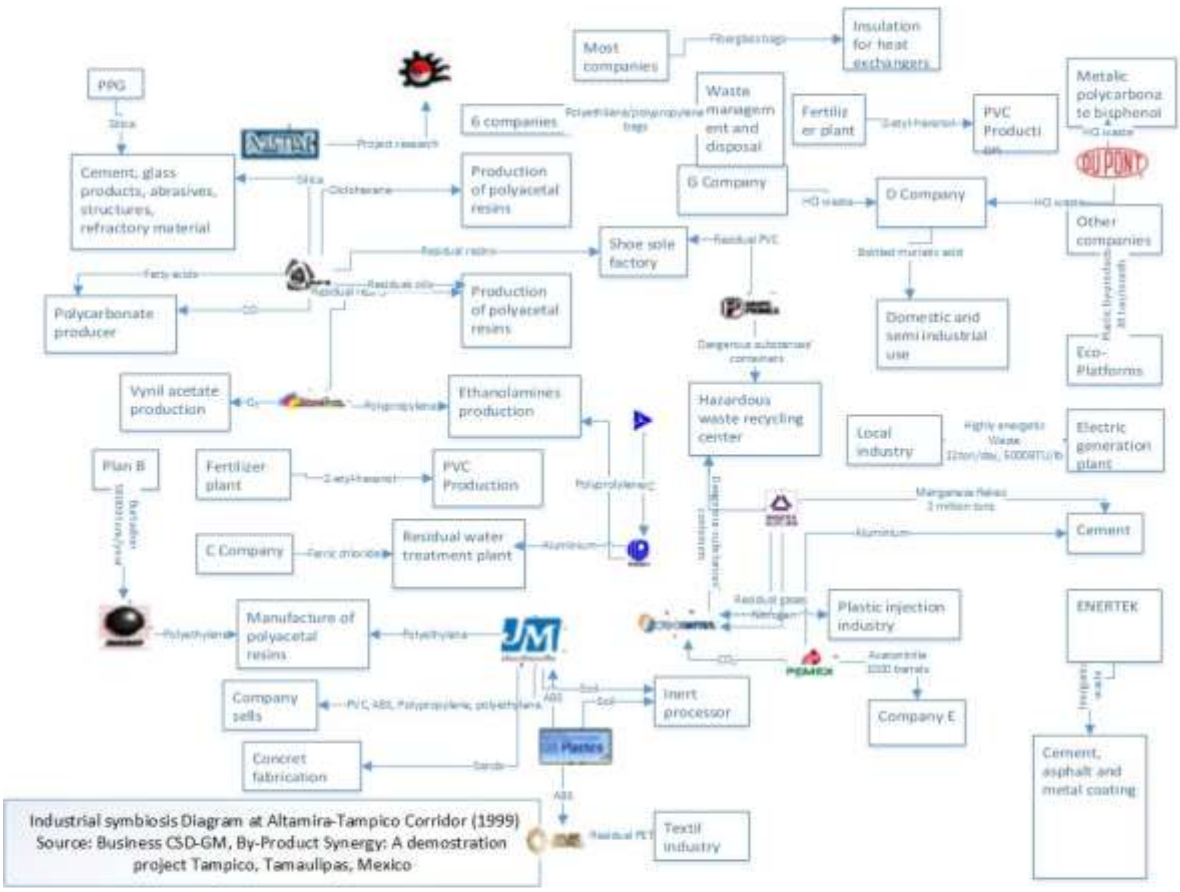
A dynamic methodology for industrial symbiosis analysis

To create a dynamic methodology for industrial symbiosis, which considers the storyline in a comprehensive overview of its organization process, we require a methodology combining the outcome of several research approaches. In what follows, we will refer to the following approaches: (1) the biophysical approach, i.e., identifying and accounting the energy and material flows evolution at the industrial symbioses in relationships within an ecosystem (accounting materials and energy fluxes); and (2) the social dynamic approach, based on the literature review, the author's as well interviews with public authorities, civil society and research and education organizations. The methodology is going to be applied to the Altamira Industrial Symbiosis case study, stressing the overarching potential application to any other industrial symbiosis to analyze the historical organizational process that influence the current situation and structure of the network.

Biophysical approach

In the phase started in 1997, the data gathering was based on a literature review supplied mainly by the World Business Council of Sustainable Development – Gulf of Mexico. According to this review, a material and energy flow diagram (Figure 2) was built to improve material and energy flow accounting.

Figure 2. Material and energy flow diagram built from information provided by the WBCSD



Source: (Lule Chable, Cervantes Torre-Marin, & Carrillo González, 2013)

The previous diagram was the only available data of BPS Altamira, where every company was taken as a black box. The internal processes were confidential: the only information shared was the waste fluxes used as raw materials by other companies through a synergic relationship. The material and energy fluxes were not explicitly described, but a symbolic language was developed at the GIEI to properly describe the Industrial Symbiosis Diagrams by Lule et al. (2010).The data gathering of the regional efficiency and the regional learning phases (phases 2 and 3) were obtained from the available literature review and from the study of Cervantes and Carrillo, described in detail in the book "The industrial ecology in Mexico: achievements, challenges and perspectives" (2013). All this research on BPS Altamira project was nourished by several visits made to the AISTAC, to the main companies linked with industrial symbiosis, and to public authorities, the construction of Synergic Diagrams, depicting existing synergies and proposing further potential synergies.

A regional diagnostic was made with secondary sources and official data to identify the industrial dimension and AISTAC's influence during the second phase. Then the role of the AISTAC was documented by interviewing some members and identifying the existing and potential mechanisms of cooperation.

Social approach

To gather the qualitative data that shed light on the social dimension of the fourth dynamic phases of BPS Altamira project, interviews were conducted to AISTAC key actors, firms' heads and non-profits stakeholders involved in the industrial symbiosis.

In the first, second and third phases of dynamic evolution, the literature review and the Ph.D. dissertation of Carrillo (2006) provide materials to identify social keys into the development of Industrial symbiosis at BPS Altamira project. From the interviews (February 2017) realized with the most engaged firms of the BPS Altamira project (CABOT, Mexichem, M&G Petroquimica Mexico, INDELPRO and INSA), we develop a better understanding about how ideological structures encompassing the biophysical and social dimension could drive firms to use a shared language which might be impossible without exploring the relevance of the political, cultural, ecological and economic dimensions.

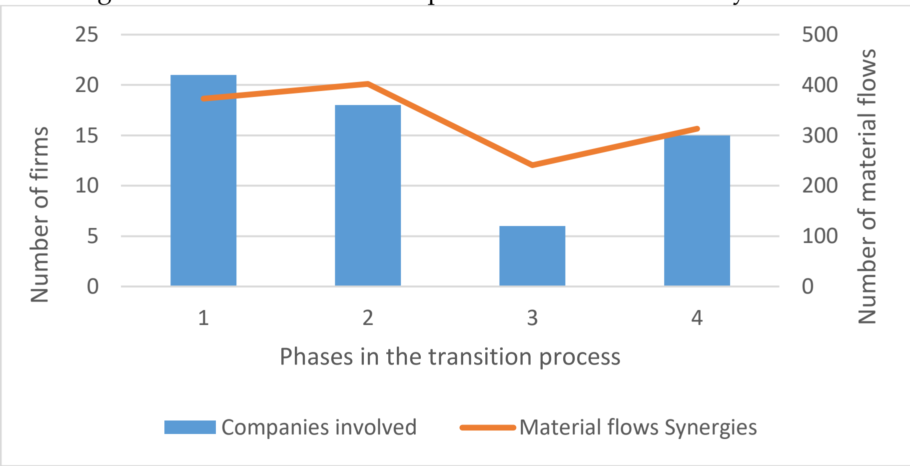
The theoretical framework proposed by Baas & Boons (2004) and the Industrial symbiosis dynamic typology suggested by Boons & al. (2016) provide a dynamic logic of phases in the industrial symbiosis which is used as an input in this study. Both explore the linkages among dynamic typologies that could build the multistage phases model of the BPS Altamira project in an overarching outlook, encompassing economic, social and environmental dimension. Without the dynamic understanding looking back to the stakeholders and regions past story, it will soon become the most tangible example of an inarticulate structure of variables and resources, acting in the short-run and trying to solve problems in day-to-day planning.

We are confident that the identification of motivation, key actors and factors and the overall storyline for each IS will exceed the attended benefits from a dynamic and multidimensional understanding of the industrial symbiosis and could assure the success of the following stages, providing potential organizational strategies, according to the stage of development of the industrial symbiosis, instead of only "end of pipe" solutions based on technology efficiency to partially solve problems.

Results and discussion

We aim to depict the benefits obtained from a comprehensive transitional process analysis in the industrial symbiosis, stating for this purpose three different stages - regional efficiency, regional learning and sustainable industrial district (Baas & Boons, 2004) - and relating them to an underpinning motivation linked to the starting actors and interacting in an overall storyline for the industrial symbiosis network (ISN). So, the understanding of the ISD depict a platform of socio-technical and environmental collaboration under different context, motivations, actors, phases of development and outcomes, thus a better understanding of the storyline will clarify the required organizational strategies and mechanisms to foster managerial skills and stakeholder's motivations to encompass a compelling interactive learning process.

Figure 3: Historical transition process in the Industrial Symbiosis



In the Figure 3, we can corroborate that from the second phase when the marginal efficiency tipping point is achieved the number of firms involved and the number of material byproduct flows in the Industrial symbiosis decreased with time until the third phase of the evolution. According to the data obtained in the interviews, this effect is triggered by the decreasing marginal efficiency of synergic investments. The previously mentioned marginal efficiency reduce the attractiveness of the symbiosis, combining with the fact that the Altamira BPS Industrial Symbiosis is based only in ancillary process in the petrochemical industry. The fourth phase represents a tipping point where the Altamira municipal government contributes to develop a strategy for the development of an eco-cluster. The further Eco-cluster includes small and medium size firms as potential stakeholders of the eco-innovative strategies, increasing through this pathway the synergetic material flows concerned.

Relevant insights were developed, that let us understand what are the concerning mechanisms that determine the attractiveness of industrial symbiosis and the willingness to join the network for a potential firm. Those mechanisms addressing the firms' incorporation to the symbiosis are settled in social and biophysical dimensions. In the social realm we can distinguishing the size of the enterprise, cost criterion; in addition, with a shared language (facilitating communication), organizational skills, environmental values (respect, cooperation, ethic and social responsibility), trust in relative structures, and environmental policies and regulations in Mexico. Then, in the biophysical realm we found the technical resources, available technology and availability of by-products in the Industrial Symbiosis Network (ISN) (Cervantes, 2013; Carrillo, 2013).

AISTAC performance: BPS Altamira project shows that corporate membership in the association incorporates environmental values and pushes further innovation and communication between members, becoming a key driver of synergies' development. In the AISTAC, they have managed to involve company employees in the seek for economic and environmentally efficient alternatives. A method for systematizing exchange, creating trust and encouraging communication among environmental managers was successfully built in Altamira.

The company size was determinant: large, and only rarely, medium-sized companies could make long-term recovery investments.

Environmental values: among the Altamira companies, market positioning and incorporation of environmental policies in their strategies make it easier to invest in current expenditures than to consolidate new projects. Additionally, environmental practices were considered as ethical investments and thus well ranked for funding. In any case, the image of an environmentally friendly/sustainable company is fairly important as it leads to a more positive relationship with the community and environmental organizations.

Cost criterion: It was clear at the beginning that the economic driver would determine the implementation of the identified synergies. Companies are engaged on cost-benefit analysis and market studies related in order to determine their viability, due to the fact that they can obtain the resources as long as it is cost-effective. These companies realized that after the project everybody would get the expected profits, meet recovery deadlines and obtain the economic and environmental benefits.

Technical resources and available technology and by-products: It was found during the project that most of the identified byproducts, as well as the needed technologies, were available and firms counted on the properties required for the transformation and reuse. In the event that the participants were not familiar with the technology, specialists were invited to explain specific processes. However, synergies were achieved where the technology let project participant's move forward in a modernization process or technological adaptation. Failed projects owed their failure to the fact that their byproducts didn't achieve the required technical specifications.

Organizational skills: time availability was identified as an important barrier because of the demands of the work day and other urgent tasks in the company. Despite this, the AISTAC's role in coordination and organization was valuable.

Environmental policies and regulations in Mexico were the largest obstacles to synergies consolidation because of the highly autocratic and centralized public legislation system. In México, instead of an environmental policy that encourages the existing collaborative examples of synergies, a wide legal framework exists and regulates the economical agents' actions. It thus became more and more difficult to comply with the law. This was not the case for large companies because, due to their size, they are very visible, so usually the internal environmental policy of these organizations observes stringently the legislation. Laws, permits and procedures in energy, handling, use and disposal of residues, transportation and recycling have become a serious obstacle for innovation in medium, small or micro enterprises in Mexico.

The industrial symbiosis approached as a process of innovation is not a perfect model, but rather an ecosystem in which interrelationships between different sub-ecosystems have been split by human activities and plans. To imagine a sustainable industry, we need to go beyond input and output flows (the study of metabolism), to get into and reconnect sub-ecosystems. We need to look for broader scopes to reconnect the different sub-systems by studying their interactions and the possibilities for producing symbiosis, and this reconnection could be motivated by the key mechanisms for IS success. The production process as we know it today is a problem, so we need to think about closing larger loops (i.e. in water, energy, material, infrastructure and non-material resources between housing, labor, energy, health, transport, population and the industrial sub-systems) in a sustainable way to reduce the amount of inputs that industry requires to supply their production processes.

Industrial symbiosis is achieving a sustainability related approach and challenging us to think about the evolution of structures in the industrial system. This evolution has been achieved by considering relevant insights as different organization patterns, that are not necessarily new if we look backwards in the history, for example the collaborative /cooperative social structure. This kind of dynamic structure could help us to achieve a better understanding of the social innovations and transition process, its underpinning motivations, mechanisms, actors and typology concerned.

Conclusion

While industrial symbiosis may not be an ideal type/process or a perfect model (case of Kalundborg), it is more an ecosystem in which interrelationships suggest cooperation more than competition and in which environmental, social and cultural dimensions improve success. A historical description was made on their trajectory, environmental capacities, environmental policies, and social and economic aspects Tampico-Altamira's experience shows that enterprise participation/membership in an association that incorporates environmental values, innovation and communication between different members is a key driver in stimulating the development of synergies and providing the dynamics of industrial symbiosis. We believe that industrial symbiosis is the core of strong sustainability in the business model--a kind of socio-ecological strategy which has the potential to significantly reduce the ecological impact of the industrial processes of various large corporations.

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