<Title> Promoting industrial symbiosis: Using the concept of proximity to explore social network development

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<Heading level 1> Summary

Industrial symbiosis (IS) has been identified as a strategy for promoting industrial sustainability. IS has been defined as the development of close working agreements between industrial and other organizations that, through the innovative reuse, recycling or sharing of resources, leads to resource efficiency. Key to IS are innovation and social network development. This article critically reviews IS literature and concludes that, to inform pro-active strategies for promoting IS, the understanding of the social processes leading to resource innovation needs to be improved. Industrial ecologists generally believe that close geographic proximity and trust are essential to the development of IS. This article argues, however, that there is a need to learn more about the meaning of, need for, and specific role of geographic proximity and trust in IS and, additionally, that other potentially important social factors have remained under-explored. To move IS research forward, this article suggests to engage with research in economic geography on the concept of 'proximity', which draws attention to the ways in which geographic, cognitive, institutional, social and organizational distances between actors might affect innovation. Arguably the analytically distinct but flexible dimensions of proximity can be useful to explore how and why IS develops. The resulting qualitative knowledge would form a basis for researching whether general patterns for IS development exist and, more importantly, could inform

public and private strategies that indicate which actions could be taken, when and in what way to promote resource synergies and sustainable industrial development.

Keywords

Resource synergies, Innovation, Social factors, Geographic proximity, Trust

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<Heading level 1> Introduction

There is a pressing need to understand the social processes that underlie sustainable industrial development (Frosch and Gallopoulos 1989; White 1994; Korhonen et al. 2004). Such understanding is necessary to inform pro-active strategies for the development of sustainable industrial systems (Korhonen et al. 2004). Pro-active strategies are needed because it is likely that the availability of many natural resources, which are crucial to the on-going functioning of a multitude of industries, will be increasingly impaired while simultaneously resource prices will continue to increase (ME Assessment 2005; Dobbs et al. 2011). One suggested route to improve the sustainability of industries is decreasing the input of natural resources into industrial systems by increasing resource efficiency (ME Assessment 2005; UNEP 2011). A strategy for increasing resource efficiency is the development of circular production systems such as those created through industrial symbiosis (IS). IS has been defined as the development of close working agreements between industrial and other organizations that, through the innovative reuse, recycling or sharing of resources, lead to resource efficiency (Jensen et al. 2011a). Allowing IS systems to develop organically would arguably take too long. For example, the IS system in Kalundborg initially developed over a period of at least 25 years (Ehrenfeld and Gertler 1997; Christensen 2012). This time period clearly does not reflect 'urgent' development of sustainable industrial systems. Hence, pro-active strategies for IS, that are informed by an understanding of the social processes leading to the adoption of IS practices, are required.

It has been recognized that the realization of resource symbioses often involves innovation (Huber 2000; Mirata and Emtairah 2005; Boardman and Gardner 2006; Jensen et al. 2011a; Lombardi and Laybourn 2012). Because IS naturally involves two or more

collaborators, social networks are considered important for its development (Ashton 2008; Doménech and Davies 2009). Thus social networks and innovation are identified as key themes to complement existing IS research. To date, it seems to be generally accepted in industrial ecology that geographic proximity and trust between companies are essential for the realization of IS (e.g. Chertow and Ehrenfeld 2012; Ashton and Bain 2012; Taddeo et al. 2012). This belief was partly based on agglomeration and cluster development studies in economic geography, which has been an important source of inspiration for industrial ecologists (e.g. Lowe 1997; Ashton 2009). This article suggests that economic geography could yet provide more insights into the pro-active development of IS by engaging with the continuously developing body of literature on the concept of 'proximity'.

There is an on-going discussion among economic geographers about the role of social networks in innovation (e.g. Howells 2002; Nooteboom and Gilsing 2004; Ter Wal 2009; Boschma and Martin 2010; D'Este et al. 2013). Pivotal in this discussion is the concept of proximity, which is about the 'distances' between actors and how these distances affect innovation (Boschma 2005). These distances can be absolute and relative, e.g. physical distance and what industrial ecologists have called 'mental distances' respectively (Ashton and Bain 2012). Mental distance has been associated with similarities at a cognitive level, such as shared norms about waste handling, which could enable collaboration between companies (Sterr and Ott 2004; Chertow and Ashton 2009; Ashton and Bain 2012). The on-going discussion on proximity in economic geography is particularly interesting for industrial ecologists because the roles of geographic proximity and trust in promoting innovation are regularly debated and, as will be argued in this article, these social factors also merit further research and debate in IS literature.

This forum article argues for using the concept of proximity as a new pathway to research how and why innovative IS develops. First industrial ecology literature will be critically reviewed, particularly focusing on geographic proximity and trust, leading to the identification of directions for further research on IS. The concept of proximity and its potential benefits to IS research will then be discussed, arguing that the analytically distinct though flexible dimensions of proximity offer valuable new starting points to explore the role of various social factors in the realization of innovative IS. The article concludes with an example of applying the concept of proximity to an IS study that resulted in practical outcomes that are likely to inform pro-active strategies for the development of resource efficient industrial systems.

<Heading level 1> Current understanding of social processes leading to industrial symbiosis

Geographic proximity and trust are generally considered important for the development of resource synergies (e.g. Chertow and Ehrenfeld 2012; Ashton and Bain 2012; Taddeo et al. 2012). In the early days of industrial ecology, this belief was largely based on conclusions derived from industrial agglomeration studies (Lowe 1997) and on studies of the self-organized IS in such places as Kalundborg (Ehrenfeld and Gertler 1997). To explain this statement further, industrial agglomerations, or the locating of companies in geographic proximity of each other, may lead to the increased likelihood of resource synergies. Similar to biological systems, the more businesses in type and number that are present in a given area, the more potential resource reuse pathways exist, and the greater the likelihood that these businesses may fill continually evolving IS niches, which, in turn, is

believed to improve the effectiveness of exchanges in the region as a whole (Ring 1997; Korhonen 2001b; Korhonen 2001a; Sterr and Ott 2004; Ashton 2009; Jensen et al. 2011b; Jensen et al. 2011c). In this theory, which derives from basic ecosystem development thinking (e.g. Odum 1969), geographic proximity can be seen to drive increased resource efficiency at a local and regional geographic scale. Additionally, industrial ecologists have studied how IS has evolved (Ehrenfeld and Gertler 1997; Korhonen and Snakin 2003; Ashton 2009; Paquin and Howard-Grenville 2012; Chertow and Ehrenfeld 2012). Ideas about the evolution of industrial ecosystems were derived from empirical examples such as Kalundborg. In the example of Kalundborg, IS primarily developed through bottom-up processes between companies that were located in geographic proximity, where the employees were part of a small community and knew and trusted each other prior to the development of IS (Ehrenfeld and Gertler 1997; Jacobsen and Anderberg 2009). This model, i.e. companies in geographic proximity in which employees get to know and trust each other prior to or simultaneously with the development of synergies, dominates current perspectives on promoting IS (Sterr and Ott 2004; Hewes and Lyons 2008; Jacobsen and Anderberg 2009; Chertow 2009; Chertow and Ehrenfeld 2012; Ashton and Bain 2012; Taddeo et al. 2012). However, there are elements of this perspective that merit further investigation.

<Heading level 2> Geographic proximity

Local and regional geographic scales are generally accepted as the most suitable for IS development (e.g. Chertow 2009; Simboli et al. 2012). However, from the point of view of metabolic flows, industrial ecologists have studied at what geographic scales resources flow and found that resources and resource networks can develop over a variety of distances

(Sterr and Ott 2004; Tong and Lifset 2007; Lyons 2007; Jensen et al. 2011a). Nevertheless, the need for geographic proximity between companies in *social* networks, for the promotion of IS, has remained largely unchallenged. There are empirical studies that suggest that geographic proximity between actors may be neither as ubiquitous nor as essential in promoting IS as is regularly presented. Indeed, the importance of geographic proximity can be challenged based on existing empirical research from within the field of industrial ecology. The assumption that geographic distances for the exchange of wastes and by-products should be short is largely based on the balance between transaction costs and the value of the material (Sterr and Ott 2004). However, within documented IS case studies there is no evidence to categorically back up this assumption. In fact, to the contrary, an empirical study into the movement of thousands of recyclates between members of the United Kingdom's National Industrial Symbiosis Programme (NISP) found that there was *no* correlation between transport distance and the quantities or value of a broad range of materials (Jensen et al. 2011a). In terms of potential environmental considerations limiting the distances that materials move, the aforementioned study also notably found that the carbon savings resulting from symbiotic resource reuse, significantly outweighed the carbon emissions produced during transportation of the materials to their point of reuse. This (and a later related study) instead concluded that the distance materials move, to realize IS, is primarily driven by relative geospatial industrial diversity and the consequent likelihood of finding a potential unrelated symbiosis partner able to reuse a given waste or by-product (Jensen et al. 2011a, 2011c). It is important to note, however, that these conclusions referred primarily to facilitated IS, where a third-party neutral practitioner employed their knowledge of a given geographic area to identify and engage with potential industrial and other IS collaborators. These findings, nevertheless, have

proven not to be unique to facilitated IS. In more general terms, it has been suggested that there is no specific scale at which recycling is best managed since a variety of resources have been observed to be recycled at multiple geographic scales (Lyons 2007; Velenturf et al. forthcoming). Since resources are recycled at multiple scales, the movement of these resources must have been organized and thus social networks must also exist at multiple scales. The existence of social networks at multiple scales implicitly challenges the importance of geographic proximity in these social networks.

In addition to transaction costs of the physical movements of materials, transaction costs have also been related to the social interactions that are required to organize material exchanges. Sterr and Ott (2004) argued that, as the geographic distances in recycling networks became longer, costs to overcome so-called 'mental distances' increased. The increase in costs would be caused by the necessity and increased difficulty to develop trust between companies that did not have any formal or informal relationship prior to the material exchange. Also communication and coordination costs would rise. Various scholars in industrial ecology have argued that geographic proximity is a necessity in building intercompany trust (Gibbs 2003; Sterr and Ott 2004; Hewes and Lyons 2008), but this necessity can be questioned, as was also recognized by Lombardi and Laybourn (2012). The assumption that geographic proximity may support the generation of inter-organizational trust has been taken from human geography (MacKinnon et al. 2002), however, this assumption has been questioned in other fields in the on-going discussion about mechanisms for interaction and coordination of learning and innovation (Boschma 2005; Ter Wal 2009; Broekel and Boschma 2012). The need to overcome mental distances and in particular to create trust merits further research altogether and this will be discussed in the next section.

<Heading level 2> Trust

Trust is considered of key importance to the development of IS, whether it is a self-organized, facilitated or fully planned process (Ehrenfeld and Gertler 1997; Gibbs 2003; Sterr and Ott 2004; Hewes and Lyons 2008; Ashton 2008; Jacobsen and Anderberg 2009; Doménech and Davies 2011; Chertow and Ehrenfeld 2012). This conviction is based on several publications that emphasize how trust is important for business and innovation (Granovetter 1985; Porter and Linde 1995; Putnam 1995; Uzzi 1996).

The importance of trust in business and innovation has been widely and methodically discussed in various disciplines. Particularly in innovation and proximity studies, trust is considered an important subject (Gulati 1995; Cooke et al. 1997; Lundvall et al. 2002; Boschma 2005; Ter Wal 2009). However, perhaps industrial ecologists have been selective in their interpretations. Despite literature emphasizing the importance of trust (for extensive overviews of 'trust' literature see e.g. Rousseau et al. 1998 and Nooteboom 2002), its importance has also been questioned and it has been suggested that trust could be substituted by other social factors, such as hierarchies and coercion as well as confidence in institutional frameworks (Nooteboom and Gilsing 2004; Boschma 2005) (discussed further in following sections). Furthermore, although various authors argue that it would indeed benefit companies to be embedded in dense social networks that foster trust (Walker et al. 1997; Tsai and Ghoshal 1998), it has also been suggested that dense networks can be detrimental to business and innovation, for example because it can lead to cognitive lock-in and reduced creativity (Granovetter 1985; Grabher 1993; Day 1994; Uzzi 1996; Boschma 2005; Granovetter 2005). Consequently, the presence of trust may also be associated with barriers

to innovation. This apparent contradictory thinking suggests that industrial ecologists should research the role of trust in innovative resource synergies in an open and holistic manner.

Many important questions about the role of trust in the development of IS have not been rigorously answered. Trust is a vague term and is regularly applied in an equally vague manner. Trust can have many meanings and without explaining what one means by 'trust', the academic and practical use of the research outcomes will be impaired. In order to maximize contributions to on-going IS research and practical IS strategies, it is important to clearly ascertain why there is a need for trust, what it is that needs to be trusted, who needs to be trusted, how 'much' trust is needed and how it can be developed over varying geographic distances. It is important to answer these questions, because generating trust is not an easy task. It requires substantial investment of leadership skills, time and money (Hewes and Lyons 2008) which are often limited in availability. Hence knowledge is necessary to formulate effective strategies to generate the right kinds of 'trust', between the right people, in the right subjects, at the right time and through the right activities – *all of which require further research*.

Nevertheless, several researchers have explored the role of trust in IS (e.g. Gibbs 2003; Ashton 2008; Hewes and Lyons 2008). However, industrial ecologists have tended to assume trust is important without fully exploring if, how and why it may be important, and instead they have focused on understanding how trust can be generated (e.g. Hewes and Lyons 2008; Doménech and Davies 2011). Trust may have remained underexplored to this extent, because it has been considered inherent to the concept of eco-industrial developments such as IS. This is expressed in the following quote:

"The concept of eco-industrial parks has as its basis inter-firm collaborating and networking, based upon trust and reciprocal relations. Without these an eco-industrial park does not exist (…)."

(Gibbs 2003: 230)

In general, it is not clear what industrial ecologists mean by trust. Trust can have many dimensions (Nooteboom 2002), covering for example different levels of social systems including inter-personal trust, inter-organizational trust, and trust in institutions governing IS. Additionally, different subjects can be trusted, such as trust in the long-term supply of a given resource, trust in competencies and intentions and/or trust in the mutual benefits derived from a synergy. Furthermore, the purpose of trust has been clarified to varying degrees. Inter-company trust has been presented as a broad general concept underlying the development of IS (Baas 1998; Baas and Boons 2004; Doménech and Davies 2011). More specifically, trust has been associated with overcoming motivational or behavioral barriers, consisting of the willingness to participate in IS projects (Heeres et al. 2004; Gibbs and Deutz 2007; Sakr et al. 2011), the lowering of transaction costs for the development of IS (Chertow and Ehrenfeld 2012), and openness to share information with potential IS partners (Gibbs 2003; Sterr and Ott 2004; Jacobsen and Anderberg 2009).

Despite the abovementioned publications, even IS literature itself provides grounds to challenge the role of trust. For example, in the specific case of facilitated IS the nature and development of trust between companies has been questioned (Jensen et al. 2011a). Despite the absence of any prior professional acquaintance or obvious 'short' mental distances, companies engaged with each other and the third-party facilitator's program (NISP) because they were confident (i.e. trusting) that there might be a business development opportunity. Another suggestion within industrial ecology that the role of

trust needs further research, was identified in Ashton (2008). The suggestion that trust could be substituted by other social factors (Nooteboom and Gilsing 2004; Boschma 2005) might be supported by Ashton's (2008) work. Contrasting existing conclusions, Ashton's results showed that, in a social network of formal and informal relations between managers, the most central network actors were also the most trusted. However, based on network theory, a central network position can also be interpreted as a powerful position, because a central network actor may have faster and multiple ways of access to resources whilst more peripheral network actors may depend on central actors (Scott 2000). Hence, it can be said that the network represents a hierarchy, in which the central actors are more powerful than the more peripheral actors. In Ashton's (2008) study, trust was found to correlate with the presence of IS. However, keeping in mind the possible correlation between trust and hierarchy of actors, it could be that both trust and hierarchy correlated with the presence of IS and that both factors may have played a role in the development of IS. This theory might be supported by other industrial ecology research, which will be discussed in the next section.

<Heading level 2> Hierarchy and coercion

Network hierarchies such as presented by Ashton (2008) can, as discussed above, represent dependencies between actors. These dependencies can come into play when an actor wants to do something that requires resources from another actor. Resources should be interpreted broadly, for example these can be contacts but also money, materials, knowledge and skills. Hierarchies are formed based on the resources available to actors. Each actor is constrained by the resources that are available to it. 'Constrain' is a synonym for 'pressure' and 'coercion' (Oxford 2007), and as such hierarchy can be the medium

through which coercion operates. Coercion generally has a negative connotation; however, it can also be used to achieve positive environmental outcomes which are arguably for the greater good. Furthermore, as suggested earlier, it should be noted that coercion does not exclude the operation of other factors such as trust (in whatever variety of forms it might exist). Despite the potential role coercion could play in the development of IS, coercion has remained largely underexplored in the literature on eco-industrial developments in Europe and the US. Conversely, publications about eco-industrial development in China and the Republic of Korea suggest that coercion has played an important role. Eco-industrial development in these countries is generally the outcome of both top-down and bottom-up processes, processes in which both coercion and trust play a role (Park et al. 2008; Mathews and Tan 2011; Behera et al. 2012).

Exemplifying the role of coercion, the development of eco-industrial parks (EIP) in China will be briefly discussed. In China, the role of governments and public bodies is not always clear (Zhu et al. 2010), nevertheless environmental management of industrial systems has been described as centralized and top-down regulated (Liu and Ma 2010) and it has been argued that EIP initiatives are primarily government led (Shi et al. 2012b; Shi and Yu 2014). Governments can initiate change in industrial systems by contracting businesses to meet environmental targets (Geng et al. 2010) and regulating the quantity, price and destination of material flows through markets (Zhu et al. 2007). The Chinese government, rather than business, initiates eco-industrial initiatives because it is considered necessary in the fast transition towards a circular economy (Mathews and Tan 2011). Applications for EIP demonstration programs and EIP planning are government led (Shi et al. 2012a) and are usually initiated by an administrative committee or a general development corporation of an industrial park, which are representatives of the local government. Nevertheless, these

organizations would like more business involvement (Tian 2013 pers. comms.). It is also interesting to note that, despite the clear top-down development of EIPs in China, the social relationships between stakeholders in an EIP do seem to help in the development of IS (Tian 2013 pers. comms.). This suggests the coexistence of top-down and bottom-up processes. Evidently coercion played a role in driving eco-industrial development in China. This example suggests that coercion can play a role in eco-industrial developments and IS, and shows that important social factors might have remained under-explored in sections of IS literature.

<Heading level 1> Engaging IS research with the concept of proximity

Although there is valuable published research on the subject of IS and its facilitation (e.g. Ashton 2008; Jensen et al. 2011c; Paquin and Howard-Grenville 2012), the critical review of industrial ecology literature in the first half of this article revealed that there is still a limited understanding of the various social factors that might play a role in IS development. As discussed earlier, it is not clear what role geographic proximity plays in social processes leading to IS. It is also not clear what 'trust' means in the context of IS, and there is no rigorous evidence about how and why it develops during the realization of resource synergies. Furthermore, social factors such as hierarchy may be important too, and more open investigations might reveal other social factors relevant to IS. To conclude, there are still significant gaps in the understanding of social processes for the development of IS. It is proposed here, however, that these gaps can be filled by various elements of the continuously developing concept of proximity. The following section recommends and demonstrates how IS researchers could engage with the concept of proximity, using it as a new 'lens' through which the development of resource synergies can be explored.

<Heading level 2> The concept of proximity

Similar to industrial ecology, scholars in geography questioned how innovation could be promoted. In cluster literature particularly, geographic proximity was considered to be of key importance for learning and innovation and it assumed that knowledge networks were confined to regional borders (Castells 1996; Ter Wal and Boschma 2008). However, further exploration of knowledge networks has proven that connections for learning and innovation also includes contacts outside the regional borders and that a combination of intra- and inter-regional knowledge networks benefits innovation (Asheim and Isaksen 2002; Bathelt et al. 2004; Broekel and Meder 2008). Hence it could be argued that geographic proximity is "neither a necessary nor a sufficient condition" for inter-organizational learning and knowledge transfer (Boschma 2005). To explore this matter further, economic geographers engaged with a group of spatial and industrial economists who had formulated the concept of 'proximity' (Gilly and Torre 2000; Torre and Gilly 2000). Whilst acknowledging the variety of applications of the concept of proximity, generally it has been used to explore, or measure, the differences between actors and the effects of those differences on inter-organizational interaction for – and coordination of – innovation (Boschma 2005). The literature basis of the concept of proximity shows some overlap with the concept of embeddedness (such as Granovetter 1985; Uzzi 1996), which is well-known to industrial ecologists. However, in contrast to embeddedness, the concept of proximity has developed an analytically distinct focus on inter-organizational processes while also 'isolating' various proximity dimensions (Zukin and DiMaggio 1990; Boschma 2005). With the concept of proximity, industrial ecologists could generate valuable contributions to further understanding on how, why and when innovative IS develops between companies.

Importantly, the concept of proximity also enables the distinction of social factors such as trust (in all its forms) and hierarchy and thus facilitates the exploration of their role in IS separately. Although the dimensions of proximity, which will be introduced shortly, are analytically separate, each dimension does show some variation in the meaning they have been given (Knoben and Oerlemans 2006). Rather than following one specific set of meanings, it is recommended to gain an understanding of the variation and explore which meaning fits best to the case of IS, i.e. to use the proximity concept as an aid or 'lens' to observe IS processes in an exploratory though not unnecessarily vague manner. Boschma (2005) argued for five dimensions of proximity that can be analytically separated which enables empirical analysis of their discrete roles: these are geographic, cognitive, organizational, social and institutional proximity. These five dimensions and their variable meaning will be briefly discussed.

<Heading level 3> Geographic

Geographic proximity has been described as the absolute distance and also as the perceived or relative traveling distance between economic actors (Boschma 2005; Knoben and Oerlemans 2006). Furthermore, geographic proximity can be permanent or temporary (Knoben and Oerlemans 2006). Geographic proximity can have a positive influence on the exchange of tacit and codified knowledge (Howells 2002), however, empirical studies have also shown that a combination of local and non-local relations benefits learning and innovation (Asheim and Isaksen 2002; Broekel et al. 2010), i.e. both types of relations are important (Jaffe et al. 1993; Bathelt et al. 2004; Boschma and ter Wal 2007).

<Heading level 3> Cognitive

Cognitive proximity is about cognitive frameworks which can differ due to the context within which people have developed. For innovation and learning, some academics consider the whole social and physical context within which an individual developed and adopted, for example, norms and values that guide their behavior (Boschma 2005). Others have a narrower and more practice-oriented interpretation of cognitive frameworks, linking them to market and technical competencies (Wuyts et al. 2005; Knoben and Oerlemans 2006). Arguably, the broader interpretation risks overlap with institutional proximity (see below) and the narrower interpretation might be related to organizational proximity (see below) (Knoben and Oerlemans 2006). Many academics have argued that cognitive diversity is necessary for learning and innovation (see e.g. Nooteboom 2000; Nooteboom and Gilsing 2004). Diversity can be measured by the number of different actors involved as well as the differences between the actors (Wuyts et al. 2005). Arguably, cognitive differences between actors are necessary to trigger creativity and develop new ideas (Cohendet and Llerena 1997; Nooteboom and Gilsing 2004). Conversely, the cognitive differences need to be sufficiently reduced to enable learning and innovation, i.e. economic actors need to have enough 'cognitive overlap' to enable communication and knowledge transfer and absorption (Nooteboom 2000; Nooteboom and Gilsing 2004).

<Heading level 3> Institutional

To analyze institutional proximity, generally the definition of institutions as provided by North (1990) has been adopted, distinguishing formal and informal institutions. Institutional proximity is thought to impact on knowledge transfer and coordination (Kirat and Lung 1999). Institutional proximity can ease communication because increased institutional overlap between actors would prevent that all knowledge needs to be made

explicit and, moreover, an institutional setting can provide institution-based trust which reduces uncertainty (Nooteboom and Gilsing 2004; Boschma 2005). Institutional proximity has been researched at two levels, the national/ regional and the inter-organizational level (Knoben and Oerlemans 2006; Boschma 2005). When researched at the inter-organizational level, institutional proximity risks overlap with social and organizational proximity (discussed next). Hence, to keep the proximity dimensions analytically separate, institutional proximity might better be interpreted and applied to research how institutions at the social macro-level promote and constrain innovation.

<Heading level 3> Social

Social proximity shows considerable overlap with social and structural embeddedness. Social proximity is about the influence of shared social space on innovation and learning and can be described as the degree to which economic relations are socially embedded at the micro level, for example through friendship, kinship and professional acquaintance (Boschma 2005; Knoben and Oerlemans 2006). These social relations might facilitate knowledge transfer (Knoben and Oerlemans 2006). Moreover, socially embedded relations have been associated with trust, which is thought to function as a control mechanism against opportunistic behavior (Nooteboom and Gilsing 2004; Boschma 2005). Particularly when innovations involve mostly tacit knowledge, trust may be an important coordination mechanism (Gertler 2003; Nooteboom and Gilsing 2004). However, when knowledge can be codified it could also be formulated in contracts and, theoretically, inter-personal trust would be of lesser importance (Nooteboom and Gilsing 2004).

<Heading level 3> Organizational

Organizational proximity has been described in a very wide sense covering all relative proximities (e.g. Gilly and Torre 2000). Others, however, have been more specific. Generally organizational proximity has been described as either the similarities in routines and incentives of organizations, for example profit and non-profit organizations would have different incentives for their economic activities, or the degree of autonomy and control that organizations have over each other (Broekel and Boschma 2012). The degree of autonomy and control can vary, for example, depending on the strength of economic and financial inter-dependencies between organizations (Kirat and Lung 1999). Dependencies do not have to be symmetrical (Nooteboom and Gilsing 2004), they can be hierarchical (Boschma 2005). As a result organizational proximity can be associated with hierarchy which can, as discussed before, facilitate coercion.

<Heading level 2> New pathways for IS research

The concept of proximity can be used in a variety of research approaches. Hence, depending on the level of knowledge in a given subject area, the most suitable research phase and accompanying methodology can be selected and make use of the concept of proximity. Economic geographers have applied the concept of proximity in mostly quantitative studies that ranged from empirical observation of phenomena to testing and theorizing about innovation (see for example Oerlemans and Meeus 2005; Broekel and Meder 2008; Broekel and Boschma 2012; Ter Wal 2014). These predominantly quantitative studies have resulted in lists of factors that can benefit innovation. Arguably, however, such lists of factors are difficult to translate into public and private action to promote innovation because of the missing qualitative understanding of how and when these factors should be brought into practice (Sorenson 2014, pers. comms.). Hence it could be suggested that

proximity research needs to increase its focus on qualitative empirical observation prior to measuring and testing, and eventually theorizing about, the role of social factors. This argumentation is also relevant to IS research, because various researchers have already started hypothesizing and theorizing about the role of various social factors in IS development, as demonstrated and critiqued earlier in this article, while qualitative gaps in understanding are evidently prevalent. Hence, at this moment, similar to the proximity literature, a qualitative exploratory methodology to observe and describe how IS has developed might be the most suitable approach to progress this body of research. IS literature does include qualitative studies already (such as Ehrenfeld and Gertler 1997; Gibbs and Deutz 2005; Hewes and Lyons 2008; Behera et al. 2012; Paquin and Howard-Grenville 2012) and the further use of empirical qualitative methodologies would prevent the problem economic geographers are currently experiencing, as explained above, the problem of knowing which factors might be important but not being able to easily translate this knowledge into tangible strategic advice because specific understanding of exactly how and when the factors play a role in innovation processes is limited. Furthermore, empirical qualitative studies could, with care, directly inform public and private strategies to promote IS while also building a robust basis to formulate and test hypothesis which could eventually lead to a more generalized theory for promoting IS.

There are important questions in IS research that are yet to be *fully* answered, such as the simple but obvious: how and why did IS develop? Was there a particular order in which social factors played a role? What do the social factors, in the case of IS, look like empirically? To answer such questions, the concept of proximity, together with empirical and theoretical contributions from IS literature, can be used to produce and inform a research framework which includes a wide range of potentially relevant social factors in the

development of IS. Such a framework can be used as a guide, which would still be open to interpretation of the selected social factors as well as other social factors not previously included in the framework, to observe how and why IS developed. The research framework could be adopted as part of various methodologies such as case studies (see for example Mason 2002; Yin 2009). Depending on resources available for the research project, a number of case studies could be carried out. If sufficient cases can be carried out some forms of qualitative comparative analyses (see for example Lambert and Fairweather 2010) might even be feasible in order to identify general patterns.

The suggested research framework has already been applied (Velenturf Under review) to IS case studies within the Humber region of northern England and has provided tangible results which, as hoped, add to existing research and conclusions on the roles of various social factors such as geographic proximity and trust within the development of IS (full results to be published). In brief, a multiple case study design was applied to explore the development of organic and facilitated innovative resource synergies between companies in the emerging bio-energy sector. Each innovation process was 'observed' using documents, from the resource partners and third parties, and semi-structured interviews with the participating businesses. Data were analyzed combining both conceptual and grounded coding methods (see for example Bryman 2012). The initial coding tree was based on social factors that were considered important in innovation and IS, and these included intra- and inter-organizational as well as social macro-factors. During the case studies the coding tree was 'pruned' in some places while it was populated with new and further refined codes in other places. The role of each social factor was then analyzed separately and also in relation to other factors. Then these analyses were combined in case study reports to generate a holistic understanding of how and why the resource synergy

developed. In each case study the innovative material synergy was realized through similar steps and revealed remarkable similarities in the social processes that had led to IS. To be explicit, the innovation process was predominantly triggered by changes in the legislative and economic context. Potential resource partners were then identified as well as other actors that had to be involved in the innovation process. An initial business case was then made followed by a longer period of building shared knowledge and understanding, indeed this was the basis for trust in the resource synergy. At this point the collaboration was formally agreed with a contract before being realized. These results and more nuanced findings partly confirmed, complemented and sometimes, notably, countered current IS literature. For example, inter-organizational trust in various subjects and characteristics of collaborators, such as confidence in mutual benefits and capability to deliver the synergy, was indeed found to be important and was generated through a number of activities, such as site visits and financial, health and safety checks, which was part of a larger 'social mechanism' in which other social factors were found to be highly relevant too. Such information, when carefully analyzed, can be used for targeted action to promote IS between companies. For example, the results surprisingly suggested that some popular informal social events, such as business dinners, had very limited value for generating trust. The presence of a tangible track-record of business professionalism, however, sometimes simply in terms of the existence of operational management systems, (i.e. for quality, environmental and/or health and safety), coupled with a convincing business case, could be far more effective in promoting collaboration. Indeed, being able to easily garner an evidence base of business professionalism, through formal site audits or less 'structured', sometimes furtive, observations of a potential symbiosis partner, played a large role in the realization of a synergy. The findings from these case studies are being used to discuss

strategies with public and private organizations aiming to actively promote innovative context specific resource synergies in the Humber region.

<Heading level 1> Conclusion

This article has discussed why industrial ecologists have generally asserted that geographic proximity and trust are important in the development of IS. During this discussion, however, it also became evident that these factors merit further research. In particular there is a need to learn more about the meaning, need for, and role of geographic proximity and trust and to explore other potentially important factors in the development of IS, such as hierarchies in networks and institutional 'space' for innovation. In order to take IS research forward, it has been recommended to engage with literature on the concept of proximity, arguing that the analytically distinct but flexible dimensions of proximity are useful tools to progress IS research. Arguably, to date, the most suitable line of research would be empirical qualitative studies that, rather than surmising, observe how and why IS develops in different scenarios and contexts. The resultant inductive and empirical understanding could be appropriately followed by research phases such as the testing of hypotheses and theorizing how IS can be promoted. More importantly, detailed qualitative knowledge could, while bearing in mind the *specific context* in which the knowledge would be generated, inform what actions public and private organizations can take, in what way and at what time, to assist the pro-active development of resource synergies and sustainable industrial systems.

<Heading level 1> Acknowledgements

This article forms one element of the doctoral research on the role of social networks in innovative industrial symbiosis conducted by Anne P.M. Velenturf at the Centre for Environmental Strategy. The partial support of the UK Engineering and Physical Sciences Research Council for programme grant EP/H021779/1 (Evolution and Resilience of Industrial Ecosystems (ERIE)) is gratefully acknowledged. The authors express their gratitude for the constructive feedback from Kate Burningham, Angela Druckman and the anonymous panel of reviewers. The authors also thank Roland Clift, Anne L.J. ter Wal and Jinping Tian for their inspiring discussions during the writing of this article.

<Heading level 1> References

Asheim, B. T. and A. Isaksen. 2002. Regional innovation systems: the integration of local 'sticky'and global 'ubiquitous' knowledge. *The Journal of Technology Transfer* 27(1): 77-86.

Ashton, W. S. 2008. Understanding the organization of industrial ecosystems - A social network approach. *Journal of Industrial Ecology* 12(1): 34-51.

Ashton, W. S. 2009. The structure, function, and evolution of a regional industrial ecosystem. *Journal of Industrial Ecology* 13(2): 228-246.

Ashton, W. S. and A. C. Bain. 2012. Assessing the "Short Mental Distance" in Eco-Industrial Networks. *Journal of Industrial Ecology* 16(1): 70-82.

Baas, L. 1998. Cleaner production and industrial ecosystems, a Dutch experience. *Journal of Cleaner Production* 6(3–4): 189-197.

Baas, L. W. and F. Boons. 2004. An industrial ecology project in practice: exploring the boundaries of decision-making levels in regional industrial systems. *Journal of Cleaner Production* 12(8-10): 1073-1085.

Bathelt, H., A. Malmberg, and P. Maskell. 2004. Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. *Human Geography* 28(1): 31-56.

Behera, S. K., J.-H. Kim, S.-Y. Lee, S. Suh, and H.-S. Park. 2012. Evolution of 'designed' industrial symbiosis networks in the Ulsan Eco-industrial Park: 'research and development into business' as the enabling framework. *Journal of Cleaner Production* 29-30: 103-112.

Boardman, D. I. and D. Gardner. 2006. *NISP case study innovation review*. Birmingham, UK: NISP.

Boschma, R. 2005. Proximity and innovation: a critical assessment. *Regional Studies* 39(1): 61-74.

Boschma, R. and R. Martin. 2010. *The handbook of evolutionary economic geography*. Cheltenham: Edward Elgar Publishing Ltd.

Boschma, R. A. and A. L. J. ter Wal. 2007. Knowledge Networks and Innovative Performance in an Industrial District: The Case of a Footwear District in the South of Italy. *Industry and Innovation* 14(2): 177-199.

Broekel, T. and A. Meder. 2008. The bright and dark side of cooperation for regional innovation performance. *Jena economic research papers* 2008(053): 1-31.

Broekel, T. and R. Boschma. 2012. Knowledge networks in the Dutch aviation industry: the proximity paradox. *Journal of Economic Geography* 12(2): 409-433.

Broekel, T., M. Buerger, and T. Brenner. 2010. An investigation of the relation between cooperation and the innovative success of German regions. *Papers in Evolutionary Economic Geography* 10.11.

Bryman, A. 2012. *Social research methods, fourth edition*. Oxford: Oxford University Press.

Castells, M. 1996. *The rise of the network society.* Oxford: Blackwell.

Chertow, M. and J. R. Ehrenfeld. 2012. Organizing Self-Organizing Systems. *Journal of Industrial Ecology* 16(1): 13-27.

Chertow, M. R. 2009. 2. Dynamics of geographically based industrial ecosystems. In *The Dynamics of Regions and Networks in Industrial Ecosystems,* edited by M. Ruth and B. Davidsdottir. Cheltenham: Edward Elgar Publishing.

Chertow, M. R. and W. S. Ashton. 2009. The social embeddedness of industrial symbiosis linkages in Puerto Rican industrial regions. In *The social embeddedness of industrial ecology*, edited by F. Boons and J. A. Howard-Grenville. Cheltenham: Edward Elgar Publishing.

Christensen, J. 2012. The Kalundborg symbiosis: What, who, when, how and why? Oral presentation at Centre for Environmental Strategy, University of Surrey, Guildford, UK.

Cohendet, P. and P. Llerena. 1997. Learning, technical change and public policy: how to create and exploit diversity. In *Systems of Innovation, Technologies, Institutions and Organizations*, edited by C. Edquist. London: Pinter.

Cooke, P., M. Gomez Uranga, and G. Etxebarria. 1997. Regional innovation systems: Institutional and organisational dimensions. *Research Policy* 26(4): 475-491.

D'Este, P., F. Guy, and S. Iammarino. 2013. Shaping the formation of university–industry research collaborations: what type of proximity does really matter? *Journal of Economic Geography* 13(4): 537-558.

Day, D. L. 1994. Raising radicals: Different processes for championing innovative corporate ventures. *Organization science* 5(2): 148-172.

Dobbs, R., J. Oppenheim, F. Thompson, M. Brinkman, and M. Zornes. 2011. *Resource revolution: Meeting the world's energy, materials, food, and water needs.* McKinsey and Company.

Doménech, T. and M. Davies. 2009. The social aspects of industrial symbiosis: the application of social network analysis to industrial symbiosis networks. *Progress in Industrial Ecology, An International Journal* 6(1): 68-99.

Doménech, T. and M. Davies. 2011. The role of embeddedness in industrial symbiosis networks: Phases in the evolution of industrial symbiosis networks. *Business Strategy and the Environment* 20(5): 281-296.

Ehrenfeld, J. and N. Gertler. 1997. Industrial ecology in practice: the evolution of interdependence at Kalundborg. *Journal of Industrial Ecology* 1(1): 67-79.

Frosch, R. A. and N. E. Gallopoulos. 1989. Strategies for manufacturing. *Scientific American* 261(3): 144-152.

Geng, Y., W. Xinbei, Z. Qinghua, and Z. Hengxin. 2010. Regional initiatives on promoting cleaner production in China: a case of Liaoning. *Journal of Cleaner Production* 18(15): 1502-1508.

Gertler, M. S. 2003. Tacit knowledge and the economic geography of context, or The undefinable tacitness of being (there). *Journal of Economic Geography* 3: 75-99.

Gibbs, D. 2003. Trust and networking in inter-firm relations: the case of eco-industrial development. *Local Economy* 18(3): 222-236.

Gibbs, D. and P. Deutz. 2005. Implementing industrial ecology? Planning for eco-industrial parks in the USA. *Geoforum* 36(4): 452-464.

Gibbs, D. and P. Deutz. 2007. Reflections on implementing industrial ecology through eco-industrial park development. *Journal of Cleaner Production* 15(17): 1683-1695.

Gilly, J.-P. and A. Torre. 2000. Proximity Relations: Elements for an Analytical Framework. In *Industrial Networks and Proximity*, edited by M. B. Green and R. B. McNaughton. Aldershot: Ashgate Publishing.

Grabher, G. 1993. Rediscovering the social in the economics of interfirm relations. In *The embedded firm: On the socioeconomics of industrial networks*, edited by G. Grabher. London: Routledge.

Granovetter, M. 1985. Economic action and social structure: The problem of embeddedness. *American Journal of Sociology* 91(3): 481-510.

Granovetter, M. 2005. The impact of social structure on economic outcomes. *The Journal of Economic Perspectives* 19(1): 33-50.

Gulati, R. 1995. Does Familiarity Breed Trust? The Implications of Repeated Ties for Contractual Choice in Alliances. *The Academy of Management Journal* 38(1): 85-112.

Heeres, R., W. J. V. Vermeulen, and F. B. De Walle. 2004. Eco-industrial park initiatives in the USA and the Netherlands: first lessons. *Journal of Cleaner Production* 12(8): 985-995.

Hewes, A. and D. Lyons. 2008. The Humanistic Side of Eco-Industrial Parks: Champions and the Role of Trust. *Regional Studies* 42: 1329-1342.

Howells, J. R. 2002. Tacit knowledge, innovation and economic geography. *Urban Studies* 39(5-6): 871-884.

Huber, J. 2000. Towards industrial ecology: Sustainable development as a concept of ecological modernization. *Journal of Environmental Policy and Planning* 2: 269-285.

Jacobsen, N. B. and S. Anderberg. 2009. Understanding the evolution of industrial symbiotic networks: The case of Kalundborg. In *The social embeddedness of industrial ecology*, edited by F. Boons and J. A. Howard-Grenville. Cheltenham: Edward Elgar Publishing.

Jaffe, A. B., M. Trajtenberg, and R. Henderson. 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics* 108(3): 577-598.

Jensen, P. D., L. Basson, E. E. Hellawell, M. R. Bailey, and M. Leach. 2011a. Quantifying 'geographic proximity': Experiences from the United Kingdom's National Industrial Symbiosis Programme. *Resources Conservation and Recycling* 55(7): 703-712.

Jensen, P. D., L. Basson, and M. Leach. 2011b. Reinterpreting Industrial Ecology. *Journal of Industrial Ecology* 15(5): 680-692.

Jensen, P. D., L. Basson, A. S. Penn, and M. Leach. 2011c. The Role of Geospatial Industrial Diversity in the Facilitation of Regional Industrial Symbiosis. *Centre for Environmental Strategy working paper* 2011(12).

Kirat, T. and Y. Lung. 1999. Innovation and Proximity: Territories as Loci of Collective Learning Processes. *European Urban and Regional Studies* 6: 27-38.

Knoben, J. and L. A. G. Oerlemans. 2006. Proximity and inter-organizational collaboration: A literature review. *International Journal of Management Reviews* 8(2): 71 - 89.

Korhonen, J. 2001a. Some suggestions for regional industrial ecosystems – Extended industrial ecology. *Eco-Management and Auditing* 8(1): 57-69.

Korhonen, J. 2001b. Four ecosystem principles for an industrial ecosystem. *Journal of Cleaner Production* 9(3): 253-259.

Korhonen, J. and J. P. Snakin. 2003. Industrial ecosystem evolution of North Karelia heating energy system. *Regional Environmental Change* 3(4): 128-139.

Korhonen, J., F. Von Malmborg, P. A. Strachan, and J. R. Ehrenfeld. 2004. Management and policy aspects of industrial ecology: an emerging research agenda. *Business Strategy and the Environment* 13(5): 289-305.

Lambert, S. J. and J. R. Fairweather. 2010. The socio-technical networks of technology users' innovation in New Zealand: a fuzzy-set qualitative comparative analysis. *Research Report* 320.

Liu, L. and X. Ma. 2010. Technology-based industrial environmental management: a case study of electroplating in Shenzhen, China. *Journal of Cleaner Production* 18(16–17): 1731-1739.

Lombardi, D. R. and P. Laybourn. 2012. Redefining Industrial Symbiosis. *Journal of Industrial Ecology* 16(1): 28-37.

Lowe, E. A. 1997. Creating by-product resource exchanges: Strategies for eco-industrial parks. *Journal of Cleaner Production* 5(1–2): 57-65.

Lundvall, B.-Å., B. Johnson, E. S. Andersen, and B. Dalum. 2002. National systems of production, innovation and competence building. *Research Policy* 31(2): 213-231.

Lyons, D. I. 2007. A spatial analysis of loop closing among recycling, remanufacturing, and waste treatment firms in Texas. *Journal of Industrial Ecology* 11(1): 43-54.

MacKinnon, D., A. Cumbers, and K. Chapman. 2002. Learning, innovation and regional development: a critical appraisal of recent debates. *Progress in Human Geography* 26(3): 293-311.

Mason, J. 2002. *Qualitative researching, second edition*. London: SAGE Publications Ltd.

Mathews, J. A. and H. Tan. 2011. Progress Toward a Circular Economy in China. *Journal of Industrial Ecology* 15(3): 435-457.

ME Assessment, M. E. A. 2005. *Ecosystems and Human Well-being: Opportunities and Challenges for Business and Industry*. Washington, DC: World Resources Institute.

Mirata, M. and T. Emtairah. 2005. Industrial symbiosis networks and the contribution to environmental innovation - The case of the Landskrona industrial symbiosis programme. *Journal of Cleaner Production* 13(10-11): 993-1002.

Nooteboom, B. 2000. *Learning and innovation in organizations and economies*. Oxford: Oxford University Press.

Nooteboom, B. 2002. *Trust: Forms, Foundations, Functions, Failures and Figures*. Cheltenham: Edward Elgar Publishing Ltd.

Nooteboom, B. and V. Gilsing. 2004. Density and strength of ties in innovation networks: a competence and governance view. *ERIM Report series Research in management*.

North, D. C. 1990. *Institutions, institutional change and economic performance*. Cambridge, UK: Cambridge University Press.

Odum, E. P. 1969. The Strategy of Ecosystem Development. *Science* 164(3877): 262-270.

Oerlemans, L. and M. Meeus. 2005. Do Organizational and Spatial Proximity Impact on Firm Performance? *Regional Studies* 39: 89-104.

Oxford. 2007. *Dictionary of Synonyms and Antonyms, 2nd edition*. Oxford: Oxford University Press.

Paquin, R. L. and J. Howard-Grenville. 2012. The Evolution of Facilitated Industrial Symbiosis. *Journal of Industrial Ecology* 16(1): 83-93.

Park, H.-S., E. R. Rene, S.-M. Choi, and A. S. F. Chiu. 2008. Strategies for sustainable development of industrial park in Ulsan, South Korea—From spontaneous evolution to systematic expansion of industrial symbiosis. *J Environ Manage* 87(1): 1-13.

Porter, M. E. and C. v. d. Linde. 1995. Toward a New Conception of the Environment-Competitiveness Relationship. *Journal of Economic Perspectives* 9: 97-118.

Putnam, R. D. 1995. Bowling alone: America's declining social capital. *Journal of Democracy* 6(1): 65-78.

Ring, I. 1997. Evolutionary Strategies in Environmental Policy. *Ecological Economics* 23: 237-250.

Rousseau, D. M., S. B. Sitkin, R. S. Burt, and C. Camerer. 1998. Not so different after all: A cross-discipline view of trust. *Academy of management review* 23(3): 393-404.

Sakr, D., L. Baas, S. El-Haggar, and D. Huisingh. 2011. Critical success and limiting factors for eco-industrial parks: global trends and Egyptian context. *Journal of Cleaner Production* 19(11): 1158-1169.

Scott, J. 2000. *Social Network Analysis, a handbook*. Second ed. London: SAGE Publications Ltd.

Shi, H., J. Tian, and L. Chen. 2012a. China's Quest for Eco-industrial Parks, Part I. *Journal of Industrial Ecology* 16: 8-10.

Shi, H., J. Tian, and L. Chen. 2012b. China's Quest for Eco-Industrial Parks, Part II. *Journal of Industrial Ecology* 16(3): 290-292.

Shi, L. and B. Yu. 2014. Eco-industrial Parks from Strategic Niches to Development Mainstream: The Cases of China. *Sustainability* 6: 6325-6331.

Simboli, A., R. Taddeo, and A. Morgante. 2012. Place-based approaches to industrial ecology. Considerations about the application in long-standing industrial clusters. In *Environment and Energy*, edited by G. Iopollo. Milano: Franco Angeli.

Sterr, T. and T. Ott. 2004. The industrial region as a promising unit for eco-industrial development - reflections, practical experience and establishment of innovative instruments to support industrial ecology. *Journal of Cleaner Production* 12(8-10): 947-965.

Taddeo, R., A. Simboli, and A. Morgante. 2012. Implementing eco-industrial parks in existing clusters. Findings from a historical Italian chemical site. *Journal of Cleaner Production* 33: 22-29.

Ter Wal, A. L. J. and R. A. Boschma. 2008. Applying social network analysis in economic geography: framing some key analytic issues. *The Annals of Regional Science* 43(3): 739-756.

Ter Wal, A. L. J. 2009. The structure and dynamics of knowledge networks: a proximity approachthesis, Faculty of Geosciences, University of Utrecht, Utrecht.

Ter Wal, A. L. J. 2014. The Spatial Dynamics of the Inventor Network in German Biotechnology: Geographical Proximity Versus Triadic Closure. *Economic Geography Research Group* Working Paper Series No. 02.09.

Tong, X. and R. Lifset. 2007. International copper flow network: A blockmodel analysis. *Ecological Economics* 61(2-3): 345-354.

Torre, A. and J.-P. Gilly. 2000. On the analytical dimension of proximity dynamics. *Regional Studies* 34(2): 169-180.

Tsai, W. and S. Ghoshal. 1998. Social Capital and Value Creation: The Role of Intrafirm Networks. *The Academy of Management Journal* 41: 464-476.

UNEP. 2011. Decoupling: natural resource use and environmental impacts from economic growth. *A Report of the Working Group on Decoupling to the International Resource Panel: Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A., Sewerin, S.*

Uzzi, B. 1996. The sources and consequences of embeddedness for economic performance of organizations: the network effect. *American Sociological Review* 61(4): 674-698.

Velenturf, A.P.M. (Under review). Promoting industrial symbiosis: Empirical observations of low-carbon innovations in the Humber region, UK. *Journal of Cleaner Production, Special issue New approaches for transitions to low fossil carbon societies: promoting opportunities for effective development, diffusion and implementation of technologies, policies and strategies.*

Walker, G., B. Kogut, and W. Shan. 1997. Social Capital, Structural Holes and the Formation of an Industry Network. *Organization science* 8(2): 109-125.

White, R. M. 1994. Preface. In *The Greening of Industrial Ecosystems*, edited by B. Allenby and D. Richards. Washington, DC: National Academy Press.

Wuyts, S., M. G. Colombo, S. Dutta, and B. Nooteboom. 2005. Empirical tests of optimal cognitive distance. *Journal of Economic Behavior and Organization* 58(2): 277-302.

Yin, R. K. 2009. *Case study research - design and methods, 4th edition*.

Zhu, L., J. Zhou, Z. Cui, and L. Liu. 2010. A method for controlling enterprises access to an eco-industrial park. *Science of the Total Environment* 408(20): 4817-4825.

Zhu, Q., E. A. Lowe, Y.-a. Wei, and D. Barnes. 2007. Industrial Symbiosis in China: A Case Study of the Guitang Group. *Journal of Industrial Ecology* 11(1): 31-42.

Zukin, S. and P. J. DiMaggio. 1990. Introduction. In *Structures of capital: The social organization of the economy*, edited by S. Zukin and P. J. DiMaggio. Cambridge: Cambridge University Press.

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