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The principles of diversity and geographical proximity in an industrial ecosystem: social network analysis in the Toluca- Lerma region
(Principios de diversidad y proximidad geográfica en un ecosistema industrial: Análisis de redes sociales en la región Toluca-Lerma

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Abstract. Industrial ecology allows the traditional model of industrial activity, where individual manufacturing process that takes raw materials in order to generate products, to be transformed into a more comprehensive model of a regional economy named industrial ecosystem. This ecosystem functions through industrial symbiosis alliances formed by firms that cooperate through the exchange of residues in order to use them as inputs to transform them into valuable products. Moreover, the principles of geographical proximity and diversity of the firms have been found in successful ecosystems in developed countries. This study contributes empirically by using social network analysis (SNA) methods to explore, the presence of these two principles in an industrial ecosystem in the Toluca-Lerma region in Mexico, consisting of 30 firms that have industrial symbiosis alliances. We conclude that in the context of developing countries, the symbiotic exchanges may not be fully explained with the principles of geographical proximity and diversity.

Key words: industrial ecosystems, industrial symbiosis, residues, social network analysis, wastes

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Resumen. La ecología industrial permite que el modelo tradicional de actividad industrial, donde procesos individuales de manufactura utilizan materias primas con el fin de generar productos, se transforme en un modelo más completo de una economía regional llamado ecosistema industrial. Este ecosistema funciona a través de alianzas de simbiosis industrial, donde las empresas cooperan mediante el intercambio de sus residuos con el fin de utilizarlos como insumos para transformarlos en productos valiosos. Por otra parte, los principios de proximidad geográfica y diversidad de las empresas, propios de los ecosistemas industriales, se han encontrado en los ecosistemas de éxito en los países desarrollados. El presente estudio contribuye empíricamente, mediante el uso de análisis de redes sociales (SNA) para explorar la presencia de estos dos principios en un ecosistema industrial conformado por 30 empresas con alianzas de simbiosis industrial en la región de Toluca-Lerma en México. Llegamos a la conclusión de que en el contexto de los países en desarrollo, los intercambios simbióticos pueden no ser completamente explicados con los principios de proximidad geográfica y diversidad.

Palabras clave: análisis de redes sociales, basuras, ecología industrial, residuos, simbiosis industrial

Introduction

Solid waste has become a serious problem in developing countries since their inadequate treatment and correct handling, poses a serious threat to both environment and public health (Al-Khatib, Kontogianni, Nabaa & Al-Sari, 2014). Governments and local authorities in these countries are incapable to deal with this problem through regulations because they possess a weak rule of law. In addition to the government incapability, the solid waste generation is escalating (Laurent et al., 2014). Therefore, there is an increasing need to cope with the waste problematic situation in an effective, innovative, and sustainable way (Yay, in press).

Since the beginning of the twenty first century, the world has experience an exponential increase in search for options that allows the firms to be economically profitable while at the same time be able to innovate in order to appropriately use the limited environmental resources (Pauli, 2010). According to Geng and Cote (2007), this concern has given impetus to a new integrated management approach in industry based in industrial ecology (IE), advocating that the firms in the industries could and should operate according to the principles that drive natural systems (Graedel, 1996). In particular, the use of the word ecology is meant to imply that the firms should conserve and reuse resources, as is the practice of the biological systems because they do not know the concept of waste.

Industrial ecology allows the traditional model of industrial activity, whereby individual manufacturing process takes raw materials in order to generate products, can be converted into an industrial ecosystem that optimize resource use through a cyclical vision where the waste generated along their production chain serves as the raw material for another firm (Frosch & Gallopoulos, 1989).

Frosch (1992) stated, "the idea of an industrial ecology is based upon a straightforward analogy with natural ecological systems. In nature an ecological system operates through a web of connections in which organisms live and consume each other and each other's waste" (p 800).

The industrial ecosystem is a comprehensive model of a regional economy, where the firms involved develop partnerships called industrial symbiosis (IS) that allow to physically exchange wastes, residues and/or by-products and innovate in order to transform these wastes into valuable products (Chertow, 2007; Erkman, 1997; Seuring, 2004). Moreover, firms that engage in residues exchanges in the form of industrial symbiosis are thought to be motivated by potential economic and environmental benefits (Chertow, 2007). Therefore in the industrial ecology field, the term industrial symbiosis is vital because it represents the partnerships among different firms in the region that through economic and social benefits start to cooperate in order to assemble an industrial ecosystem capable of optimizing resources.

For the industrial ecosystems it is very important that firms involved in the IS have two key characteristics (Chertow, 2007; Desrochers, 2001; Korhonen, 2005). The first one is that the firms involved have geographical proximity because it allows diminishing transportation costs, therefore increasing profitability. The second is diversity of the firms within the partnership since this allows triggering innovation in the form of new or redesigned technology in order to deal appropriately with the characteristics of the residues that are used as inputs.

After reviewing most of the world-class industrial ecosystems cases available in the literature, we are confident to conclude that the majority of them are present in developed countries (Chertow, 2007; Gibbs & Deutz, 2005; Gertler, & Ehrenfeld; 1996; Jacobsen, 2006; Korhonen, 2001b; Korhonen, Wihersaari, & Savolainen, 1999; Van Beers et al., 2007).

Literature suggests that since industrial ecology is a multidisciplinary field, the methodologies for addressing the phenomenon could vary depending on the study. From qualitative cases of study (Yin, 2009), to a more quantitative tool such as Life Cycle Assessment (LCA) (Suh & Kagawa, 2005), or even hybrid LCA based on combining methods (Bryman, 1984; Johnson, Onwuegbuzie & Turner, 2007) were it involves technical qualitative and quantitative characterization and assessment of the impacts on environment (Keoleian & Garner, 1994). The reviewed previous studies have relied on qualitative methods to derive theoretical and practical insights that have focused more on the technical aspects rather that the social ones (Ashton, 2008). While qualitative interpretations have their merits, their validity is threatened by a researcher's bounded rationality, which includes the difficulty to conceptualize complex phenomena such as networks.

Consequently, due to the relative freedom of applicable methodologies and its corresponding data gathering tools and analyzing techniques, the present research paper examine the industrial symbiosis phenomena by analyzing the structural characteristics of an industrial ecosystems using a formal, quantitative modeling approach based on social network analysis (SNA) (Borgatti & Li, 2009).

The present study contributes empirically to the industrial ecology literature by exploring through SNA methodology the following research question: how the geographical proximity and diversity of the firms relates to the observed IS linkages in the Toluca-Lerma region in Mexico?

SNA is selected as the methodological framework for this study preponderantly by the fact that industrial ecosystems are networks by definition, and also as SNA represents a powerful tool currently being employed in a wide variety of disciplines to examine interactions among different types of actors. SNA have been applied to study interaction of biological populations such as plankton, humans, to non-biological ones such as firms, institutions and even countries (McMahon, Miller & Drake, 2001).

The paper proceeds as follows. In the first section we provide the theoretical framework of industrial symbiosis, the definition, specific characteristics and the relationship with industrial ecosystems. In the next section we present the key social network analysis metrics and the theoretical relationship with the industrial symbiosis in order to generate the hypotheses. Moreover, we describe SNA methodology and how it is applied to industrial ecosystems. Afterwards we describe the results and the corresponding analysis. Finally, we offer our conclusions.

Industrial symbiosis and industrial ecosystems

In natural ecosystems the concept of waste is entirely absent, as all discarded and remaining material is reused within the system; outputs from organisms are almost entirely consumed by other organisms in the system (Pauli, 2010). Human economies, on the contrary, discard a great deal of unwanted material and energy as most systems follow a linear extraction, production and discard approach (Leonard, 2010). Therefore, by using nature as a model it has been possible to notice the emergence of industrial ecology as a framework for identifying ways to extend the life of materials, to make use of undesired materials and prevent waste production (Boons & Spekkink, 2012).

The 'waste is resource' metaphor has proven very attractive for industrial ecologists, and has given rise to another analogy called industrial symbiosis **(IS)**. The IS analogy refers not to a particular organism represented by a firm but to an ecological mutualism where two species cooperate for mutual gain (Norohna, 1999).

Chertow (2000) is one of the most influential authors of the industrial ecology and she defines industrial symbiosis as a strategic alliance between two firms that belong to traditionally separate industries and that through a collaborative approach intend to obtain competitive advantage from the physical exchange of materials, energy, water and/or residues. Moreover, she stated that the keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity among firms. Furthermore, it can be established that Chertow's (2000) definition of industrial symbiosis is very inclusive because it has largely fuelled initiatives to reduce waste output by extending the useful life of residues that are now seen as input resources (Ehrenfeld & Chertow, 2002; Mirata, 2004).

When a comparison is done between the industrial symbiosis and the exchanges related to the geographical economics, then it becomes evident that three type of particular resources exchanges emerge in order to distinguish the IS from other type of alliances (Chertow, Ashton & Espinoza, 2008). The first is infrastructure, which involves the delivery of electricity, gas and wastewater. The second is the join provision of services; this includes the gathering of additional requirements that are not directly related to the core business of the firms such as fire suppression, security or cleaning. The third is the use of wastes generated in the production processes as raw materials in order to obtain a transition from a linear flow into a circular flow.

The industrial ecology conceptualizes an ecosystem as the linkage of ecological mutualism, where two organisms cooperate because the residue generated by one could be used as input for the other (Wright, 2007). Particularly, this perspective establishes that an industrial ecosystem is formed by all of the regional linkages of firms that metaphorically represent the ecological mutualism (Chertow, 2007; Gibbs & Deutz, 2005). Therefore, in this study the industrial ecosystem is conceptualized as the network of firms interacting with industrial symbiosis within a region in which the waste of an entity becomes the feedstock for another.

The opportunities for a firm to develop IS are present in the regions by identifying consumers for their residues, waste and/or by-products. The IS postures is centered on the way that business can gain additional revenue though increased innovation, increased marketability and access to new markets; and realize cost savings from avoided disposal and the reduction of the operating costs (Jackson & Clift, 1998; Chertow & Lombardy, 2005; Mirata & Emtairah, 2005; Jacobsen, 2006).

Erkman (1997) made a comprehensive literature review in which he established that all authors agree on two characteristics that are present in an industrial ecosystem. The first one is that it emphasizes the complex patterns of material flows within the residues use of the industrial system, in contrast with current approaches which mostly consider the economy in terms of abstract monetary units or alternatively energy flows. The second one, it considers technology as a crucial element for the transition from the actual unsustainable linear industrial system to a viable industrial ecosystem where there are many alliances in the form of industrial symbiosis in which residue of one firm becomes the input of another firm.

Additionally, Korhonen (2001a) states that regions with industrial ecosystem have four basic principles. The first is roundput, meaning that the residues can flow in cascade-like fashion in order for the symbiotic firms to use the wastes as feedstock. The second is diversity, which is related to the need of having firms of different industries because this generates distinct wastes that can be exchange. The third is locality, which is associated to the cooperation only between firms that are within the region. The fourth is gradual change referring to the process of adaptation required regarding the amounts and times in which the generated waste can be used.

At this point, it can be stated that the industrial ecosystem is represented by network of IS alliances of firms that are geographically enclosed inside a region and have certain degree of diversity as they belong to different industries. Moreover, from a managerial perspective the industrial symbiosis can be understand as a strategic alliance among already existing firms that are geographically proximate and belong to different industries which exchange residues in order to innovate and use them as inputs for their production processes (Chertow, 2000).

Social network analysis

Chertow wrote a seminal paper in 2007 in which she established that there were six successful cases of industrial ecosystems: Kwinana (Australia), Gladstone (Australia), Barceloneta (Puerto Rico), Kalundborg (Denmark), Guitang Group (China) and Jyvaskyla (Finland). Additionally, she established that these cases were formed through a self-organizing process in which the IS alliances emerged spontaneously from decisions by existing private regional firms that were motivated to exchange residues to meet goals such as cost reduction, revenue enhancement, or business expansion. Moreover, she argued that in the early stages, the industrial ecosystem began with residue exchanges among the firms, and these alliances then faced a market test. If the exchanges were successful, more might follow if there was ongoing mutual self-interest. In particular, according to Chertow, in the early stages there was no consciousness by participants that they were forming an industrial ecosystem, but rather this developed over time.

To date, there have been few studies of real life industrial ecosystems, due to the difficulties of finding a region where the industrial symbiosis are present (Chertow, 2007; Gibbs & Deutz, 2005; Jacobsen, 2006; Korhonen, 2001b; Zhu, Lowe, Wei & Barnes, 2007). Moreover, most of previous research has been qualitative. While qualitative interpretations have their merits, their validity is threatened by a researcher's bounded rationality, which includes the difficulty to conceptualize complex phenomena such as networks. However, there is one study done by Ashton (2008), in which she used the social network analysis (SNA) in order to examine a successful industrial ecosystem case study of the Barceloneta in Puerto Rico. Particularly, she discovered that the alliances of IS are correlated with the relationships of trust between the managers of the firms in the region.

Up to date, there is scant amount of research over the topic of industrial symbiotic ecosystems using SNA methodology. The only record of using SNA for analyzing this phenomenon is the work performed by Ashton (2008) where she analyzed one of the most known IS case in the Barceloneta, Puerto Rico. Ashton's (2008) study showed that the use of SNA is important in order to understand and industrial ecosystem because it allows to study the interactions among actors in the system and linking observed behavior to their relationships. This research established a precedent of the fruitfulness of using SNA into IE related topics.

The SNA is relevant for IS as it provides a supply network perspective enabling to observe that the relative position of individual firms, within the network with respect to one another, influences both strategy and behavior. In this context, it becomes imperative to study each firm's role and importance as derived from its embedded position in the broader relationship structure network (Borgatti & Li, 2009). The importance of SNA in industrial ecosystems lies in the goodness of the methodology to explain the interactions between actors of a network.

SNA is based on the study of networks, which are constructed by nodes (actors) that are linked by ties. Along with the network analysis and the computational foundation in graph theory (Kim, Choi, Yan & Dooley, 2011), SNA analyzes the patterns of ties in a network. These ties represent relationships between two nodes. These relationships could be membership, knowledge transfer, or in the present research the alliance for the exchange of a residue, waste o by-product. According to Borgatti and Li (2009), SNA provide the ability to explore the supply network from another perspective by further understanding the operations within the network and at node level as well. The SNA is vital for understanding the industrial ecosystem because the firms behave as a supply network where the inputs exchanged are residues.

According to Ashton (2008) researchers can use SNA to study the industrial ecosystems in which firms operate. She adds that the SNA should be performed by concentrating on the interactions among actors in the system and relating observed behavior to their relationships that are represented by IS.

Carter and colleagues (2007) identified SNA as a key research method to advance the fields of logistics and supply chain management. Moreover, according to Borgatti and Li (2009), a more systematic adoption of SNA will be instrumental in exploring behavioral mechanisms of entire supply networks. A SNA approach allows understanding better the operations of supply networks, both at the individual firm level and network level. Consequently, the SNA could be applied to the industrial ecosystems where the firms develop alliances in order to form a network that can exchange the residues as supply. In particular, the Table 1 highlights some important terms used to describe social networks in this study.

Table 1. *Social network terms*

Social network term	Description	Example in this study
Node	An actor in the network	Firm
Attributes	The characteristics that each actor has in the network	The industry to which the firm belongs, the physical location of the firm, the type of waste that the firm generates.
Tie	A relationship between a pair of nodes. Actors may share several different ties. A tie can be direct or indirect via another actor and directional.	Among firms: exchanging wastes A→B or A↔B
Dyad	A pair of nodes with a direct tie	A pair of firms exchanging wastes

Note: Authors own construction based on Ashton (2008) and Kim et al. (2011)

Every actor has a position in the network, determined by how each is connected to others. By definition, actors in the center of a network are more connected than those on the periphery. Beyond characterizing the networks and the positions of actors, SNA can be used to determine how certain ties are related to other ties as well as with the attributes of actors (Stevenson & Greenberg, 2000). Consequently, this study tries to analyze the way in which the geographical proximity ties and the diversity ties among the participant firms, are able to represent the industrial symbiosis alliances.

Hypotheses

Korhonen (2001a) states that industrial ecosystems with IS activities among actors must have enough diversity in order to achieve residue exchanges among them. In other words, this means that if an industrial ecosystem tries to emulate a natural ecosystem, then the firms that are willing to cooperate in the residue exchanges in the form of IS must belong to different industries because this allows that diverse types of waste, residues and by-products could be used as input by other firms.

After reviewing six case studies of successful industrial ecosystems of Kwinana, Gladstone, Barceloneta, Kalundborg , Guitang Group and Jyvaskyla, it was possible to observe that diversity was vital in all of them because the regions had participant firms of very different industries that were exchanging residues and transforming them into valuable products (Ashton, 2008; Corder, 2005; Jacobsen, 2006; Korhonen, 2001b; van Beers et al., 2007; Zhu, Lowe, Wei & Barnes, 2007). Therefore, we hypothesize:

H1: *The IS dyadic relations are found when firms of different industries interact in the network*.

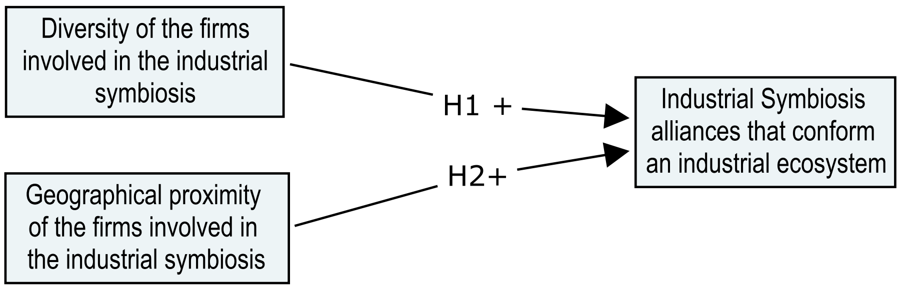
Chertow and colleagues (2008) have established that the alliances of industrial symbiosis are influenced by geographical proximity because the transportation costs will limit the spatial boundaries that are economically viable. In addition, Seuring (2004) indicated that the boundaries are defined by the firms that are within the region and this causes that the flow of the waste must be arranged within that particular network.

After reviewing six case studies of the successful industrial ecosystems, it was possible to observe that geographical proximity was vital in all of them because the regions had participant firms that were located physically closed and were exchanging residues in the form of industrial symbiosis (Ashton, 2008; Corder, 2005; Jacobsen, 2006; Korhonen, 2001b; van Beers et al., 2007; Zhu, Lowe, Wei & Barnes, 2007). Therefore, this study proposes the next hypothesis.

H2: *The IS dyadic relations are determined by the geographical proximity among the firms in the network.*

The two hypotheses are graphically represented in the Figure 1:

Figure 1. *Hypothesis graph*



Note: Authors own construction using CmapTools

Methodology

After reviewing several industrial ecosystems, it is possible to establish that they are mostly center in developed countries (Chertow, 2007; Gibbs & Deutz, 2005; Jacobsen, 2006; Korhonen, 2001b; Zhu, Lowe, Wei & Barnes, 2007). Furthermore, the previous studies have relied on qualitative methods to derive theoretical and practical insights. However, there is one study done by Ashton (2008) that used a quantitative analysis in order to conceptualize complex phenomena such as networks. Therefore, we propose to analyze the structural characteristics of the industrial ecosystems in a developing country, using the formal quantitative modeling approach of social network analysis.

The importance of focusing in an industrial ecosystem in a developing country lies in the fact that as Hobday (2005) mentions, firms in developing countries frequently operate within small, underdeveloped markets and the innovation infrastructure may well be lacking.

Furthermore, Hobday (2005) establishes certain characteristics that particularly apply only to the firms in developing countries. First, they must create new strategies to overcome their sometimes sensitive technological and market disadvantages. Second, to the extent that these firms do not simply follow existing models when competing, then the innovation is possible at the level of strategy, marketing and technology because in many circumstances firms cannot merely imitate the leaders. Third, firms will have its own distinctive resources, capabilities and stage of backwardness. Fourth, it is highly likely the firms must develop its own distinctive strategies based on its own particular resources and residues.

This study is an empirical quantitative research of IE. The sample data was obtained from the National Industrial Symbiosis Program (NISP) of England that funded a pilot of an industrial ecosystem in the region of Toluca-Lerma in Mexico in 2009. Basically, the program invited the firms of the region to participate by giving information about the inputs for the production processes and the types of residues generated. Then the NISP contacted the two firms that could exchange wastes that served as feedstock. Moreover, the present study sample, consists of 30 firms that exchanged wastes or were in the implementation phase in the program.

The sample selection were firms from the NISP given that this assured that the IS was present according to the following definition "the physical exchange of energy, water or waste products from industrial processes" (Chertow, 2000). Furthermore, the Toluca-Lerma region could be considered as an industrial ecosystem because if fulfills Lowe and Evans (1995) definition that an IE is present whenever is possible to find a network of firms interacting with IS within a region in which the waste of an entity becomes the feedstock for another.

To obtain further information regarding control variables in form of attributes of the firms, we used their corporative webpages as a reliable source of information. This allowed us to identify the industry to which the firms belong as well as their geographical location.

The quantitative data analysis was performed with the social network analysis software UCINET 6. The software allows the use a quadratic assignment procedure (QAP) regression and the double deckert semi-partialling method (Borgatti, Everett & Freeman, 2002) in order to test the two hypotheses at the dyadic level.

Additionally, NetDraw software was used to graph the relationships among the actors in the network (Borgatti et al., 2002) as well as to position the nodes according to the similarity in their geodesic distances (shortest path lengths among nodes).

Measurement

I. Dependent variable

The IS relationships found in the region. It is a matrix that contains the waste exchanges done by the 30 firms. Specifically, this matrix is centered in the type of waste (solvents, plastic, cardboard, metal, tires and wood) and not in the amounts of the exchange because the units used in each type of waste are different and the characteristics of the residues are not alike.

II. Independent variables

The first variable is physical location. This was evaluated through a matrix that contains the distances in kilometers between all the firms. Furthermore, it was constructed using Google maps and selecting the shortest possible path in order to be coherent with all of the distances.

The second variable is the industry that each firm belonged because this allows to identify if diversity is present. For recording this variable we used the North American Industry Classification System (NAICS) as proxy for identifying each of the networks' actors industry to which the firm belongs. For the analysis we reduce the five-number NAIC code into a three-number code as it facilitates the visual analysis of the networks. This allowed generating a matrix of exact matches in order to identify if the firms were in the same industry.

Results and analysis

The results are disclosed in two sections. The first one corresponds to the first hypothesis regarding the industrial symbiosis among firms and their diversity. The second explains the relationship of IS with the physical location.

The IS among firms and diversity

The firms were categorized according to their three digit North American Industry Classification System codes (NAICS) and placed in eleven groups as shown in the Table 2.

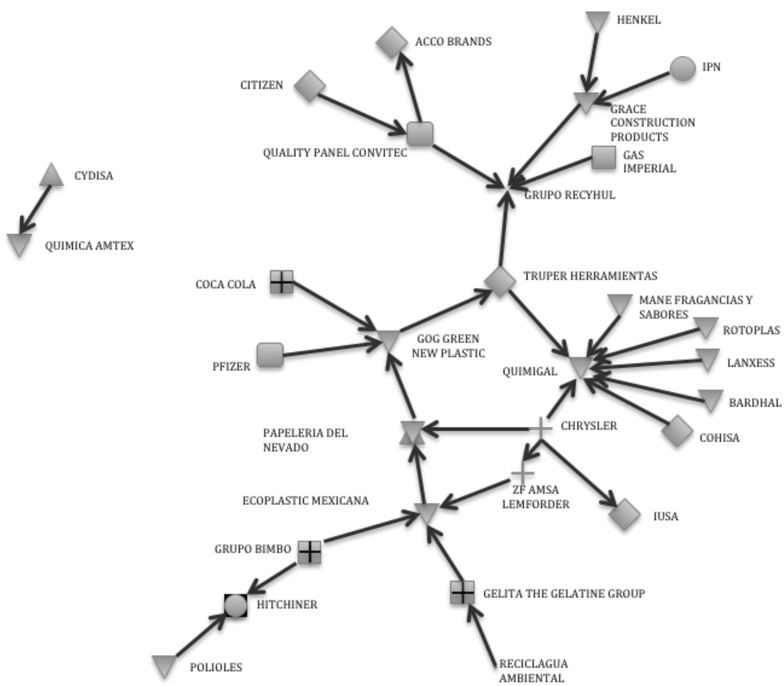
Table 2. *Firm groupings according to NAICS categories*

Group	NAICS	Node Shape	No. Firms
Chemical and plastics manufacturing	325	down triangle	11
Machinery manufacturing	333	diamond	4
Food manufacturing	311	box	3
Waste management and remediation services	562	no shape	2
Pharmaceutical manufacturers	352	rounded square	2
Transportation equipment manufacturing	336	plus	2
Construction	236	up triangle	1
Miscellaneous manufacturing	339	thing	1
Oil and gas extraction	211	square	1
Primary metal manufacturing	331	circle in a box	1
Academia	111	circle	1

Note: Authors own construction

The drawing of the network of IS relations of firms, where the node has an specific shape according to their industry, can be seen in the Figure 2.

Figure 2. *The IS relations network with the nodes shape according to their industry*



Note: Each node represents a firm, and the lines indicate the residue exchange between two firms (arrows point to receptor). Authors own construction using NetDraw network visualization tool.

Afterwards, the QAP regression and the double deckert semi-partialling method was performed with the IS relationships as the dependent variables and the diversity of the firms as the independent. Moreover, it has to be mentioned that the QAP regression tests focus on evaluating the dyadic relationship among two actors but can be handled and interpreted like ordinary least square tests (Tsai, 2002). The results of the QAP regression are shown in the Table 3.

Table 3. *QAP regression results for IS and diversity*

Model	Type of variable	Significance	Un-standardized coefficient	Standardized coefficient	Standard Error
Yi = IS relationships	Categorical				
Intercept			0.037088	0	
X1= Diversity	Exact matches	0.3898	-0.001877	-0.003571	0.019365

Note: Authors own construction using UCINET 6

From the above results, it is possible to observe that the independent variable “diversity" it is not significant in the explanation of the IS relationship. Therefore, H1 is not supported. However, even that the hypothesis is not supported, it is interesting to notice that the standardized coefficient has a very low negative sign and this indicates that actually the firms that belong to the same industry are the ones who slightly tend to exchange more residues. Moreover, it has to be acknowledged that the values of the coefficients of the QAP regression tend to be small because this type of regression uses an iterative permutation process which randomly changes rows and columns of the predictor matrices and then computes regression coefficients that are robust against multicollinearity (Dekker, Krackhardt, & Snijders 2003).

The lack of support of H1 can be attributed to the importance of co-development– “development without co-development webs is as impossible for an economy as it is for biological development” (Jacobs, 2002). The concept of co-development holds two important lessons for an industrial ecosystem based in IS relations. First, a regional economy cannot be sustained over the long-term on a single industry or company like in the Toluca-Lerma region that most of the IE is supported by the chemical and plastics manufacturing industry accounting for 37 % of all the studied firms. Secondly, the factors that affect a regional economic development are interrelated and interconnected to other macro and micro economic levels. This allow to establish that the diversification of an industrial ecosystem in a developing country should be analyzed at multiple levels (industries, firms, education, inflow sources, etc.), while still focusing on the basic strengths of the region that can substantially reduce economic risk, create a more attractive business climate, establish a long-range trend of positive performance and create synergy amongst individuals, firms and industries that exchanges residues.

The lack of support of H1 regarding diversity can also be explained by the fact that in successful industrial ecosystems the IS alliances took place where successful regional practices such as well-informed systems existed (Erkman & Ramaswamy, 2003). In particular, this information system allowed for the formation of the IS linkages because the firms were able to realize a supply and demand exercise in which one firm supplied a residue, and if other firm was able to use it as input in its process, then the alliance was formed. However, in the Toluca-Lerma region not all of the firms had updated information concerning the characteristics of their residues and as a consequence there were many alliances that were abandoned among diverse partners due to the fact that the implementations fail because of the non-compliance of the minimal characteristics for the residue to be used as feedstock by other firm.

In sum, the results do not support hypothesis 1, which states that IS relations are found when firms of different industries interact in the network. However, the fact that diversity of firms encourages the formation of symbiotic linkages does not apply to industrial ecosystems in developing countries could be grounded in the lack of attention that the firms have placed in co-development and the lack of commitment to generate a regional practice of sharing a well-informed production system.

The IS among firms physical location

To represent the geographical proximity a matrix of the calculated distances among all participants was created using Google maps shortest distance tool. Distances among firms ranged from 2.4 km up to 125 km. Once constructed such matrix, the QAP regression and the double deckert semi-partialling method was performed using IS relationships as the dependent variables and the distances of the firms as the independent. Results can be found in Table 4.

Table 4. *QAP regression results for IS and distances among firms*

Model	Type of variable	Significance	Un-standardized coefficient	Standardized coefficient	Standard Error
Yi = IS relationships	Categorical				
Intercept			0.037821	0	
X1= Distances	km	0.5017	-0.000021	-0.003972	0.000190

From the above results, it is possible to observe that the independent variable “geographical proximity” is not significant in the explanation of the IS relationship. Therefore, H2 is not supported. However, even that the hypothesis is not supported, it is interesting to notice that the standardized coefficient has a very low negative sign and this indicates that actually the firms that are not close to each other in geographical distance are the ones who slightly tend to exchange more residues. Moreover, it has to be noticed that one mayor limitation when using QAP regression *vis a vis* to logit regression is that the latter could yield better approximation due to the nature of the dependent variable. This limitation could not be overcome as the network software have not yet evolved to appropriately deal with this type of regressions.

Moreover, the lack of support of H2 can be attributed to new advances over economic geography. Economic geographers, who theorize that regional systems evolve from locations where co-located firms are unconscious of the greater potential of coordinated actions and simply benefit from economies of scale; to systems where there coordination and the technological learning is vital in order to boost regional advantages (Harrison, Kelley & Gant, 1996; Porter, 1998). Furthermore, as regions develop, several parameters characterizing the system increase. This allows establishing that the location of firms in an industrial ecosystem in a developing country should be analyzed at multiple levels that could include the characteristics of coordination, innovative capacity and adaptability to the system as proposed by Belussi and Gottardi (2000).

At this point, it can be stated that the principles of diversity and geographical proximity that explain the existent of successful industrial ecosystem in developed countries do not apply to the industrial ecosystem found in the Toluca-Lerma region in the developing country of Mexico. Moreover, the explanations of the noncompliance of these two principles in the developing region are based on economic geographers, the lack of an updated information system and that a regional economy cannot be sustained over the long-term on a single industry or company.

Conclusions

The present research has shed light on several matters of importance for the field of industrial ecology and more specifically for the industrial symbiosis literature. The industrial ecology paradigm has put the natural ecosystems as a key pattern that should be emulated in order to be efficient with the resources and the residues generated. Moreover, the main studies of the field have been successful cases of industrial ecosystems in developed countries (Chertow, 2007; Gibbs & Deutz, 2005; Jacobsen, 2006; Korhonen, 2001b; Zhu, Lowe, Wei & Barnes, 2007). However, when the basic principles of the industrial ecosystems established by Korhonen (2001a), Chertow et al. (2008) are tested in a developing country such as Mexico, it becomes possible to find that they are not fulfilled.

Due to the context found in the developing countries, the complex phenomena of the relationship of industrial symbiosis in a region cannot be explained with the reductionist view of geographical proximity and the diversity of the firms.

This study proposes for further research to analyze the diversification of an IE at multiple levels (industries, firms, research centers, incubators etc.), while still focusing on the basic strengths of the region that can substantially reduce economic risk and create a more attractive business climate. Furthermore, the location of firms in an industrial ecosystem in a developing country should also be analyzed at multiple levels including coordination, innovative capacity and adaptability to the system.

Another research line that this study proposes is the relationship between firm size and industrial symbiosis exchanges. This has a specific focus in industrial ecology because usually the large firms have a corporate environmental care that is dictated in a top-down way (Schick, Marxen & Freimann, 2002) and this could create problems in the implementation of IS. Moreover, empirical research suggests that small and large firms have different determinants of innovation (Rogers, 2004; Van Dijk, Den Hertog, Menkveld, & Thurik, 1997) and this could have an impact on whether the large and small firms are willing to innovate because perhaps they are not synchronized appropriately considering that the main relative strengths of small firms lie in behavioral advantages.

Specifically small firms usually enjoy internal conditions like entrepreneurship, flexibility and rapid response (Lewin & Massini, 2003), which encourages IS. Furthermore, this type of firms have been credited with increasing flexibility in production (Fiegenbaum & Karnani, 1991) , price (MacMillan, Hambrick & Day, 1982), with enhancing speed (Katz, 1970) and risk-seeking behavior (Hitt, Hoskisson, & Harrison, 1991) that could aid in the rapid implementation of IS.

Small firms are motivated to constantly seek threats and opportunities in order to survive and prosper (Aldrich & Auster, 1986). Particularly, this can be seen in ecological developments that may require longer periods of time in order to achieve market breakthroughs than conventional entrepreneurial activities (Randjelovic, O'Rourke & Orsato, 2003). Additionally, if it is assumed that small firms generally face severe problems of legitimacy (Aldrich & Auster, 1986), it makes sense that they would try to implement IS exchanges in order to appear reliable and legitimate.

Finally, it can be concluded that the chaotic growth of industrialization and the tremendous mobility of physical and economic resources throughout the world have created the need of efficiency on natural resources and the environment.

One solution to the problem can be the industrial ecosystems. However, due to the complexity of the IS exchanges, the main principles established in the literature are not found in the context of a developing country. Consequently, the principles of diversification and location should be analyzed at different levels. Furthermore, we encourage the integration for new variables such as firms' size as better determinant of IS exchanges in developing countries.

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