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Social Aspects of Industrial Symbiosis Networks

A Thesis submitted in fulfilment of the Degree of Doctor of Philosophy

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I, Teresa Ana Domenech Aparisi, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

ABSTRACT

The field of industrial ecology aims to transform industry into cyclical systems so that the "*waste of one process can be used as resource for another process*" (Frosch and Galloupoulos, 1989). Within this field, Industrial Symbiosis (IS) has emerged as a set of exchange structures to advance to a more eco-efficient industrial system, by establishing inter-organisational networks of waste material and energy exchanges. Even though the area has attracted much academic attention and has been reported to lead to economic and environmental benefits (Chertow and Lombardi, 2005), initially, most of the contributions focused on the engineering and technical feasibility of the exchanges, whereas social elements remained mostly unaddressed. Although relevant literature has partly addressed this gap and recognized the role played by social aspects, there is still little understanding of how social mechanisms work; how they affect the emergence and operation of IS networks and, most importantly, there is a lack of comprehensive frameworks for the analysis of the soft elements of IS. This research has been designed to contribute to these areas, by exploring the social aspects surrounding IS networks and providing a framework for their analysis. The framework provided covers the material, social and discursive dimensions of IS networks and focus on the dynamic analysis of the interaction between them. The research design relies on the cross-comparison of a number of IS networks: Kalundborg (Denmark), Sagunto (Spain) and NISP (UK). Social Network Analysis and Discourse Analysis have been used as main methodological approaches. Findings of the research cover two key areas: 1) the formulation of a comprehensive analytical framework that addresses the social dimension of IS initiatives in a systematic and integrative way and 2) empirical learning on the main social processes affecting the operation of IS networks.

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ACKNOWLEDGEMENTS

This work could have not been possible without the help and support from many people. I would like to take the opportunity here to acknowledge my gratitude to all of them. Any shortcomings or mistakes of the thesis are the solely responsibility of the author.

I would like to start by thanking my supervisor Prof. Michael Davies for guiding me throughout the process of the thesis and for supporting me at all stages. He has been very patient and has always provided invaluable input into my research. This work could not have been done without his help. I would also like to thank my second supervisor Dr Joanna Williams and Prof. Yvonne Rydin for their extremely useful comments, ideas and their mentorship. I would also like to express my gratitude for the help and support of Dr Ben Croxford and all the staff at the Bartlett School of Graduate Studies who have always been willing to share their knowledge and experience with me. Thanks to all of you for being so generous with your time and knowledge and always being ready to give a hand.

I would also like to thank my colleagues in the PhD room for all the good (and sometimes difficult) times we spent together. I feel very lucky for having had the opportunity to meet all the wonderful and bright people here.

Very special thanks goes to my family for being so loving and caring, specially my father and mother, without whom I would have never been able to undertake this project. Also, I would like to thank my brother, aunty, cousins and, of course, my little nephew for being there for me and showing me their unconditional love and understanding. Thank you papa for sending me so many letters and keeping me informed of all that happened in Spain and thanks mama for taking so much care of me and always making sure I was doing fine. Sometimes it is difficult to live far away in a foreign country and I have missed you all a lot, but I am happy for feeling so loved and appreciated.

My special thanks to Filip, moja laska, because all makes sense when he holds my hand. Thanks for being there in the ups and downs of the PhD and, well, for just being.

EXECUTIVE SUMMARY

The growing evidence of the impact of current patterns of production and consumption on natural systems and the recognition of the interconnection of social, economic and environmental dimensions, have called for new policy strategies to face the global challenges of pollution. Sustainable development has progressively gained relevance in the policy arena as a core concept, fostering the emergence of new approaches to guide the change of unsustainable dynamics in the use of resources. The relatively new field of industrial ecology aims to transform industrial systems into cyclical systems so that the "*waste of one process can be used as resource for another process*" (Frosch and Galloupoulos, 1989). Within this field, Industrial Symbiosis (IS) has emerged as a set of exchange structures for progress to a more eco-efficient industrial system, by establishing a collection of webs of material and energy flows among different organisational units. Even though the area has attracted much academic attention and has been reported to lead to economic and environmental benefits (Chertow and Lombardi, 2005), initially, most of the contributions focused on the engineering and technical feasibility of the exchanges, whereas social elements remained mostly unaddressed (Korhonen, 2001). IS exchanges cannot be considered in isolation of the social context in which they take place and the understanding of this context is crucial for the design of policy action to promote IS. Behind the flow of materials in the industrial system there is a complex network of actors, with different and sometimes conflicting, interests, interacting with each other and which are, in fact, defining the actual realisation of the physical flows. Therefore, IS networks are "embedded" (Uzzi, 1996) in social systems and, as such, decision taking processes are shaped by social relations. Aspects such as regulation systems, trust, beliefs and knowledge are crucially influencing the direction and management of physical exchanges. Although recent contributions in the literature have recognized the role played by these aspects, there is still little understanding on how these mechanisms work, how they affect the emergence and operation of IS networks and, most importantly, there is a lack of comprehensive frameworks for the analysis of the soft elements of IS.

Advancement in the field of IS thus requires further investigation of the social mechanisms, which allow IS networks to emerge and thrive and the conditions under which they can lead to the reported outcomes, as well as the design of integrative frameworks for the systematic

analysis of these elements. This research contributes to these areas, by exploring the social aspects surrounding IS networks and providing a framework for the analysis. More concretely, the objective of the study was to bring some understanding about the social and institutional processes that favour the emergence of collaborative structures in environmental issues between independent industrial units and the tacit norms and rules that govern the operation of these cooperative networks. A first step is, necessarily, the definition of an analytical framework, which allows a deeper insight into the processes behind the adoption of IS solutions and provides the basis for the evaluation of the potential contribution of IS to the wider process of sustainable development. In this framework, special attention was given to: a) the analysis of the structure and the formation of social mechanisms of collaboration and b) the discursive elements that shape actors' perceptions and behaviour, shaping the scope of the network.

The research design relies on the cross-comparison of multiple case studies. Three different typologies of IS networks have been selected as case studies: Kalundborg (Denmark), NISP (UK) and Sagunto (Spain). The two first cases stand as "successful" and operational examples of industrial symbiosis networks while the third has been considered as a "deviant case", where IS opportunities are not fully exploited. However, all three cases differ greatly in their structural characteristics. Kalundborg, identified in the literature as a model of industrial symbiosis networks, has been selected as the paradigmatic case. Sagunto can be considered as a kernel of an IS network, where some IS exchanges are taking place but the full potential of IS opportunities is far from being achieved. The contribution of this case is precisely to point out the socio-institutional elements that may hinder the full development of IS relations, even in contexts where there is a combination of activities that provides an ideal material basis for IS exchanges. This case study looks into why, under similar material conditions, the actual emergence and operation of industrial symbiosis networks can result in radically different outcomes, depending on the socio-institutional framework in which they operate. Sagunto, thus, allows to test the hypothesis of the relevance of the socio-institutional scenario in the development of industrial symbiosis networks, beyond the merely material and technical conditions. NISP provides an example of a political driven initiative with a central coordination body. In this case, the focus of the analysis is on how network governance structures can emerge in non-spontaneous networks and on the understanding of the role of the coordination node in the promotion of IS solutions. From a comparative analysis, some structural features of successful networks can be identified, helping to determine the conditions under which IS networks are likely to emerge and develop. From a methodological perspective, the research is based on an innovative design that combines qualitative methods, including grounded theory, ethnography, social networks analysis and content and discourse analysis. The main sources of data have been: a) in-depth interviews carried out with relevant actors involved in the design, creation and operation of industrial symbiosis networks and b) company and policy documents. The analysis of the institutional framework has also involved the review of the regulatory framework and the mapping of institutions and policy analysis.

The main contributions of this research to the field of IS cover two key areas: 1) the formulation of a comprehensive analytical framework that addresses the social dimension of IS initiatives in a systematic and integrative way and 2) empirical learning of the main social processes affecting the operation of IS networks gained through the application of the framework to the analysis of three different typologies of IS networks. Regarding the first contribution, an innovative framework has been designed as part of this research to evaluate the social dimension of IS networks. The conceptual and methodological basis of the framework relies on the combination of elements from Social Network Analysis and Discourse Analysis that have been adapted to the particularities of IS networks. The framework includes three different levels of analysis: 1) the structure and morphology of the network; 2) the social dynamics and processes and 3) the underlying environmental discourse.

On the area of the empirical learning, the application of the analytical framework results in some interesting findings regarding the role played by social aspects in IS networks. In the first place, the research confirms the hypothesis that stresses the key role played by socio-institutional factors in shaping the outcomes from IS networks. The research highlights that even in the presence of favourable material conditions, IS relations are unlikely to develop or acquire richness and complexity unless they are supported by a well-developed knowledge network. The findings also confirm that the knowledge network relies heavily on the degree of development of social mechanisms of control and aspects such as trust and reciprocity. Based on the findings of the case studies, a number of exchange conditions have been identified as prompting the emergence of IS networks: 1) stringent environmental regulations; 2) shortage of essential raw materials and/or the existence of large volumes of high value by-products; 3) the need for customised solutions that require close collaboration between organisations and 4) the existence of an underlying business macroculture of cooperation.

Further development of the network is supported by the parallel development of social mechanisms of control. The research found that social mechanisms of control such as collective sanctions, reputation and a macroculture of cooperation contribute to the process of trust building and creation of general reciprocity; issues that have been identified as essential in increasing the richness and complexity of IS relations and thus the potential outcomes of the cooperation. The research also indicated that the ability of the network to generate positive outcomes both in economic and environmental terms and, especially, its ability to innovate and develop emerging technologies, is related to its degree of embeddedness. Embedded relations have been characterised by four key elements: 1) trust; 2) exchange of fine-grained information; 3) joint problem solving and 4) multiplexity. The case of NISP also provides understanding of the role of coordinator bodies in non-spontaneous networks. This is of utmost relevance in the case of policy-driven strategies, where social mechanisms of control are unlikely to develop naturally and therefore may need to be fostered artificially. The role of coordinator, as concluded for the analysis of NISP, is essential in: a) reducing path distance and facilitating information flows and knowledge transfer and b) removing technological barriers and social obstacles to IS exchanges.

Based on these findings, the research proposes different phases in the process of emergence and development of IS networks: 1) emergence; 2) probation; 3) development and expansion and 4) termination. The organisation of the process into phases is of special importance for analytical purposes and for policy making, as it allows the identification of key factors leading the cooperation process in each of the phases and its potential outcomes. Finally, the research concludes by providing some policy guidelines for the promotion of IS networks and pointing to future research areas that need to be further investigated. Among the policy-making guidelines, long-term policy objectives and clear environmental strategies are crucial in guiding innovation and technological processes. Stringent regulatory frameworks have proved of utmost relevance in fostering IS exchanges and changing the relative prices of less sustainable waste and pollution management strategies. Looking ahead to future work, it is important to emphasise the need for refining the proposed analytical framework and its application to different typologies of networks to build on understanding of the social processes that foster and hinder the further implementation of IS networks. It is also important to further test the causal claim made in this thesis about the connection between the degree of development of the knowledge network and the material/energy network. Moreover, further insights into the processes that foster collaboration and the possibility to be replicated in non-spontaneous networks are needed.

INTRODUCTION

Motivations for the Research

The environmental crisis has stressed the interrelation between social, economic and environmental systems; therefore solutions need necessarily to come from new integrated approaches and perspectives. Sustainability emerged in the last decades as a paradigm shift in the way development problems are framed and addressed. By focusing on the multi-dimensional and co-evolutionary character of development, sustainable development has opened up new paths for the redesign of strategies that try to take onboard economic, social and environmental dimensions. One of the challenging areas of sustainability is concerned with the restructuring of the complex patterns of production and consumption, on the basis of current environmental problems. Industrial ecology (IE) explicitly addresses the sustainability of industrial systems. The overarching aim is the transformation of industrial systems into cyclical systems, so that the "*waste from one industrial process can serve as the raw materials for another*" (Frosch and Gallopoulos, 1989, p. 94). Within this field, Industrial Symbiosis (IS) has emerged as a body of exchange structures to progress to a more eco-efficient industrial system, by establishing a collaborative web of material and energy exchanges among different organisational units.

The field of IE/ IS is very appealing for a number of reasons. As an emerging field, as suggested by Harper and Graedel (2004), there is a need to test the theoretical constructs and generate new knowledge that helps to refine theory; from a methodological point of view, there is also room for the definition of analytical and evaluative frameworks that strengthen the theoretical foundations of the discipline. On a more pragmatic level, progress in the field could assist in opening new paths for the practical implementation of sustainable development and to overcome the complex conflicts it poses. Research in this area aims to define new models for the design of more sustainable industrial systems, and thus, for the greening of the industry.

The overall aim of this thesis is to contribute to the understanding of the social elements that shape the process of emergence and development of IS networks, as an attempt to shed light upon the mechanisms that favour or constrain the development of such initiatives. Although there have been some contributions to addressing the drivers and barriers of IS, the field lacks a comprehensive framework for the evaluation of the social and discursive dimensions of IS. By building on a number of research and knowledge disciplines, the research described in this thesis has developed an innovative methodological and analytical framework that aims to address this gap.

Outline of the Thesis

The thesis has been organized in four main parts and divided into eight chapters, the contents of which are summarized below:

A. LITERATURE REVIEW

Chapter 1. Sustainable Development and Industrial Ecology: Towards an Eco-Industrial Paradigm of Sustainable Development. Building on the concept of sustainable development, this chapter explores the key elements of the emerging field of industrial ecology. The chapter provides an overview of the concept, tools and agenda of industrial ecology and its role in the process of greening industry and progressing towards more sustainable industrial systems.

Chapter 2. Industrial Symbiosis. The focus of Chapter 2 is the inter-organisational level of industrial ecology, that is, industrial symbiosis. Industrial symbiosis looks at networks of companies that engage in mutually beneficial waste, energy, material and knowledge exchanges. This chapter reviews main contributions in the field, paying special attention to the social dimension of these networks. From the literature review, potential opportunities and obstacles that could challenge the further implementation of this approach are identified and examined.

B. METHODOLOGY

Chapter 3. Methodology: Research Design describes the methodology used in the research. The research question and hypotheses are defined and the general research design strategy outlined. Data collection methods and general methodological approaches are explained. Finally, the chapter also discusses the main caveats and limitations of the methodological approach adopted.

Chapter 4. Analytical Framework. Building on the previous chapter, Chapter 4 explicitly deals with the analytical framework designed. In an attempt to contribute to the gap identified in the literature review regarding the lack of comprehensive frameworks for the analysis of the social components of IS networks, this chapter presents the innovative analytical protocol adopted in this research. The framework designed builds on two main methodological approaches: Social Network Theory and Discourse Analysis.

C. ANALYSIS

The findings from the analysis have been divided between three chapters, which present each of the case studies selected. Chapters 5 and 6 are structured in a similar way and the findings are directly comparable. Chapter 7 analyses the case of NISP, a large, non-spontaneous IS network. Due to the substantially different character of the network, the aim of analysis and structure of the chapter differs from previous chapters, although it shares the core elements of the analysis to ensure comparability.

Chapter 5. Case Study: Kalundborg (Denmark) addresses the case of the IS network of Kalundborg, Denmark. Kalundborg has been selected as the paradigmatic case of IS networks. Although the case has been extensively studied in the literature, the contribution of the analysis undertaken in this thesis is to test the novel analytical framework and to contribute to the existing body of knowledge by providing a comprehensive understanding of the key elements that explain the success of this initiative. The analysis covers institutional, social and discursive dimensions.

Chapter 6. Case Study: Sagunto (Spain). The industrial area of Sagunto has been selected as a kernel of an IS network. The combination of activities in the area offers a good material basis for the development of IS network, and has fostered the emergence of a number of IS exchanges among organizations located in the area. However, the full potential of IS is far from being exploited. The chapter presents the findings of the analysis and discusses the social and institutional aspects that explain the underdevelopment of IS relations as well as the prospects of the further development of the network.

Chapter 7. Case Study: NISP (UK), presents the finding of the analysis of NISP, a policy-driven initiative to create IS linkages between companies from a wider spatial (national/regional) perspective. In this case, NISP, a governmental funded organization, acts as a coordinator and facilitator for IS exchanges. Outstanding environmental and economic outcomes have been reported from the first years of operation of the network, but there are important issues that need to be addressed in relation to the opportunities of further development as well as the barriers and obstacles encountered in the realization of IS exchanges. This chapter describes the approach to IS and methodology implemented by NISP. The structural characteristics of NISP are analysed and the role of the coordinator discussed.

D. DISCUSSION AND CONCLUSIONS

Chapter 8. Discussion and Conclusions. Building on the cross-comparison of the case studies, this chapter summarise the main conclusions of the thesis regarding the critical social elements that favour the process of emergence and development of IS networks. Also reference is made to the role of embeddedness in maximizing the benefits of network collaboration. Different phases in the process of building IS networks are identified and key factors highlighted. Finally, a condensed summary of a response to the research question is provided and main courses of action and policy measures to foster the emergence and development of IS networks are discussed.

Related Publications

As part of this research, a number of publications relate to the analysis and main findings of this thesis, including four international refereed journal papers and several refereed conference papers and presentations. The content of the four journal papers is briefly outlined below.

Domenech and Davies (2009) **"Social aspects of industrial symbiosis: the application of social network analysis to industrial symbiosis networks",** *Progress in Industrial Ecology - An International Journal (Special issue on System Boundaries of Industrial Symbiosis)*, **5** (5-6): 68-99.

This paper explores the potential of the application of social network analysis (SNA) and network theory to the field of Industrial Symbiosis (IS), both as a methodological stance and as a conceptual framework, as a way to approach an understanding of the complexity of IS networks. The paper discusses how SNA could provide a comprehensive framework for the understanding of the social aspects behind material and energy exchanges. A methodological protocol is proposed to address social and institutional aspects of IS.

Domenech and Davies (2009) **"The Role of Industrial Symbiosis in Sustainable Development",** *the International Journal of Environmental, Cultural, Economic and Social Sustainability*, **5** (3): 173-188.

This paper critically examines the contribution of IS networks to Sustainable Development and the role that discourse may play in shaping the actual scope and outcomes of industrial symbiosis networks. The paper discusses the potential of this approach to understand the process of formation and development of IS networks and proposes methodological guidelines for the application of discourse analysis to IS. The role of IS networks in moving towards more sustainable paths of industrial development is reviewed and limitations and contradictions of the process unveiled.

Domenech and Davies (2010) **"The Role of Embeddedness in Industrial Symbiosis Networks: Phases in the evolution of industrial symbiosis networks",** *Business Strategy and the Environment, Special Issue on Industrial Symbiosis*. First version received January 2009; Revised: June 2009; Accepted July 2009 (in press).

This paper further investigates the process of emergence and development of IS networks from an evolutionary perspective. Based on the theoretical framework provided by social network analysis and economic geography and the empirical data collected through qualitative methods, a modelling framework to analyse the main mechanisms in the building of trust and embeddedness is proposed and different phases in cooperation leading to effective IS exchanges identified.

Domenech and Davies (2010) **"Structure and Morphology of Industrial Symbiosis Networks: the Case of Kalundborg",** Procedia- Social and Behavioural Sciences. Accepted: January, 2010 (in press).

Based on the analytical framework presented in the first paper, this article provides methodological guidance for the application of SNA to the field of IS, based on the case study of Kalundborg. A detailed analysis of the structure and morphology of the network is presented. The paper provides a close look at the patterns of interaction and how these influence the outcome of collaboration, both in economic and environmental terms. The paper concludes that SNA proves to be useful in the analysis of the structural characteristics and morphology of the network and the understanding of the role that different actors play.

A. LITERATURE REVIEW

The aim of the literature review is to examine the theoretical foundations that frame the study. It focuses on the analysis of the research fields of Industrial Ecology (IE) and Industrial Symbiosis (IS), within the wider framework of Sustainable Development. For organisational purposes, the literature review has been divided into two chapters.

Chapter 1 provides an overview of the research field of industrial ecology. The first section briefly outlines the concept of sustainable development and investigates its contested nature. Within the area of sustainability, the field of industrial ecology is then examined. The chapter explores the core elements that define IE, the main tools and approaches it comprises and its policy agenda. Lastly, at the level of the practical implementation of IE, the concept of industrial symbiosis is introduced, which would be the focus of the next chapter.

Chapter 2 specifically addresses the inter-organisational dimension of IE. This chapter outlines the role of IS networks in moving towards more eco-efficient industrial systems. The chapter reviews the concept of IS and its practical implementation. As the main focus of this thesis, the main contributions addressing the social dimension of IS networks are examined.

Chapter 1.
Sustainable Development and the Greening of Industry: Towards an Eco-Industrial Paradigm of Industrial Development

The aim of this chapter is to explore the connections between the fields of sustainable development and industrial ecology. Sustainable development has become a new paradigm that points to the restructuring of social and economic systems in a more balanced way and in co-evolution with natural systems. Within this new paradigm, industrial ecology focuses on the industrial metabolism and production processes. Industrial ecology proposes a new way of understanding industrial development that puts the emphasis on eco-efficiency and closing the loop of industrial systems, overcoming the traditional conflict between industrial development and environmental protection.

1.1 Sustainable Development

1.1.1 Sustainability: The Concept

The rapid and steady economic development in modern societies has resulted in a parallel process of degradation of natural systems worldwide. Natural resources have been extracted and consumed at a faster rate than that of regeneration, emissions derived from the use of fossil fuels have been released to the atmosphere and hazard waste and chemical compounds have been dumped into natural ecosystems. This has led to the degradation of eco-systems and, thus, to the diminishing of their capacity to provide resources and life-sustaining services such as clean air or water (Hark Park and Labys, 1998). Awareness of the changes operated in natural ecosystems has led to the reconsideration of the interaction between social, economic and natural systems, and has stressed the need to shift from a conflict to a co-evolutionary perspective. In this context, sustainable development emerged as a new paradigm for the balanced interaction and mutual reinforcing relationship of natural, economic and social systems. As Rees (1989, p. 13) noted:

> *"Sustainable Development is positive socioeconomic change that does not undermine the ecological and social systems upon which communities and society are dependent. Its successful implementation requires integrated policy, planning, and social learning*

processes; its political viability depends on the full support of the people it affects through their governments, their social institutions and their private activities"

Sustainable development, therefore, entails a comprehensive process of social, economical and political change. As Holling (2001, p.390) argues, key to this process is adaptive capability:

> *"Sustainability is the capacity to create, test, and maintain adaptive capability. Development is the process of creating, testing, and maintaining opportunity. The phrase that combines the two, "sustainable development" thus refers to the goal of fostering adaptive capabilities and creating opportunities. It is therefore not an oxymoron but a term that describes a logical partnership"*

Although the origins of the term can be traced back to the 1970s, it was not until later, when *Our Common Future*, better known as the *Brundtland Report* (World Commission on Environment and Development, 1987), popularised the term, bringing it to the front of the policy arena. Indeed, this report presented a very appealing definition of sustainable development, simple but catching, that seemed to embrace the conflicts of the modern (post-modern) era. According to this report, sustainable development would make it possible "*to meet the needs and aspirations of the present (society) without compromising the ability to meet those of the future*". As emphasised by Edwards (2005), the Brundtland report contributed in at least two main ways to the articulation of sustainability: Institutionally, it defined an integrative framework for a new understanding of the main conflicts and contradictions of the modern world (environmental degradation, poverty and exclusions, resources distribution, North/south fracture, etc...) and, conceptually, it emphasised the interaction within the three main spheres of sustainability (environment, economy and social equity). According to this, sustainable development stresses the connection between economic, environmental and social spheres and understands that the achievement of environmental quality cannot be isolated from the processes of economic and social development (Downs, 2000). A much discussed issue has been the association made in the Brundtland Report between poverty and environmental degradation (see, for examples, Duraiappah, 1999).

Five years after the publication of the Brundtland report, the UN Conference on Environment and Development, the "Earth Summit", held in Rio in 1992, set sustainable development at the centre of the policy debate. The conclusion of the conferences were reflected in a number of documents and agreements, among which, the most important are: a) The "Rio Declaration", which contained 27 principles for the integration of environment and development; b) the Agenda 21, an action plan that covers a diversity of areas and aims to turn sustainability into action in the 21st century; c) The UN convention on Biological Diversity and d) the UN framework Convention on Climate Change, that established the basis for the Kyoto protocol. In 2002, the UN Conference on Sustainable Development, held in Johannesburg, reviewed the situation 10 years after the Summit in Rio. The main outcome of that conference was the "Johannesburg Declaration on Sustainable Development" that focuses on the means and approaches to put sustainability into practice, paying special attention to the integration of the social, economic and environmental dimensions of sustainability.

Sustainable development has successfully managed to be integrated in the policy agendas of most governments. However, the institutionalisation of the concept has not always been accompanied by a practical implementation of sustainable principles, and the integration of the environmental variable in the decision making processes of policy and economic actors is far from being achieved in many cases. Some approaches have attempted in the last decades to operationalise the concept of sustainability, by defining new paths of change towards a better integration of economic, social and environmental system. Before reviewing these approaches, it is necessary to outline the main perspectives on sustainability and operating principles.

1.1.2 Perspectives on Sustainability: Weak vs. Strong Sustainability

Sustainable development has been conceived as a desirable goal for some and as a paradigm shift for others (Downs, 2000). The ambiguity contained in the term has given rise to different interpretations, ranging from maintenance of the status quo with small changes, to major structural changes in the way societal and economic systems are organised, becoming an umbrella term for a multiplicity of approaches.

The range of interpretations of sustainability has been captured in two contrasting views: weak sustainability vs. strong sustainability. These two perspectives have concentrated the academic debate on the assumptions made about the degree of substitutability between natural and manmade or manufactured capital (Ayres and Ayres, 1998).

The perspective of weak sustainability assumes that there is a perfect (or quasi-perfect) substitutability between man-made and natural capital (Pearce and Turner, 1990). Therefore, a sustainable economy, from this point of view, should aim at maintaining or increasing the total stock of capital over the years. The process of environmental degradation (or diminishing of natural capital) is not critical as long as it is compensated with an increase of manufactured capital, including human capital. This position fits within the neoclassic economics of utility maximisation models, where welfare is equivalent to utility, measured as aggregated consumption.

From the perspective of strong sustainability, the idea of sustainable development is associated with the maintenance or improvement of the life or realisation opportunities of human societies (Daly and Cobb, 1989), overcoming the material dimension of "happiness" or welfare associated with consumption. Within this perspective, it is assumed that minimum amounts of different types of capital (technology, human capital, natural capital) are essential for the productivity of the other factors. Therefore, different types of capital can only be substituted to a certain degree, beyond which they become complementary. Natural critical capital refers to this minimum amount of natural capital that needs to be secured to guarantee the production of the other types of capital. Moreover, some forms of natural capital are subjected to irreversible processes of environmental degradation and cannot be substituted by manmade artefacts or systems. The levels of substitutability and complementarity vary according to different authors, as well as the determination of the levels of natural critical capital. The right of existence of nature, independently of its "utility" to human societies is also recognised from the point of view of Deep Ecology (Ayres and Ayres., 1998).

1.1.3 The Principles of Sustainable Development

As the previous section has highlighted, even though there is a wide agreement on the normative dimension of sustainable development, disagreement can be found in its interpretation and implementation. Thus, although much has been advanced in the institutionalisation of the term, its operationalisation remains still a largely discussed issue. The definition of "sustainable principles", as a guiding tool, has been said to contribute to the practical implementation of sustainability.

Costanza and Daly (1992), within the approach of strong sustainability, defined the following set of principles for the move towards more sustainable scenarios: 1) limit the "human scale" within the carrying capacity of the biosphere; 2) the technological path should be directed towards achieving improvements in efficiency rather than to increase the throughput; 3) renewable natural capital, both in its resource as in its sink functions, should be maintained, which implies that (Daly, 1990): a) harvesting rates should not exceed regeneration rates and b) waste emission rates should equal natural assimilation capacity of the ecosystem; and 4) non-renewable natural capital should be exploited in a "quasi-sustainable" way, that is, "at a rate equal to the creation of renewable substitutes" (Daly, 1991, p.45), where part of the benefits obtained from the exploitation of non-renewable resources are invested in the development of a renewable substitute.

However, as expected, the diversity of perspectives contained within the sustainable development framework also crystallises in a myriad of guiding principles. Different actors define and select different principles in their strategic approach to sustainability. The UK government, for example, in the strategic document "securing our Future" (HM Government, 2005), agreed in the selection of four priority areas of action in sustainable development: sustainable consumption and production, climate change and energy, natural resource protection and environmental enhancement and sustainable communities. Moreover, it agreed upon a set of shared sustainability principles that must be respected for a policy to be sustainable: a) living within environmental limits, b) ensuring a strong, healthy and just society, c) achieving a sustainable economy, d) using sound science responsibly and e) promoting good governance. A more concrete and comprehensive set of principles is that contained in the NEPP, the Netherlands National Environmental Policy Plan, enacted in 1989 and updated on a four-year basis. Some of the major principles that guide the NEPP are the following (Edward, 2005): intergenerational equity, precautionary principle, the standstill principle, abatement at source, polluter pays principle, use of the Best Available Technology (BAT), prevention, integrated life cycle management and environmental space.

Notwithstanding the disparity and diversity in the principles of sustainable development, the very process of their definition has stimulated the debate upon the desirable path of development and progress and the connection between natural and social systems. However, in advancing towards more sustainable scenarios, together with guiding principles, the design of new approaches, tools and methods for achieving them is necessary. The next section discusses the role of industrial ecology in redefining the role of industry in the process of sustainable development.

1.1.4 Methods and Approaches of Sustainable Development: Industrial Ecology

One of the most common criticisms of the concept of "sustainable development" points to its vagueness and its inability to provide concrete choices, which has led in some cases to its indiscriminate or inappropriate use. To counteract this, some attempts have been made to provide new approaches and tools which help to give concrete and practical content to the concept. Under the umbrella of sustainable development, new approaches, tools and instruments have been defined to support the application of the principles of sustainability to the processes, procedures, practices, norms and rules that shape the actual interaction between natural and anthropogenic systems. Among these approaches, industrial ecology stands for a new way of conceiving the resource flow in the economy so that they mimic the resource and energy efficient cycle of natural systems. Indeed, industrial ecology has also been referred to as the "science of sustainability" (Powers and Chertow, 1997. P.26). In stressing the compatibility between economic and environmental spheres, industrial ecology has been devised as one of the "paths" to make "*sustainable development.... operational in an economically feasible way*" (Erkman, 1997, p. 2), overcoming the traditional opposition between industrial development and environmental protection. The next sections explore the concept of industrial ecology and its contribution to sustainability.

1.2 Industrial Ecology: Overcoming Antagonisms

The concept of industrial ecology is very appealing as it joins two aspects that have traditionally been considered as opposed: industry and ecology. Industry has played a major role in improving the standard of living in modern societies. However, despite its achievements, the growing capacity of transformation of industry has also had an increasing impact on ecological systems. The over exploitation of natural resources and the intensive use of fossil energy sources, have generated an increasing volume of emissions, effluents and wastes that have been dumped on natural ecosystems, causing a degradation of their carrying capacity. The planetary scale of these changes caused by human activity in natural ecosystems has led to the move from local pollution to the era of *global change*. Industry, among other human activities, has been identified as a major inductor of the degradation process and critiques have been raised about the sustainability of the actual pattern of development and the future of industry. Even when more developed countries have been showing an absolute or relative delinking of economic growth and environmental impact (Janicke et al., 1989), it is not clear if the actual "national" delinking has been based on any improvement of eco-efficiency and reduction of the material basis of the economy or, on the contrary, it is consequence of the process of "exporting" polluting activities into less developed countries, where environmental requirements are less stringent and costs of production are in general lower. Notwithstanding the relevance of this discussion, and accepting the need to move towards a more "dematerialised" economy, human development has a material basis that needs to be satisfied by a more eco-efficient industrial sector. The implication is that major changes in the production patterns need to be undertaken if sustainable development is the goal.

In this context, industrial ecology aims to overcome the antagonism between industrial production and environmental degradation by pointing to a new understanding of the binomial industry-nature by bridging the gap and establishing a more harmonic relationship between them. According to this perspective, natural ecosystems are taken as archetypes which industry systems should strive towards in order to achieve higher levels of eco-efficiency.

Industrial ecology envisages a number of sustainable scenarios that could be achieved by the reorganisation of industrial systems into more organic elements. With this approach, increasing the level of complexity of industrial sectors and closing the loop of production and consumption are identified as major goals. The definition of industrial ecology proposed by Lowe and Evans (1995, p. 47) captures this by defining industrial ecology as a:

> *"...framework for environmental management, seeking transformation of the industrial system in order to match its inputs and outputs to planetary and local carrying capacity. A central industrial ecology goal is to move from a linear to a close-loop system in all realms of human production and consumption"*

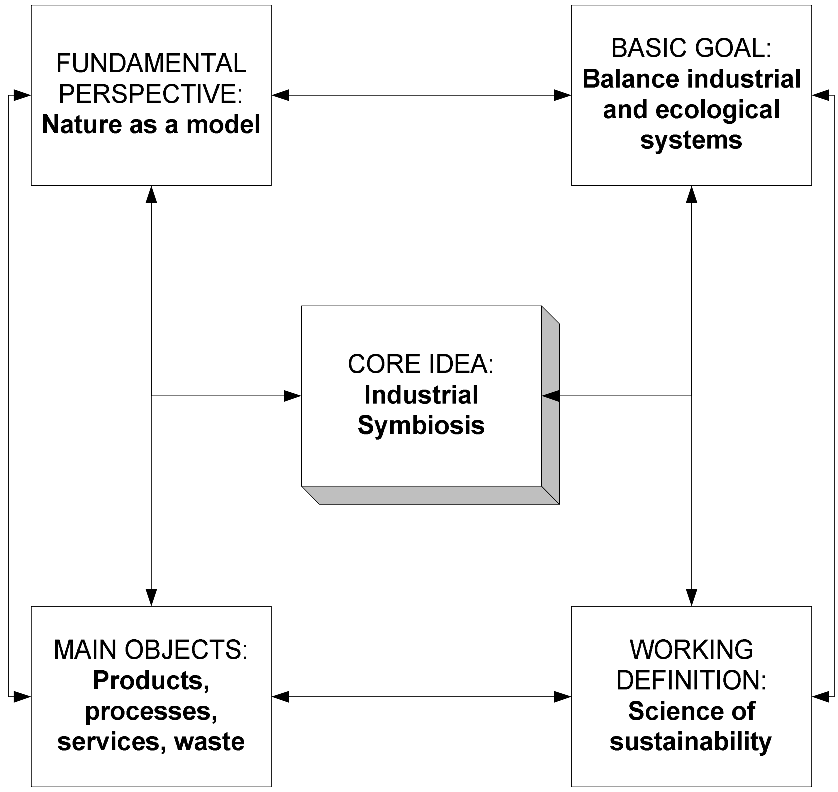
However, the most often cited and, probably, the first attempt to define industrial ecology comes from Frosch and Gallopoulos (1989, p.144), who defined it as a system in which *"the* *consumption of energy and materials is optimised, waste generation is minimised and the effluent of one process…serve as the raw materials for another process"*.

Although first contributions in the field of IE pointed to the lack of a precise definition or the confusion of terms and approaches encompassed within the IE framework (Sagar and Frosch, 1997), important progress has been taking place to offer more precise boundaries for this analytical framework (Allenby, 2006; Boon and Bass, 1997). A comprehensive definition of IE is given by Graedel and Allenby (1995, p.9):

> *"Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital"*

In an attempt to contribute to the creation of a more consistent definition of IE, while recognizing the diversity of perspectives, approaches and ideas contained in the term, Isenmann (2003) proposed a framework to the concept, that builds on five distinctive areas: 1) the core idea, 2) the fundamental perspective, 3) basic goal, 4) working definition and 5) main objects. Following this framework, the core idea of IE relates to the concept of system view, in which human and natural systems are bounded by material and energy flows. The fundamental perspective of IE refers to the ecological metaphor, according to which nature is taken as a model for inspiring the reorganization of industrial systems. The basic goal points to the rebalancing of the interaction of industrial and natural systems, so that industrial systems adapt to the constraints and dynamics set by natural support systems. The working definition considers the elements mentioned before and integrates IE within the "science of sustainability". Finally, IE focuses on a diversity of "objects" that vary between products, processes, services and wastes at different spatial scales.

Figure 1.1: Elements of industrial ecology



\Source: Isenmann, 2003.

All these definitions emphasize the system perspective introduced by IE. Beyond the materials/ energy exchanges, a feature that forms part of the history of industrial systems (see a comprehensive account of the history of materials/ energy by-product exchanges in Desrochers, 2002), the real innovation of IE is to provide a systemic perspective on the operation of industrial activities and resource flows in the economy. As Sagar and Frosch (1997, p. 40) stated, IE "*refers to an integrated, systems-perspective examination of the nexus of industry and environment*". Therefore, it can be concluded that IE stands as an analytical framework that offers an innovative way of thinking (or re-thinking) the industrial sector, from a system-oriented perspective. This implies considering industrial units and processes not in isolation but as a part of an interacting and integrated system, where material and energy flow are circulated and re-circulated throughout the system. Although, as an analytical framework, IE is composed of a multiplicity of approaches, tools and analytical instruments, all these elements entail a clear goal or mission, related to closing the loop of industrial systems and moving towards more eco-efficient and sustainable scenarios for industry.

1.2.1 The Core Elements of Industrial Ecology

Independently from the definition adopted and following Erkman (2001), some core elements of IE can be identified:

a) It is a systematic, integrative and comprehensive approach to the industrial system in its relation with the natural system. As Korhonen (2005, p.86) affirms, it is this systemic approach the "*specific and unique contribution of the field of industrial ecology to sustainability*".

b) The emphasis is put on the "*biophysical substratum of human activities*" and the "*patterns of material and energy flow within and outside the industrial system*" (Erkman, 2001, p.531).

c) It considers the technological trajectories and engineering of processes as having a crucial, although not exclusive (and not sufficient on their own) role, in the transition from a linear to a cyclical industrial system

1.2.2 Operational and Related Concepts within IE

Within IE, a myriad of related concepts has emerged, which appeal to different perspectives with distinctive focus. Two main complementary approaches have been developed within the field of IE: a) the "industrial metabolism" approach, which explores the circulation of material and substance flows and b) The "industrial symbiosis" approach, which focuses on the networking and coordination of actors for the recirculation/reuse and recycle of waste flows within a defined boundary. It is important to note that although these terms have been used in many cases as synonyms, they specifically refer to different areas and/or approaches.

The term "industrial metabolism" is mainly concerned with the study of materials and energy flows of the industrial system. Based on the biological concept of "metabolism", by which an organism ingests a certain amount of materials to provide for its own subsistence and reproduction and generates waste outputs in the process of assimilation, the concept of industrial metabolism points to the analogy between biological and industrial processes. According to this view, industrial systems are seen as a "*collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes*" (Ayres 1994, p.3). The basic idea behind this concept is, that industrial systems, and more generally, human systems, are "*embedded into the biosphere-geosphere system and are thus dependant on factors critical for the co-existence of both systems*" (Bringezu, 2003, p. 20). The industrial metabolism approach aims to a more sustainable industrial system "*characterised by minimised physical exchanges with the environment, with the internal material loops being driven by renewable energy flows*" (Bringezu, 2003, p. 20). This concept is mostly used in the context of material flow analysis, and aims at the understanding of the circulation of materials in human systems in interaction with natural systems.

Industrial symbiosis, although closely related to the theoretical foundation provided by the "industrial metabolism" approach, is mainly concerned with the introduction of an integrated approach to the managing of waste flows across companies and market sectors. The term emphasizes the idea that cooperation and networking between separate economic units can contribute to improving the overall eco-efficiency of the industrial sector, by favouring the achievement of synergies and the exchange and (re-) utilization of waste material and energy flows. As a main focus of this thesis, this concept will be analysed in more detail in Chapter 2.

1.2.3 The Ecological Metaphor

Independently of the approach adopted, and as noted by Isenmann (2003), at the core of the IE framework lies the basic conception of the interaction between natural and social systems captured by the "ecological metaphor" (Ehrenfeld, 2003). The ecological metaphor compares the efficient operation of ecosystems where resources and materials are continuously reprocessed and reused, assimilating waste to resources, as waste from one process or organism is a resource for another process or organism, to the wasteful and inefficient operation of industrial systems, where the conversion of wastes into resources is far from being achieved. The basic idea behind the captivating image of the "ecological metaphor" is that, the functioning of natural systems, with an efficient biological cycling of material flows throughout the system, maintained by the self-coordinated activity of producers (plants), consumers (animals) and decomposers (fungi and bacteria), can serve as a model for the reorganisation of the societal systems of production and consumption. Graedel (1996) explored the biological characteristics of an organism and discussed the degree to which they can be extrapolated to industrial or social "organisms". From the comparison between industrial and biological system, he concluded that the main differences were: 1) the role of the decomposer is undertaken in industrial systems by the recycler, b) the industrial system has an additional actor, which is the disassembler and, finally and fundamentally, c) whereas high efficiency in the use of resources is achieved in natural systems, industrial systems generated great losses of resources throughout the process. Other differences are the divergence in the time scales when comparing biological processes and industrial systems (Ayres and Ayres, 2002) and the physical proximity and functional matching between the producers and the consumers in natural systems, in comparison to the displacement between production and consumption in industrial activities. The "ecological metaphor" thus aims at inspiring the transformation of industrial systems by mimicking the efficient energy and material flows in natural ecosystems. Indeed, Korhonen (2001) suggested that the divergence of the "principles of system development" between industrial and natural systems is the main source of friction and environmental degradation.

The ecological metaphor identifies a core of features in biological systems that "should" be mimicked by industrial systems (Boons and Baas, 1997):

a) Energy requirements, consumption of scarce materials and waste generation should be minimized.
b) Waste flows should be used as raw materials for industrial processes, mimicking the cycling of nutrients in biological systems
c) The system should be "diverse and resilient", so that it can recover easily from shocks.

Similarly, Korhonen (2001) proposed some desirable "ecosystem principles" to be applied to industrial systems, in moving towards the ideal industrial eco-system, where the industrial system is embedded in the natural support system, and where the only energy input outside the system comes from the sun and the only waste generated is dissipated heat or energy. Although this ideal scenario is arguably achievable, it serves, as the ecological analogy, as orientation for action. Four ecosystem principles are identified as relevant for the transformation of industrial systems: a) roundput, which refers to the circulation of matter and cascading of energy throughout the system, b) diversity, that points to the increase of diversity in actors, inputs and outputs of the industrial system, c) locality, referring to the local utilisation of resources and waste flows, and operation within the restrictions posed by local ecosystems and d) gradual change, which points to the gradual evolution towards more eco-efficient scenarios in the use of matter and energy.

1.2.4 The Critiques to the Ecological Metaphor

Even though the strength of the industrial ecosystem metaphor as an inspiration has been widely recognised (Boons and Baas, 1997, Korhonen, 2001), critiques have also been raised by the partial, and sometimes idealised, vision of the functioning of natural ecosystems captured in the metaphor and its "*appropriateness and pragmatic value*" questioned (Ehrenfeld, 2004, p. 825).

A first remark is the recurrent confusion in the literature between the terms "ecological metaphor" and the "ecosystem analogue" (Husar, 1994). Ehrenfeld (2003) explores the differences in meaning and prescriptive implications between the two concepts. Although the terms metaphor and analogue are semantically close, they do refer to different phenomena. The term metaphor refers to a "*figure of speech that is suggestive or transformative*" (Ehrenfeld, 2003, p.2), it is therefore, a rhetorical device to transform cognitive structures and promote creative thinking. On the other hand, the term analogy is used to compare two situations that are rendered similar and therefore it suggest the application of related solutions to address the problem "*based on the presumption that the same rules apply*" (Ehrenfeld, 2003, p.1). Thus, the implications of using one term or another in industrial ecology are significantly different. While the ecological metaphor would imply only inspirational thoughts of restructuring the industrial system looking at the nature and the way it organises itself, the ecological analogy or ecosystem analogy would assume that the two systems are operating under the same rules, something far more challenging to probe. As Ehrenfeld (2003, p.2) stresses "*a metaphor is never wrong or incorrect; it is only useful or incorrect; it is only useful or not. An analogy may be objectively false*".

Boons and Baas (1997) also observed that the use of the ecological metaphor could mistakenly lead to the assumption that industrial and natural systems are ruled or can be ruled by the same set of principles or modes of operation. By stressing the differences between natural and social systems, especially in regard to the way coordination is conceived, the authors restrict the terms in which the ecological metaphor should be employed. In biological systems the evolutionary mechanism generally leads, through an algorithm process of selection and adaptation, to more efficient states. Therefore, it could be stated that coordination occurs spontaneously in natural systems and it is not the result of a consciously designed process. In social systems, however, such as industrial systems, coordination is in most of the cases generated by an intentional action by a group of actors. Therefore, striving towards a more resource-efficient industrial system is unlikely to be the result of a spontaneous process. From the perspective of environmental economics, the "intentional action" could be substituted by a comprehensive price system, which includes the cost of substitution and the real scarcity of the "environmental goods". This position has also raised many criticisms in regard to the limitation of monetary valuing of natural resources and environmental services (a general outline of this debate can be found in Turner, 2001). Moreover, aspects such as social values, trust, adequate behaviour or corporate responsibility are also shaping "intention" and when embedded in business practices, could lead to a situation of spontaneous coordination and cooperation as is the case with the industrial symbiosis network of Kalundborg, one of the case studies examined in this research, which seems to point in this direction.

Isenmann (2003) focused his analysis on unveiling the "hidden philosophy" of nature, by analysing the assumptions about the functioning of nature, and the "relationship between human and nature", underlying the epistemological foundation of industrial ecology. The author stressed the need to revise the use of the ecological metaphor or analogy, without making a distinction between them. According to Isenmann, the use of the metaphor is fully appropriate and legitimate in the "context of discovery", where it can render as a fruitful inspiration and source of new insights and ideas; the author, however, questioned its application to the "context of justification" as a "means for logical proof", where it can lead to "pitfalls and fallacies", and therefore, unless it has been properly developed and grounded in a conceptual framework, the use of metaphor and analogies should be avoided in the context of justification and proof of scientifically validity.

Critiques have also been raised in relation with the idealised vision of "nature" and the operation of natural systems made by IE. These critiques emphasise the very partial and incomplete vision of the biological processes presented in the ecological metaphor. As pointed out by Wells (2006), natural eco-systems are rarely in equilibrium stages, but rather in semi-equilibrium, achieved through evolutionary processes, in a different time scale from human systems. Imbalances of natural eco-systems are also common. In this archetypical vision of nature, every element in an ecosystem has a mutually beneficial relationship with the others; the term symbiosis has been restricted to mutualism, whereas the symbiotic relationships of parasitism and commensalism have been ignored in the vision of nature presented by IE. It is also assumed that no waste is generated in natural processes. However, natural processes also generate waste and there is not always a "solution" or an alternative use (an example of waste generated by natural systems is the calcite $CaCO_3$ accumulation) (Adams and Deutz, 2006).

Therefore, it can be concluded that there is a wide consensus in the discipline about the value of the ecological metaphor as: a) an inspirational and catching image and b) a source of innovation and learning. IE can invoke some of the ecosystem principles such as connectedness, closed loops, diversity, locality or evolutionary process (Korhonen, 2001) as a creative inspiration without assuming that both systems, natural and social, are going to operate under the same dynamics. From the metaphor new rules and practices can also be derived, that can indeed be based on an analogy, that is, what Ehrenfeld (2003) refers to as "analogy-learning", but they can also be transformed by cognitive processes (deduction or reinterpretation). However, restrictions in its use have still to be scientifically explored, so that: a) analysis does not fall into simplifications and b) it allows the understanding of the cognitive element behind the assumed interaction between nature and social systems, that means, to make explicit the assumptions behind the image.

1.2.5 IE's Toolbox

The development of the field of IE has run parallel to the development or adaptation of sophisticated analytical tools to orientate and assess the progress made towards more sustainable ways of operation of industry. Although not exclusive some of the most relevant tools employed in IE are: a) green design, b) life cycle analysis (LCA), c) Material Input-Output analysis and, principally, d) Material/ Substance Flow Analysis.

Green Design and Life Cycle Analysis (LCA) are regarded as relevant tools in IE for their potential contribution to the target of optimization of material and energy flows (Sagar and Frosch, 1997 and Chertow, 2000). Green Design refers to "*methodologies or algorithms for selecting among a set of design choices to minimize the estimable environmental impacts associated with the production of an item*" (Sagar and Frosch, 1997, p.40).

Life Cycle Analysis/ Assessment (LCA) is a well-developed tool within the field of sustainability that assesses the environmental impacts of a product/process over its complete life cycle, that is, from the design phase to the final disposal. The series of environmental management standards ISO 14,000 refer to the procedure of LCA in the standards: ISO 14,040 and 14,044. As pointed out by Chertow (2000), LCA incorporates a wider perspective as it is not limited to the boundaries or a firm or facility, covering the entire life cycle of a product/process and identifying the impacts generated in each of the phases involving different actors/ units; therefore, it can be of relevance in assessing potential symbiotic opportunities at different phases of the productive process.

Material input-output, also called hybrid-unit input-output tables, is based on the adaptation of the economic information contained in standard input-output tables to the identification of the materials flows throughout the economy. For this, multiple units, generally a physical unit and monetary values are adopted. This allows the identification of the flows of material throughout the economic system and assessment of the degree to which "*dematerialisation*" or "*rematerialisation*" is occurring. Applied to IE, hybrid input-output tables help to track the flows of materials through the system (Hoekstra and Van den Bergh, 2006).

Assessment of industrial metabolism has in the Material Flow Analysis (MFA) its main tool. MFA can be described as a method that "describes and analyses the material balances of a system" (Lang et al., 2006, p. 106). MFA has been applied to different boundaries from industry to regional and national studies, with different levels of success (Binder, 2007). The principles behind MFA are based on thermodynamics and the conservation law. The flow of a material or substance (substance flow analysis) is tracked throughout the system and the "losses" identified. Tracking of materials helps in the process of optimisation of material and waste flows and in identification of synergies. However, despite the growing number of studies on MFA (Ayres and Ayres, 1996), there is still "*no general framework on*

MFA" (Binder, 2007, p.1597) and the availability and quality of data on which MFA is based are still low (Bringezu, 2003 and Binder, 2007).

1.2.6 IE Agenda: Transitional Stages towards Industrial Ecology Development

Although the field of IE has been mainly addressed by engineering approaches that focus on closing the material loop, there have also been attempts to contribute to the understanding of the process of transition to more cyclical industrial systems. Assuming the hypothesis that the transition towards an industrial sustainable system is an "evolutionary step" (Jelinski et al., 1992 and Wallner, 1999), the evolutionary systems approach offers a framework for the analysis of the evolution towards industrial systems inspired by industrial ecology principles. This would lead to a scenario defined by high complexity and interaction.

Jelinski et al. (1992) proposes a conceptual model for industrial ecology development based on these premises. This model differentiates between *type I, type II and type III ecosystems* that represent divergent levels of complexity and interaction. Type I ecosystems describe linear materials flows, where the "*flow of material from one stage to the next is independent of all other flows*" (p.793). Type I ecosystems are thus rather simple and immature, and they rely on unlimited resources and generate large volumes of waste. Traditional industrial systems can be assimilated to Type I ecosystems, with a linear flow from resources extracted from the ecosphere and transformed into products and waste. As noted by Jelinski et al., "*materials are degraded, dispersed, and lost in the course of a single normal use, mimicking the Type I unconstrained resource diagram*"(p.794). Type II systems, are increasingly complex. In such a system, where resources are limited, the components of the system become embedded in highly interlinked networks, with increasingly complex patterns of material flow. However, these material flows occur normally within the "*proximal domain*", being the flows "*into and out of that domain*" (for example, from resources to wastes) rather uncommon. Although type II ecosystems, with semi-cyclical flows, are more efficient than the type I, they are still unsustainable, as the resources are "*running down*". Some industrial activities, such as some cement production complexes, may demonstrate ecological type II behaviour. Finally, type III ecosystems are presented as "*completely cyclical (….), with resources and waste being undefined, as waste to one component of the system represents resources to another*"(p.793). The relative scarcity of resources and the problems in dealing and managing an increasingly high volume of waste are prompting the industrial sector to "*move from "linear (type I) to semi-cyclical (type II) modes of operation"* (Jelinski et al., 1992, p.794). This evolution from a linear to a closed-loop system is the central goal of industrial ecology, "*seeking the transformation of the industrial system in order to match its inputs and outputs to planetary and local carrying capacity*" (Lowe and Evans, 1995, p.47).

On a more action-oriented level, Erkman (2001) highlighted the key strategies that the industrial ecology agenda must address in order to facilitate the evolution of the industrial system towards a more sustainable mode compatible with the carrying capacity of the biosphere and the satisfaction of societal standards of development. The author points to the following strategy-lines:

a) Waste and by-products must systematically be exploited

b) Exchange networks between companies have to be fostered so that the wastes can be transformed into usable materials and reintroduced in the industrial process. The crucial link between producers of wastes and consumers has to be facilitated by a spectrum of waste management companies that undertake the necessary adaptation and transformation of wastes into valuable raw materials.

c) Loss caused by dispersion must be minimised. Inefficient product processes and inadequate product use can lead to the dispersion of materials and energy, without serving any purpose. Dispersion, apart from having a negative impact on the environment and being economically irrational, reduces the technical and economical feasibility of recycling activities. Example of dispersion can be found in the use of products such as chemicals, fertilisers or solvents, which may eventually become ecological hazards.

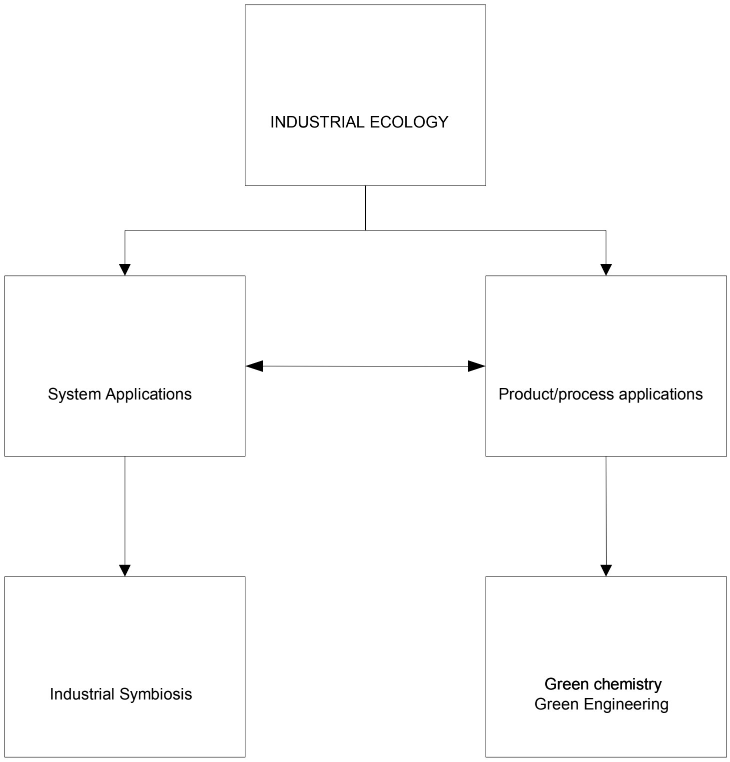
d) The economy must be dematerialised. Minimising the total flows of materials and energy while maintaining or increasing the services provided should also be stated as a goal of industrial ecology. This objective contradicts some of the critiques raised against IE. Criticisms of the approach have pointed to the weak commitment of IE with the goal of waste reduction. It has been assumed that the "valorisation" of waste materials could induce an incentive to their generation. However, as Erkman (2001) stresses, the prices of waste, and thus the benefits generated, could never overcome the "economical losses" that waste represents in terms of consumption of resources, energy, labour force, etc, and therefore, the most sensible option is avoidance in the first place.

e) The dependence on fossil fuels and hydrocarbons should be reduced and substituted by renewable sources. The agenda of industrial ecology should also incorporate a shift towards less environmentally harmful and more abundant sources of energy. Hydrocarbons are not only a source of pollution but they are also expensive (due to their scarcity) resources. Renewable sources could offer an interesting alternative to the traditional hydrocarbons-based industrial system.

1.2.7 Practical Implementation of IE: Trajectories and Scales

The practical application of IE has undergone two main basic trajectories (Van Berkel, 2006, Korhonen, 2001): a) application of the principles of IE to the operation of local local/regional eco-system or IS networks, also known as the *geographical system approach,* corresponding to the inter-firm level examined in the next section, and b) tracking of material flows in an attempt to reduce the intake of virgin raw materials, identify alternative ways of re-circulating materials and energy, reducing resource intensity and moving towards higher degrees of dematerialisation and decarbonisation in production and consumption, referred to as the product/process-based system approach. Both approaches focus on material and energy flows, aiming at reducing the burden industrial and societal systems pose on the natural ecosystems.

Figure 1.2: Trajectories in the application of industrial ecology



\Source: adapted from Van Berkel, 2006.

Similarly, Chertow (2000) noted that IE can occur at different levels: 1) the facility or firm level, 2) the inter-firm level and 3) the regional/ global level, according to the following scheme:

Figure 1.3: Scales of Industrial ecology

\Source: Adapted from Chertow (2000)

Industrial symbiosis, as will be explained in the next chapter, focuses on the inter-firm level of IE, although it could be argued that it covers also regional and global levels, by the further connection of inter-firm networks.

1.3 Summary

Sustainable development has emerged in the last decade as a new way to conceptualise the interaction between natural and human systems in mutually reinforcing ways. This approach recognises the dependency of human systems on natural systems and the need to increase their adaptive capability; however, instead of conceiving this interrelation in limiting terms, the approach proposes the fostering of positive partnerships between social and natural interfaces, by relying on creativity and innovation, both at the technical and social level.

Notwithstanding the success of sustainable development in accessing the core of policy-making agendas, the practical implementation of the concept has been a much discussed process. The ambiguity of the conceptual dimension of sustainability and its inherent complexity has resulted in a diversity of perspectives and practical approaches. Among these approaches, IE has attracted attention as an attempt to reconcile industrial and natural systems, by fostering the cyclical resource flow in the economy and the re-engineering of industrial processes, inspired by mimicking the efficient functioning of natural systems. The aim of IE is to move from linear to closed-loop industrial systems, where resource-use is maximized and the production of waste reduced to a minimum. The ecological metaphor lies at the core of the field, providing conceptual but also discursive strength to the approach. Within IE two main different trajectories and levels of analysis can be identified. One main trajectory is concerned with the identification of material and energy flows in the economy and the design of technical solutions to foster the cyclical use of resources. The other main trajectory deals with the design of inter-firm networks for the exchange of resources. Both trajectories are intrinsically connected, but, while one focuses on the technical and engineering perspective, the other, IS, focuses on the design of social systems to support material exchanges. The main characteristics of the latter approach will be reviewed in the next chapter.

Chapter 2.
Industrial Symbiosis

The research here presented focuses on Industrial Symbiosis. Industrial symbiosis, as noted before addresses the inter-company level of IE and basically refers to the development of inter-organisational networks for the exchange of material and energy flows and, more generally, the cooperation between industrial units in moving towards more closed-loop systems. This chapter specifically focuses on the review of the main contributions and debates regarding IS, paying special attention to the understanding of the social dynamics that shape the operation of IS networks and exploring the connection of this approach with network theory. The chapter starts by reviewing the controversies and multiple conceptions of IS and its connection with IE and sustainable development. Different typologies of IS networks proposed in the literature are critically reviewed and the conditions for the emergence of IS, both from a physical and especially from the social point of view are examined. The chapter finishes with a discussion of the main potential obstacles and barriers to the further implementation of IS.

2.1 Industrial Symbiosis: Concept, Challenges and Opportunities

As already noted, IS can be defined as an application of the principles of IE to the inter-company interface. There are various definitions of IS and other similar concepts "*implying different objectives, operational characteristics and system boundaries*" (Mirata and Pearce, 2003, p.1). As a result of this, terms such as industrial symbiosis, eco-industrial parks or industrial ecosystem have been used as partial substitutes in reference to the inter-organisational interface of industrial ecology. All these concepts and the linkages between them will be examined in the following sections.

2.1.1 Exploring the Definition of IS

Within the field of industrial ecology, industrial symbiosis is principally concerned with the *"cyclical flow of resources through networks of businesses as a means of cooperatively approaching ecologically sustainable industrial activity"* (Chertow and Lombardi, 2005, p. 6536). Therefore, the emphasis of industrial symbiosis is on the interfirm interface, focusing on ways of resource optimisation based on collaboration among different industries and activities. It aims to overcome the traditional boundary of the organisation to achieve better environmental collective performance offered by a more global approach to material and energy flows.

A comprehensive definition of industrial symbiosis is that offered by Chertow (2000, p.314):

> *"Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity".*

Although commonly referred to in the literature, this definition can be extended in at least two aspects; one aspect is related to the role played by geographic proximity. Although, industrial symbiosis generally refers to material and energy exchanges "*among co-located firms*", giving rise to "eco-industrial parks", the concept has widened to include collaborative networks of companies that are not necessarily co-located, operating on a regional scale, as Chertow (2007) clearly identifies in her proposed "taxonomy" of industrial symbiosis initiatives.

Thus, as noted by Van der Bergh et al. (2004), industrial symbiosis needs not to be limited to a park. The term can be extended to a city (Desrochers, 2002) or to a sector of activity, as it is in the case presented by Sager and Frosch (1997) of the metals sector in New England. Indeed defining the boundaries of industrial symbiosis has been an object of debate in the literature of industrial symbiosis. Korhonen (2007) and Melanen and Korhonen. (2007) discuss the challenge of defining system boundaries of industrial symbiosis networks, as a crucial element in analysing the sustainability of industrial eco-systems.

Dissent can be found regarding the "content" of the collaboration. While some authors emphasise the material aspect of "industrial symbiosis" exchanges (Graedel and Allenby, 2003), collaboration in aspects such as expertise and technology transfer have also been included in some working definitions of industrial symbiosis (see, for example, NISP, 2009). Chertow (2007) considers generally three primary opportunities for resource exchange: 1) by-product reuse; 2) utility sharing and 3) joint provision of services. Mirata and Emtairah (2005) argued that, even though physical exchanges are core elements of IS networks, cooperation based on the exchange of knowledge and other resources, such as shared utilisation of infrastructure and other logistical elements should also be included in their definition. The authors propose a wider definition of IS networks as (p. 994):

> *"a collection of long-term, symbiotic relationships between and among regional activities involving physical exchanges or materials and energy carriers as well as the exchange of knowledge, human or technical resources, concurrently providing environmental and competitive benefits".*

Jacobsen and Anderberg (2005, p.313) emphasise the economic dimension of industrial symbiosis networks by stressing that "*industrial symbiosis is one type of industrial network and it resembles other types of collaboration among industrial companies*". This view also encompasses the idea that industrial symbiosis networks generate "*concrete economic and environmental advantages*".

These open-ended definitions of industrial symbiosis seem to state that the notion of industrial symbiosis encompasses a variety of shapes and structures that are the result of different processes, time and spatial scales and different cultural and institutional settings (Chertow, 2000). This idea of diversity of approaches has given rise to the emergence of different typologies and taxonomies of industrial symbiosis in an attempt to theoretically organise different practical realisations of the term, as it will be explored in the next sections. However, despite the diversity of visions, some common elements seem to characterise industrial symbiosis:

- it implies different industrial actors, belonging to different sectors of activity
- it involves more than one by-product exchange or resource sharing
- although the exchanges can be assimilated in some cases to market transactions, they transcend mere market exchange and involve different degree of cooperation and collaboration
- collaboration takes place through networking
- the environmental and economic outcomes should surpass the outcomes that the individual organisations would obtain by acting individually
- resources, water and energy are optimised through cooperation

Most of the confusion generated by the terminology and attempts at classification has arisen, as pointed by Van Beers et al. (2007, p.56), from the lack of a "*standardised and internationally accepted methodology for defining and classifying industrial symbiosis and regional resource synergies*". The authors argue that it can be useful to distinguish between "industrial symbiosis" that denotes physical exchanges of resources between companies and "regional synergies", a term with a wider scope, that includes also utility sharing and a wider geographical perspective. Similarly, the authors propose to refer to "by-product synergies" when characterising "exchange of by-products between industrial operation" and "utility synergies" when referring to shared infrastructure and utilities for example for the production of energy carriers, joint waste/emissions treatment or production of process water. Chertow (2007) proposes the "3-2 heuristics" rule to distinguish IS from other types of exchanges. According to this, IS networks would involve at least three different entities, none of which is primarily a recycling company, exchanging at least two different resources. Chertow also refers to "kernels" or "precursor" to describe those situations where the 3-2 criterion is not met yet but there is a potential to evolve to a full IS. Thus, industrial symbiosis characterises complex networks formed by different industrial actors belonging to different sectors of activity that, by collaboration and networking, achieve a better optimisation in the use of resources, energy, water, technology and knowledge, resulting in better environmental and economic outcomes, from a sustainability perspective.

2.1.2 Industrial Symbiosis and Related Concepts: Eco-Industrial Parks

Different terminologies and concepts have been used to refer to the inter-firm level of industrial ecology. Cote and Rosenthal (1998, 1995) used in their work the terms "eco-industrial parks" and "industrial eco-systems" and Schwarz and Steininger (1997) referred to "by-product exchanges". Although, as will be discussed later, these terms refer to slightly different approaches, all can be encompassed within the concept of industrial symbiosis.

The term eco-industrial park, although closely related to IS, generally refers to eco-industrial projects taking place within the narrower geographical scope of an industrial estate. The definition proposed by Indigo Development has wide acceptance in the literature. Indigo Development defines Eco-Industrial Park as (Lowe, 2001, p.1):

> *"a community of manufacturing and service businesses located together on a common property. Member businesses seek enhanced environmental, economic, social*

> *performance through collaboration in managing environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realise by only optimizing its individual performance".*

Indigo development (2001, p.1) also specifies as components of eco-industrial parks "*green design of park infrastructures and plants (new or retrofitted); cleaner production, pollution prevention; energy efficiency: and inter-company partnering*".

Other definitions emphasize by-product exchanges as the key feature defining Eco-industrial parks. Peck and Ierfino (2003, quoted in Lowe and Dajian, no date, p.5) refer to eco-industrial parks as parks "*in which there is a material and energy cycling, and "webs" of firms that mimic the activity of producers, consumers, scavengers, and descomposers in a natural ecosystem*". This feature is also highlighted by Desrochers (2001, p.345) who describes an eco-industrial park as "*a community of companies, located in a single region, that exchange and make use of each other's by-products or energy*". However, focusing on waste-exchange networks as solely characteristic is a too restricted image of the possibilities offered by the approach of industrial ecology.

As Lowe (2001, p.1) stated, an eco-industrial park should be more than:

- a single by-product exchange pattern or network of exchanges
- a cluster of recycling companies
- a collection of manufacturers of green technologies
- a collection of companies producing green products
- an industrial estate designed around a single environmental theme
- a park, with an environmentally friendly design, environmental infrastructures or landscaping
- a mixed-use development combining industrial, residential and service activities

From the definitions above it can be concluded that both the concepts of IS networks and eco-industrial parks are rather loose. This has raised issues regarding the application of the concept in practice. Deutz and Gibbs (2004) argue that the concept has been used more as a spatial marketing strategy than as a genuine attempt to improve the environmental effects of industrial activity by promoting cooperation and networking. This has resulted in a growing number of industrial land developments dubiously labelled as eco-industrial parks or green business parks and has raised questions about the benefits of the approach (Gibbs, 2000). Therefore, even assuming that a certain degree of openness and diversity is desirable so that alternative views can be tested and developed, the normalisation of the concept of eco-industrial park is a necessary step if its aim is to be integrated and to play a relevant role in the industrial policy agenda.

In an attempt to contribute to the clarification of the terminology within the field, Lowe (2001, p.7), differentiates three different categories of eco-industrial projects:

1) Eco-industrial park or estate (EIP)—referring to an industrial park "*developed and managed as a real estate development enterprise and seeking high environmental, economic, and social benefits as well as business excellence*".
2) By-product exchange (BPX)—this term is used to refer to bilateral or multilateral agreements between companies "*seeking to utilize each other's by-products (energy, water, and materials) rather than disposing of them as waste*".
3) Eco-industrial network (EIN), here mostly referred to as industrial symbiosis network, (ISN)— defined as a "*a set of companies collaborating to improve their environmental, social, and economic performance*" in an area or region.

This classification proposes a rather wide understanding of collaboration and networking. According to this, it is also possible that one project encompasses more than one typology of eco-industrial projects. Indeed as emphasised by Lowe (2001, p.8), "*an industrial network may include stand-alone companies, companies in industrial parks, and the park management organisations*" and the "*exchange of by-product materials, energy or water among companies*" (p.8) can be one of the forms of collaboration, within a "*broader agenda for improvement of environmental and business performance*" (p.9).

Some terminological conventions are also proposed here. The focus of the research is IS networks, that is, networks of companies that are not necessarily co-located. A wide conception of IS networks has been adopted, which includes initiatives with 1) different spatial approaches and 2) different organisational or planning structures.

Following Chertow's (2000) subdivision, IS networks encompass three different spatial dimensions: local, regional and supra-regional. Disregarding the spatial scale, IS initiatives at these three levels will be generally referred to in this thesis as IS networks. In this study the term "eco-industrial park" is used when referring to material, energy and water exchanges between companies that are co-located in an industrial estate; Although the term "Networked Eco-industrial Park Systems" (Mirata, 2004) has been used to allude to supra-regional initiatives, here the more general IS networks or regional IS networks will be used.

It is also possible to differentiate industrial symbiosis projects according to the organisational structure in place. Generally, the term eco-industrial park encompasses the idea of planning and estate development, while industrial symbiosis network projects do not necessarily imply the existence of a planning or formal organisational structure.

Finally, regarding the content of the cooperation, and arguing in the line of Peck (2001), in this research industrial symbiosis projects and eco-industrial park developments will only be considered if they include physical exchanges of resources, water or energy. They can also include utility sharing, but this alone and/or environmental design or landscaping will not be sufficient conditions to be considered industrial symbiosis initiatives. To distinguish IS initiatives from other types of material exchanges, this thesis will follow the "*3-2 heuristic*" rule defined by Chertow (2007). When examining IS networks, the types of exchange considered will include: 1) re-use of material by-products and cascading of energy; 2) utility sharing; 3) joint provision of services and 4) exchange of knowledge. However, as noted earlier, the existence of material or energy exchange has been considered a necessary requisite of IS networks, as it ensures a certain degree of reduction in the environmental impact of the industrial system and it is generally also linked to cost savings and reduction in virgin raw material requirements, therefore helping to clearly differentiate IS from other types of inter-organisation cooperation, such as knowledge transfer or green twinning.

2.1.3 Industrial Symbiosis Networks and Eco-Industrial Parks: Typologies of Eco-Industrial Developments

A categorisation of eco-industrial development initiatives can shed some light on the concept. The Research Triangle Institute, in the USA, has produced a classification that covers different types of eco-industrial park, inspired by the practical implementation of the concept that draws upon the initiatives carried out to date (Research Triangle Institute, 2001):

1) **Mixed-use developments that combine residential, agriculture, commercial and industrial activities onsite**. These parks require a careful evaluation of the activities and processes located onsite that guarantee the safety of all the stakeholders. An attractive design of infrastructures and landscape is also needed to assure a successful combination of activities that could attract companies, residents and visitors. Illustrative of this kind of combined development is the Fujisawa Factory in Japan.

2) **Environmental designed eco-industrial parks**. The design, construction and infrastructure provision in these parks are inspired by environmental criteria and guidelines so that the environmental impact of the park during design, construction and operation phases is minimised. In many cases a balance between conservation of nearby valuable eco-systems and the development of industrial and commercial activities is expected. An example of this can be found in Dyfi Eco-park in Machynlleth (U.K).

3) **Industrial parks designed around a single environmental theme** e.g. removable energies, waste management, etc. This category of estates focuses on the development and clustering of companies around a single environmental theme so that knowledge and technological transfer is favoured and acts as a symbol and pioneering anchor of the sector of activity. The IBA Emscher Park in Gelsenkirchen (Germany) is an example of this form of development. The estate tenants are mainly companies involved in the development of solar technology and other environmentally-friendly production techniques.

4) **Eco-innovation and green technology parks**. Clustering companies involved in research and development activities in the area of renewable energy and green technologies in an estate promotes the technological transfer among companies and generates spin-off effects in other sectors of activity while becoming a regional anchor for attracting new companies and high-tech activities. The Environment Park in Torino (Italy) fits into this category of eco-industrial development.

5) **Environmentally-friendly products and processes park**. This category includes initiatives and estates formed mainly by companies involved in green manufacturing and production, where the environmental impact along the product life-cycle is minimised.

6) **Resource and energy recovery and waste management parks**. Industrial estates formed by a community of companies working in the reuse and recycling sector are included in this category. The clustering of this kind of company in an industrial estate is considered a guarantee of their safety and compromise with the recovery of waste for its use as raw materials in new processes. The London Remade initiative (UK) can be included into this category.

7) **Industrial Symbiosis Park**. The most representative type of eco-industrial development is doubtless an industrial symbiosis park based on the connectedness of companies and activities through exchange and cooperative networks. This allows the material and energy exchange among companies and technological and knowledge transfer. The most commonly referred case is that of Kalundborg symbiosis, which is discussed in more detail in Chapter 5.

It is also possible to distinguish between greenfield developments and those based on the recovery of brownfields and environmentally and socially degraded areas that can be redeveloped in a sustainable way by such planning strategy (UNEP, 1997).

These categories are only indicative of the wide range of initiatives included under the concept of eco-industrial parks. It should, then, be understood that these are not pure categories and many initiatives share characteristics and elements of different categories, being a combination of types from the proposed classification.

More generally, beyond the concept of the eco-industrial park, Chertow (2000) has proposed a widely accepted taxonomy of "*material exchange types*". The author differentiates between the following types of exchange:

Type 1: Through waste exchanges

Type 2: Within a facility, firm or organisation

Type 3: Among firms co-located in a defined eco-industrial park

Type 4: Among firms that are not co-located

Type 5: Among firms organised “virtually” across a broader region

As noted by Chertow (2000), types 3 to 5 can be identified as industrial symbiosis initiatives, addressing the inter-firm level.

These classifications seem to leave out other initiatives that could also be encompassed by the concept of eco-industrial development. There have been some projects that gravitate around the implementation of an Environmental Management System in industrial estates, so that a common policy and management structure is introduced as a way of directing the efforts of the community of companies toward an agreed set of targets, criteria and procedures which aim to improve the environmental impact and safety of the area while providing benefits to companies in terms of marketing and image and resource efficiency.

However, it should not be forgotten that, even though there are important differences between these types of eco-industrial development, the key feature defining all of them is the existence of networking and connectedness between companies, favouring knowledge and technology transfer, a cooperative approach in facing environmental problems and the exchange of waste materials and energy. So, the emphasis should be stressed on the connectedness and cooperation as the relational component plays a crucial role in all these initiatives.

2.2 Core Characteristics of Industrial Ecology: Networking and System Approach

This section briefly explores two of the distinctive features of the approach of IS: networking and system thinking. The first subsection focuses on identifying the main characteristics of successful networking, based on the findings from network theory and economic geography. The application of these findings to IS and the peculiarities of IS networks are discussed and main differences and similarities highlighted. The next section particularly provides an introduction to system thinking and the changes it introduces in the way industrial systems are conceived and designed.

2.2.1 Networking and Successful Networks: Key Characteristics

As implied in the definition of industrial symbiosis, networks and networking are key elements in eco-industrial development, binding the companies together into a coherent and innovative system of collaborative linkages and inter-organisational alliances aiming to reduce environmental impact in an economically rational way. Although, as argued by Jacobsen and Anderberg (2004), industrial symbiosis differs in its aims, scope and operation from traditional inter-organisational networks, some elements of the theory developed for inter-organisational networks, can help to shed some light on the dynamics that characterise the operation of industrial symbiosis networks. In this section, I briefly outline some of the main findings from the network theory developed in the fields of economic geography and organisational sociology (Staber, 2001; Grabher,1993; Weick, 1982).

Inter-firm networks define a cohesive web of relationships between firms that creates benefits which are external to the individual firm but internal to the system in which it participates. What Staber (2001, p.538) states for industrial clusters, may also apply to eco-industrial initiatives, where "*firms innovate and prosper through a collective learning process which depends strongly on existing synergies among a group of firms*". However, this web of ties among companies that characterise networks and the dependencies it creates can also increase the weakness of the system in an ever-changing environment. Therefore, as noted by Staber (2001, p.538), "*without an explanation of network structure, the implications of the network approach are indeterminate, because networks both enable and constrain action*". The key question is, then, defining what type of network organisation can promote innovation and foster the realisation of the economies of agglomeration.

Successful networks face two *opposing forces* (Staber, 2001). On the one hand, innovation and beneficial collaboration requires a highly flexible network structure that favours the free exchange of information and knowledge. On the other hand, networks need to be sufficiently stable to allow the development of long-term collaborative links, even more so when collaboration needs some time to settle. The key question is then to determine what is the "*optimal balance of change and stability, control and flexibility, and consensus and dissension*" (Staber, 2001, p.539). Literature on networks normally draws attention to dense networks, as a characteristic of high-performing clusters. However, the definition of "density" varies greatly according to different authors. In *The structure of networks in industrial districts*, Staber (2001) concludes that, according to an evolutionary perspective on networks, high-performing interfirm networks need take account of the following:

a) **Loose coupling**. Loosely coupled networks are more prompted to change and adapt in volatile and fragmented environments. By loose coupling it is implied that the effect of one unit of the network on another is punctual rather than continuous, occasional rather than constant, negligible rather than significant, indirect rather than direct and eventually rather than immediately (Weick, 1982). Loose coupling networks are able to face changes and disruptions, adapting to the new environment, while tightly-coupled networks might find it difficult to cope with structural changes. This relates to what Grabher (1993) describes as *"political lock-ins"*, that can encourage short-term strategic thinking but discourage structural adaptation, and then negatively affecting long-term competitiveness.

b) **Diversity**. Diverse interfirm networks seem to work better in complex and variable environments (Staber, 2001). Diverse interfirm networks, composed of firms with different routines, competencies, raw materials, techniques and waste flows, enrich the network *"knowledge"* content, and therefore innovation capacity, and also favour the emergence of complementary opportunities and synergies, so that competences, knowledge and resources are in fact complementary, and collaboration stands as a positive sum game.

c) **Redundancy**. The overlapping and duplication of network relations and collaboration linkages reduce the risks the network is exposed to when a unit or a particular relationship fails. Redundancy keeps networks away from "*competency traps*" (Staber, 2001), favouring a more flexible inter-relation between the members of the network.

d) **Self-regulation**. A contested issue refers to the regulatory structures of networks. Some authors, like Chisholm (1998), point to self-regulation, as opposed to centralized power, as an inherent characteristic of networks. The definition of the goal, shared vision and purpose of the network is not, according to this author, the result of a designed plan but of the interaction among units.

From this, it is possible to conclude that even though literature on industrial networks often assumes that all kinds of network are desirable and may enhance the learning and innovation capacity of a region, and, thus, foster economic development, a closer look at empirical outcomes seems to suggest that it is special structures among networks rather than networks in themselves that explain the success of a cluster or industrial area. Drawing on this conclusion, some interesting implications for eco-industrial development are offered by network theory:

- Eco-industrial networks are more likely to succeed when they are diverse. Within a wide range of companies operating in different industrial sectors, the emergence of synergies and collaborative linkages is more probable, as the greater diversity of materials and wastes generated allows more matches. As noted by Korhonen (2005, p. 85), an industrial ecology system "*relies on diversity in the actors involved, which sustains the system in case of disturbance*". Empirical evidence seems to support this claim, diversity being identified as a key factor in the most referred to model of eco-industrial park, that of Kalundborg. However, a too diverse network producing low volumes of a wide variety of wastes can reduce the feasibility of the exchanges by increasing transaction costs. Moreover, the "*diversity of interests, preferences and values, which can be conflicting*" (Korhonen, 2005, p. 92) can also negatively affect the viability of waste and energy exchanges.
- Eco-industrial networks are more able to cope with changes in the composition of the mix of industries participating in the network when relations are multilateral (waste flows occur among a group of companies and a number of companies can produce or be the recipient of a waste flow) rather than when they are specialised (there is only one main producer/ recipient of waste flows). In a highly specialised network when one of the components fails, it could threaten the operation of interrelated partners. However, the importance of redundancy in eco-industrial networks is not as crucial as in the case of an industrial cluster. In eco-industrial networks, collaborative linkages are mainly based on waste materials and energy exchanges, so the failure of one of the units of the system can temporarily cut the provision of raw materials or reduce the capacity of disposal of waste, but it does not normally imply the collapse of the activity of the company, as generally waste material and surplus energy represent a marginal amount of the total intake of raw materials and energy.
- Given that eco-industrial networking might require some technical adaptations in the processes and even, in some cases, the construction of physical infrastructures, a too loose-coupling network might not provide a sufficient incentive for the undertaking

of the necessary investments and therefore can be an obstacle to the exploitation of synergies. Case studies analysed in the literature seem to support (see, for example, Lowe, et al. ,1996; UNEP, 1997), the idea that some degree of formal or informal organisation is required.

2.2.2 System Approach

Industrial Symbiosis draws largely upon systems theory. The approach emphasises the interaction of industrial and ecological systems. According to this approach, industrial systems are embedded within the ecological systems and therefore are dependent on them, both as a source of resources and as a drain of waste and emissions. As noted by Allen et al. (2006), the systems perspective overcomes the myopic view of industrial systems held by the traditional science paradigm, dominated by the mechanical model, which assumed that the behaviour of a system could be predicted by the independent analysis of each of parts of the system and the relations among them. However, this vision does not recognise the effects of the interaction effect by which the sum of the individual actions do not match to the behaviour of the system as a whole, and does not explain the structural change of the system over the time. The introduction of a systems perspective in the analysis of the interaction of industrial (human) systems and ecological systems aims to overcome the limitations of the traditional approach by introducing the whole system perspective and the evolutionary approach in the understanding of interaction between industrial and natural systems. Industrial systems are, therefore, not seen in isolation but within the ecological systems of which they are a part. Wallner (1999) proposed to analyse the industrial system as a subsystem within the complex-*metasystem*. Both, the *subsystem* and the *hostsystem*, are connected to each other by a multiplicity of linkages and dependency relations. The industrial system, thus, is embedded in the ecological systems, but it is also a complex system on its own, formed by a network of interacting units, the enterprises. According to systems theory, all these units have autonomy but are also dependent from one to another, through direct and undirected links. The understanding of these linkages is thus a first step towards the better integration of natural and industrial systems.

2.3 IS in Practice: The Process of Design and Implementation of IS Networks and EIP

This third section reviews some of the main contributions in the prescriptive dimension of IS. Firstly, some guidance on the design and implementation of EIP is proposed and main strategic areas and objectives are identified. The next subsection, examines more generally potential areas of networking in IS, covering not only EIP but also other forms of IS.

2.3.1 Prescriptive Dimension of IS: Designing and Implementing EIP

Prescriptive attempts to facilitate the process of designing and developing IS networks and EIP have been undertaken, with different degrees of success, in the last years. In 1997, UNEP published *Environmental Management on Industrial Estates* which, based on a practical approach, gave orientation in the introduction of a more environmental rational design, construction and operation of industrial estates. The process of design of new industrial areas and restructuring of existing industrial areas is examined under the perspective of industrial ecology and cleaner production. Following this UNEP publication and largely based on it, the *Handbook for Development of Eco-Industrial Parks* is a comprehensive guide to the development of eco-industrial projects, including EIP, IS networks and by-product exchange structures (Lowe, 2001). This handbook covers the conceptual aspects of eco-industrial development and more practical aspects of the implementation of eco-industrial principles and the restructuring of industrial systems. The planning and development of eco-industrial projects is examined and practical guidelines and examples are provided regarding recruitment strategy, funding, project management, integration within the community, design and construction and operational management of either new or existing industrial areas (see table 2.1).

Table 2.1: Guidelines for the development of eco-industrial initiatives

CONSTRUCTION AND IMPLEMENTATION	
CONSTRUCTION	Integrative project Management • Enlisting Contractors to the vision • Setting and monitoring performance goals and measures
	Minimize impact of construction processes on the site
	Minimize energy demand of construction
	Reuse/ recycle construction materials Construction discards recycling plan Construction discards programme documentation Reuse/ recycling logistics
IMPLEMENTATION OF BUSINESS AND SOCIAL PROGRAMMES	Building the community of companies
	Implementing regulatory agreements • Policy definition • Onsite regulations (common facilities and individual plots)
	Creating regional by-product exchange
	Support to EIP tenants
	Redesign

\Source: Adapted from Lowe (2001)

Although as noted by Chertow (2000), eco-industrial projects needs to be adapted to the specific socio-economic and environmental characteristics of the area in which they are implemented, some general strategies for the design or restructuring of industrial areas according to eco-industrial principles have been identified in table 2.2 (Lowe, 2001; UNEP, 1997; Heeres et al., 2004):

Table 2.2: Strategic areas of eco-industrial development

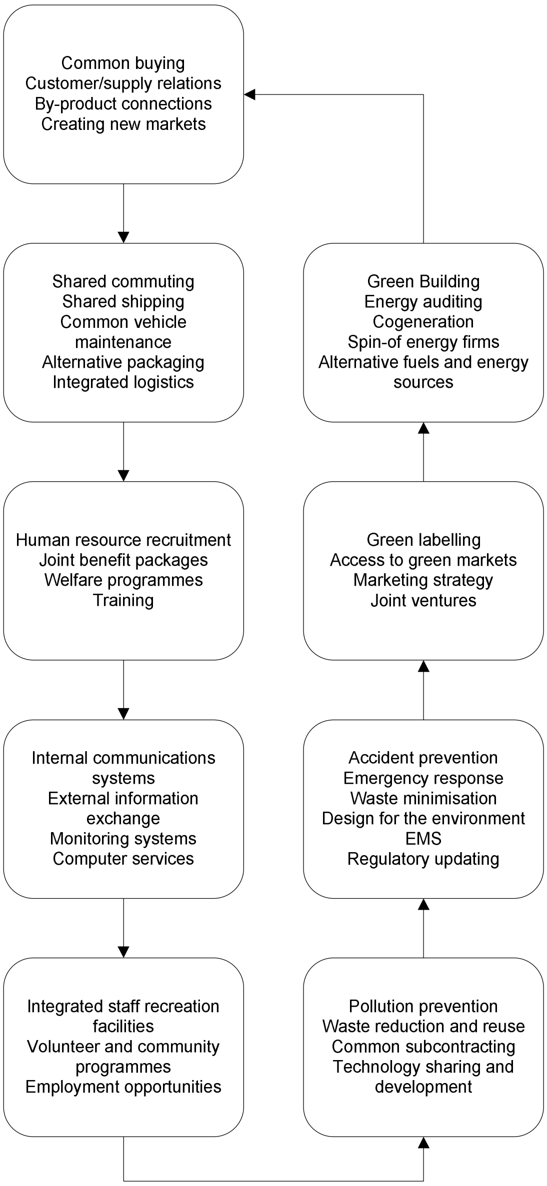
Main Strategic Areas	Objectives
Integration into natural systems	Site selection should take into account the ecological carrying capacity of the area and adjust to it Minimize local environmental impacts by adapting to landscape, hydrologic systems and local ecosystems Assess and control contribution to global impacts
Energy Systems	Maximize energy efficiency through facility design Assess the feasibility of cogeneration, energy cascading and renewable energies Identify energy efficiency opportunities for processes and activities
Materials flows and waste management	Emphasis on cleaner production and pollution prevention Substitution of more pollutant substances Maximize recycling and reuse of by-products and materials Find alternative uses for waste materials Integrate producers and consumers in resource exchange and recycling networks
Water	Cascading of water Conservation of water resources More efficient water usage
Environmental Management	Support improvement of environmental management in individual companies Favour the interaction and collaboration between different activities in order to minimize resource consumption and waste generation Operate information systems that favour inter-company communication and connection

\Source: Adapted from Lowe (2001)

2.3.2 Prescriptive Dimension of IS: Potential Areas of IS Networking

Although special attention has been paid in IE to specific exchanges of material flows, applying a broader conceptualisation of IE can foster the identification of new connections and remove barriers for the implementation of more innovative ways of integrating processes and facilities, leading to important environmental and economic benefits (Cohen-Rosenthal, 2000). Cohen-Rosenthal (2000) points to the necessity of broadening the vision of IE and linking it with the core drivers of companies. Some possible areas of cooperation beyond the exchange of by-products and waste flows are shown in Figure 2.1:

Figure 2.1: Areas of potential cooperation between businesses



\Source: Adapted from Cohen-Rosenthal (2000)

2.4 Benefits of IS

According to the literature (Ehrenfeld and Gertler, 1997: Mirata, 2004: Lowe, 2001), the benefits of IS networks transcend the boundaries of the companies involved to permeate the whole socio-economic fabric of the communities in which they operate. Generally, benefits of IS networks are identified in the following areas (Lowe, 2001; Mirata, 2005):

- Economic benefits for the companies emerging from savings in the cost of inputs and the management of waste and opportunities of revenues generated by the higher values of by-products and waste streams
- Environmental benefits due to the reduction in the overall resource needs of the industrial system, reuse and recycling of waste streams and control of pollution
- Other business benefits derived from improvement in the relationships with other agents and the community, green marketing, social corporate responsibility and the creation of new business and market opportunities
- Benefits for the community as a source of new employment, securing existing jobs, improving the local ecosystems or the creation of a cleaner and safer environment

2.5 Strategies in Implementing IS networks: Managing the Transition

In most cases the prescriptive dimension of IE and IS offers guidelines for the development of eco-industrial parks or IS networks. Emphasis is put on the end state or final outcome but the transition process towards the desired scenario remains largely unexplored. This section focuses on the contributions that examine the progress rather than the outcomes of moving towards more sustainable industrial systems, from an evolutionary perspective.

2.5.1 Evolutionary Approach

The review of different experiences of IS networks reveals that cooperation "*develops over time*" (Chertow, 2000, p. 332). This conclusion reinforces the need of evolutionary approaches in addressing the promotion of IS networks. Chertow proposes three evolutionary approaches to IS. The first approach focuses on projects *"where some type of material or energy exchange already exists"* (p. 333). This facilitates the identification of new opportunities of exchange and acts as a demonstration project for other companies. The second approach suggested by Chertow is to build on *"pre-existing organisational relationships and networks"* (p. 333). Past experiences on cooperation and the existence of a framework of cooperation and interaction of companies can help to overcome some of the social barriers to cooperation and therefore constitute an opportunity to start IS projects. Finally, the third approach proposed by the author, relies on the *"anchor tenant model"* (p.

333). The anchoring company helps to achieve the *"critical mass"* and a combination of by-products and wastes from which to generate different IS linkages. The anchoring company acts thus as an attractor of other complementary activities and projects.

2.5.2 Attention to the Process

Drawing on the evolutionary perspective, attention should not only be set on the results but also on the process. The development of IS networks is the result of a complex process that implies the interaction of several actors over a period of time. In fact it has been recognised that the process itself *"proves to be a crucial success factor"* in implementing IS principles (Brand and Brujin, 1999, p. 221). However, the elements of the process that can lead to cooperation and integration remain still unclear. Wolf et al. (2005) propose a protocol for understanding the process of integration, consisting of the following phases:

1) Identifying the actors
2) Achieving a good knowledge of the system, including detailed information on energy, materials and waste streams
3) Considering different system levels and boundaries, so that optimal linkages can be better identified
4) Providing a "Forum" for actors to meet, in an attempt to favour aspects such as trust, shared vision, etc.

Some detailed guidelines for the development of synergies are also provided by the US Business Council for Sustainable Development (2003).

2.5.3 Phases of Industrial Ecology

The evolutionary approach therefore conceptualises the construction of industrial symbiosis as a process that evolves over time, going through different phases or stages of development. Baas and Boon (2004) identified three different stages in the evolution of IS initiatives:

1) Regional efficiency. In this stage, based on local existing networks and facilitated by coordinating bodies or local government, some win-win opportunities are identified.

2) Regional learning. Trust and mutual recognition facilitates a more ambitious scope of sustainability and patterns of exchange and membership are broadened.
3) Sustainable industrial districts. A strategic vision of sustainability is adopted and shapes the actions taken.

The transition between stages is not well studied and more research is needed in identifying the crucial components in moving from one stage to the next.

2.6 Exploring the Social Aspects of IS Networks

IE has mostly focused on the study and tracking of material and energy flows throughout the systems and the identification of opportunities to increase the efficient use of materials, by pointing to potential linkages and opportunities to reuse and recycle materials. However, for these changes to happen it is necessary to explore the social interface of IE and its policy implications. As Korhonen et al. (2004, p.292) suggested, *"Without the understanding of the human dimension, the full prescriptive and normative dimension of the field of IE is unlikely to be exploited"*. The description of the industrial metabolism, although crucial, is insufficient to lead the change required in industrial systems that would enable them to progress to more sustainable stages of development. The following sections address the role of the social component of IS process and some of its main mechanisms. The main contributions that explore the policy component of IS projects are also briefly covered and some of the main obstacles in fostering IS cooperation reviewed.

2.6.1 Social Aspects in Industrial Ecology and Industrial Symbiosis

Although the field of industrial ecology was at first mainly addressed by engineering approaches (see, for example, Ayres and Ayres, 1998/99), considerable progress has been undertaken in introducing economic, social and institutional aspects in the understanding of the decision-making structures that govern material and energy flows. The integration of a social perspective in the field of industrial ecology, has taken place at two different levels: at the conceptual and at methodological level. Binder (2007a, 2007b) provides a comprehensive review of attempts to couple social science modelling approaches with material flow analysis. Most of these attempts stem from the field of economics (Binder, 2007a). General or partial equilibrium models, input-output approaches or microeconomic models have been proposed to analyse the relationship between material flows and economic factors (Binder, 2007a). However, as noted by Kytzia et al (2004, p.878), "*all of these approaches lack a common system definition for both physical and economic dimensions of industrial systems*". The economic analysis is, thus, often introduced as an "add-on" dimension. To overcome the shortcomings and inconsistencies identified in the previous attempts to integrate material and economic dimensions, Kytzia et al (2004, p. 878) proposed the *"Economically Extended Material flow Analysis (EE-MFA)"* as a "*combined analysis of material and money/cash flows*", which derives from the integration of Material Flow Analysis and Input-Output analysis. Even though these approaches have brought a wider understanding of the transition process towards a more cyclical approach to material and energy throughout the industrial system, as Binder (2007a, p.1601) points out they fail to address other important aspects shaping decision-making processes, such as "*personal preferences and social norms or cultural backgrounds*". These aspects are difficult to capture by quantitative economic models. Therefore, in the transition towards a more sustainable organisation of the industrial system (Korhonen, 2004a), the integration of material and economic systems might not be sufficient for the *"system understanding"*. The combination of material flow and agent analysis (Binder et al, 2004) provides a useful approach for a wider understanding of the agent networks as well as the social and cultural norms that shape the definition of the *"environmental"* problem. Building on this, Binder (2007b) provides a comprehensive framework for the integration of social aspects in industrial ecology, based on Gidden's structuration theory. A methodological approach, "*Structural Agent Analysis*", is proposed to analyse the impact of social structures in action as well as *"the feedback of actions on structure"* (Binder, 2007b, p. 1607). According to this approach, social structures are divided into rules and resources. The action of an agent is thus shaped by the social structure and it has an impact on the environment. At the same time, changes in the environment affect the agent, his awareness and perception of the problem, and, diachronically, the social structure. A seven-step method is proposed (Binder, 2007b), consisting of: 1) identifying relevant agents, 2) defining the relevant structural factors affecting agents' actions, 3) weighting of structural factors on agents' actions, 4) drawing an "*agent-structure diagram"*, 5) identifying agents' options and restrictions, 6) identifying potential interactions and interferences among agents and 7) estimating the potential effects of agents' actions on structure.

All these previous studies have contributed to the progressive integration of the social dimension in the analysis and understanding of the material and energy flows, in the field of industrial ecology. Although many of these approaches offer guidance for the understanding of the *"soft components"* of IS, there is still a lack of integrative approaches for the evaluation, analysis and understanding of the social and organisational dimension in IS developments. IS initiatives have tended to focus on engineering and technical solutions for the connection of processes and activities for the exchange of materials and energy. Even though the engineering approach of IS sets the basis for the functioning of these exchange networks, social aspects that influence the decision-making process of single units constitute critical factors in the development of IS (Domenech and Davies, 2009). The growing attention that IS has recently received in academic and policy spheres has not always been accompanied by well-defined strategies for its implementation at the practical level and the use of modelling techniques is still limited (Domenech and Davies, 2006). On the empirical level, IS networks are still a *"rare"* phenomenon and, although new IS projects have been launched, the "success" of many of these initiatives has been questioned (see, for example, Goss et al, 2005), raising doubts about the ability of planning initiatives and policies to promote IS (Desrochers, 2002).Even though the importance of social aspects has been increasingly recognised in the literature (see, for example, Eilering and Vermeulen, 2004 and Korhonen et al., 2004), as has been pointed out before, most of the analyses fail to provide a comprehensive framework for the evaluation of the social aspects of IS and the understanding of the dynamics of collaboration and networking.

Examining the social factors of IS requires an understanding of the rationale of the individual units in interaction with their context, as companies and networks are influencing each other on a continual basis. This will lead to a subsequent question: why may networking and cooperation provide better results in environmental and economic terms compared to other forms of interaction or environmental management alternatives? Indeed, it is necessary to emphasise that networking has implications that differ from other market-based waste management solutions. Understanding these differences may also help to distinguish when IS initiatives are genuinely operating as networks or when they only consist of market exchanges of material and energy by-products. These two forms of governance have different implications and may lead to diverse results. Therefore, the strategy to promote one or the other necessarily differs. Indeed, IS literature has generally emphasised in its discourse the *"cost-based"* approach as a main driver for the emergence of IS networks (see, for example, Lowe and Evans, 1995). However, when doing so, they are assimilating IS networks to atomistic market conditions, overlooking the *"structural"* conditions that might actually set the basis of IS networks and that can better explain the emergence of IS networks. Binder et al. (2004) provides an example, applied to the wood flows in a Swiss region, of how structural conditions (*"rules"* and *"resources"*) can foster or hinder the progress to more sustainable scenarios. In this research, it is argued that IS networks are closer to the theoretical construct of networks rather than market-based exchange conditions and therefore, even though the potential for IS networks to reduce the costs associated with environmental management is recognised, I contend that the central elements in explaining the network exchanges challenges a narrow *"costs-view"* (Larson, 1992), falling closer to the "*heuristics*" approach (Lewis and Weigert, 1985). According to the latter, the decision-making process of companies interacting in a network would not only be influenced by cost but other rather more *"qualitative"* factors, such as trust and information, which would have a primary influence (see also Begre and Hadorn, 2002 and Hadorn et al., 2002).

2.6.2 Decision-making Process and IS

As noted above, the social aspects surrounding industrial ecology have been gradually considered in the literature. The prospects of industrial ecology depend not only on a detailed knowledge about the flow of material and energy in the industry but also on a deep understanding of the decision-making process of the main actors involved. Ultimately and independently from the material flow of the processes involved, industrial systems are complex social structures and the realisation of the potential synergies and opportunities of resource or energy optimisation rely at the end on the simultaneous decision-making of different actors. As recognised by Cohen-Rosenthal (2000), knowledge of the possibilities of establishing waste streams and energy cascading is crucial to determine the potential of industrial symbiosis, but they do not in themselves lead to change. Industrial symbiosis is mostly about interaction and connection and how these connections take place in the socio-cultural sphere. Understanding the nature of this process and the way actors interact among them and with their context is of crucial importance in explaining the dynamics of industrial symbiosis networks and their opportunities to emerge and thrive.

The process of decision-making consists of the selection of an action path from a range of alternatives. It therefore requires the gathering of information about the context and possible ways of action, defining alternatives, selecting the best one according to the desired goals and available knowledge and monitoring the implementation and outcomes of the action taken.

The traditional approach to decision-making, proposed by the Rational Choice Theory, (Arrow, 1987) characterises the decision-making process as an optimisation problem. The individual knows all the relevant information and all the possible alternatives and selects the best solution according to his preferences. The idea of *"rational"* agent, or homo-economicus, however, has been challenged by pointing to the unrealistic character of its assumptions such as perfect information and restricted economic calculus. The Bounded Rationality Model by Simon (1991) suggested that individuals do not employ optimal approaches in making a decision due to the limited availability of information and the constraints in managing it. Therefore, this model differs from the rational choice theory in the following main ways (Stroh et al., 2001):1) the individual has a restricted perspective on the problem and context, 2) there is a sequential, rather than simultaneous, evaluation of the alternatives, based on pair-wise comparisons, 3) gathering information for decision-making is a costly and time-consuming process and therefore, most often decision-makers satisfy, that is, select an acceptable alternative, rather than optimise, which would require a thorough evaluation of all possible alternatives and 4) judgmental heuristics based on aspects such as past-experiences or rules of thumb are also used to reduce the information processing cost and time demands. Norms, rules and inertia can be understood as strategies to approach complex decision-making processes.

As noted by Baas and Boons (2004), the scenario defined by IE poses two central challenges to the organisational decision-making structures: it suggest modification of the *"system boundaries"* in decision-making from the locus of the individual firm to the system, and they also entail a high degree of risk and uncertainty. The authors point to *"incrementalism"* as a strategy for reducing risk, and distinguish between three different approaches: 1) strategy of decision; 2) the epistemic rationale and 3) the adaptation rationale. The first of this form of incrementalism points to the importance of reinforcement and past experiences in shaping the decision-making process. The epistemic rationale considers that a theoretical understanding of the system is not necessary, and decisions are based on short-sighted economic calculus. Finally, the third approach alludes to small and cautious changes. These strategies are reinforced by the *"confirmation trap"* and *"regression-to-the-mean"* biases (Baas and Boons, 2004). According to this, the dynamics of the decision-making process can partly explain why even win-win-win IS projects are difficult to implement in practice and they generally lead to rather conservative results.

Solem and Brattebo (1999) also reflected on the process of decision making in IS. According to the authors, the interaction between actors and the underlying vision or system perspective will determine the outcomes of the process. A main problem in advancing towards more far-reaching solutions rather than incremental changes comes from the friction between the objectives, perspectives, system boundaries and vision of sustainability of different actors. As pointed out by the authors, this could lead in some cases to the phenomenon of *"disappearing decision"*, where decisions are continuously postponed, as no common understanding is achieved by the actors' interaction.

Although organisations are regarded as main decisional actors in IE/IS projects, political and other institutional actors play an essential role in defining the context and process of decision-making. Among the political actors, Solem and Brattebo (1999) distinguished between decision-makers (elected politicians), experts (providers of information) and other planners (that are involved mainly in the implementation phase). Baas and Boons (2004) also point to local communities and coordination bodies (either if it is a private, public or mixed entity) as important actors shaping the decision-making process. The position of the different actors towards the project and the distribution of power among them will be crucial aspects in determining the outcomes of the process. Also, it should be noted, that even though organisations have been labelled as an actor, they are made up by a number of different internal actors. In this sense, it can be useful to differentiate, following Baas and Boons (2004), between CEOs, plant managers and technical staff.

Finally, in reference to contextual aspects influencing the decision of companies in IS projects, Baas (1998) identified for the INES project in the Rotterdam Harbour area, the following: infrastructural aspects, the size of the companies, the level of trust and expectation of reciprocity and the characteristics and degree of flexibility of the industrial ecology network.

2.6.3 Trust

Conditioning the process of decision-making and shaping the strategy of the actors, trust seems to play a crucial role, not only favouring IS exchanges but also deepening the cooperation and promoting the adoption of more challenging projects. Indeed, among the social and contextual aspects, the role of trust in building and realising IS exchanges has been widely recognised in the literature (Gibbs, 2003; Jacobsen and Anderberg, 2005; Hewes and Lyons, 2009; Chertow et al. 2008). Ashton (2008), using a framework based on Social Network Analysis, observes a positive correlation between trust and the position of the agent in the social hierarchy in IS linkages in the case of Barceloneta, Puerto Rico. Hewes and Lyons (2008) address the humanistic side of industrial symbiosis by focusing on the role played by champions in IS projects and the relevance of creating trust and embedded relations for an IS project to succeed. Based on two case studies, the authors analyse the different strategies adopted by the project champion to generate trust and commitment and engage local communities in the project. The conclusions of the research emphasise social relations as a key element in the development of IS, over system engineering or technological fixes. Trust is generally created on a one-to-one, face-to-face basis, either through more formal structures such as steering committees or through informal and personal linkages. In both cases, the creation of trust requires a considerable amount of time and effort to build. Spatial proximity and engagement in the local context are also seen as fundamental in building the relations and developing the project. Doubts are raised about the longer-term viability of IS projects once the champion has left. Hewes and Lyons (2008) also stress the role of qualitative methods in understanding the subtle social mechanisms that favour IS development. However, there is still little understanding of the mechanisms of building trust and cooperation in IS projects. Chapter 3 and 4 review in detail the concept of trust, its role in IS and the mechanisms that promote and hinder the process of trust building. It also proposes a framework for the understanding of the mechanisms of trust building in IS projects, which is applied to the case studies analysed in this research.

2.6.4 IS and the Need of Coordination

From an organisational perspective, the emergence and development of IS networks implies the coordination of a multiplicity of actors, with different goals, visions and routines of interaction. This process of coordination is complex and, in most of the cases, requires the tacit or explicit definition of rules and dynamics of interaction. Boons and Baas (1997), explored the "*organisational implications*" of the inter-company interface of industrial ecology. According to the authors, different types of industrial ecology developments, would imply different problems of coordination. Four different types of industrial ecology developments are identified: Sector, product/material life cycle, geographical area and miscellaneous. IS projects do not necessarily fall into one of these categories, but they can be a combination of them. Therefore, *"The problem of coordination"* can take different forms depending on the context and characteristics of the IS network. Thus, for example, in an IS network that "*comprises organisations that are not automatically dependent on each other*" the role of coordination might be difficult to built as no *"network"* between the organisations exists a priori. In this case, *"an initiating organisation with sufficient status for the different stakeholders is a critical factor"* (Boons and Baas, 1997, p.84).

However, as remarked by Boons and Baas (1997, p.85), *"coordination does not automatically mean cooperation"*. Coordination is just the means but the process of building cooperation requires a sense of community, the existence of shared goals and meanings. Although these elements can be facilitated through coordination, they are not necessarily the result from it. Coordination and exchange of information is thus a necessary but not sufficient conditions for the development of IS networks. Examples of this will be given in the analysis of the case studies, and more specifically in chapter 7.

2.6.4.1 The Role of Coordination Bodies and IS Brokerage

Many of the policy driven initiatives to encourage the emergence and development of IS networks have consisted in the creation of a *"coordination"* body to catalyse and uncover the benefits of potential IS synergies. An example of this is NISP, which has been selected as case-study and therefore will be analysed in more detail in Chapter 7.

The role of a coordination body can be adopted by different actors, who may be private companies, research institutes, NGOs or public bodies (Mirata and Pearce, 2006), depending on the context and circumstances in which it has been created. The main role of these bodies is to set the basis and provide the necessary support for promoting the creation of IS networks. Mirata and Pearce (2006) identify three main areas of action of coordination bodies:

a) To offer informational support to companies, so that complementarities can be identified and potential synergies and opportunities for collaboration uncovered. Moreover, coordination bodies can play an important role in the transfer of knowledge and the dissemination of better technologies and practices.

b) To contribute to the creation of an appropriate institutional framework that favours cooperation among industrial actors. The role of the coordination body is to connect and promote the communication between the different actors and to set the basis for a dialogue between policy makers, regulatory bodies, companies, investors, etc to help overcome the potential regulatory, institutional or financial barriers for the implementation of IS opportunities. This is of special relevance in those cases where there is little interaction between actors or where networks are excessively locked-up.

c) To guide and support the IS development, by providing a wider perspective and a long-term sustainability approach.

Lowe (2001) proposes the distinction, in the case of EIP, of two levels of management structures: a) the management of the property and 2) the management of the community of companies, and proposes the implementation of separate but integrated management systems to cover a full range of managerial responsibilities. According to Lowe, the management structures should provide and manage some common facilities and services that cover a range of general company needs, such as training and meeting facilities, general environmental structures, social facilities, purchasing and common supplies, security and many others. It is also responsibility of the management structure to define the common environmental policy of the industrial area, to identify environmental performance goals and implement an EMS for the area.

The role played by coordination bodies has also been critically reviewed by some authors who argue that, if IS projects entail benefits, the coordination among companies will spontaneously emerge without the need of policy-driven mechanisms or ad hoc coordination bodies. According to this, IS should result from an autonomous process led by the companies themselves. Desrochers (2004) argues against regulation and policy-driven measures to promote IS for he considers them to be more distorting than encouraging of the process of innovation and cooperation, so misleading economic actor behaviour. The ideal of autonomous coordination is also present in the analogy or ecological metaphor in which industrial ecology and industrial symbiosis are based. Behind this metaphor implicitly hides the idea of an *"invisible hand"* that coordinates the exchanges without the intervention of any central coordination node. Indeed, this is pointed by Boons and Baas (1997) as a "*basic flaw*" of the ecological metaphor, as the idea that industrial systems will evolve to more efficient systems (in terms of use of material and energy) without the intervention of an external actor, so as natural systems do, mistakenly assumes that social and natural systems operate by the same laws and principles. However, the autonomous evolution of natural systems is unlikely to occur in industrial system unless it is addressed as a directed *"intentional action"* (Boons and Baas, 1997, p.80).

2.6.5 Clustering, Networking and Agglomeration Economies in IS

The theoretical constructs from agglomeration economics, cluster and network theories have provided an essential foundation for understanding the social aspects surrounding IS projects. Even if, as pointed out by Jacobsen and Anderberg (2004), the scope and context of traditional and IS networks differs, parallels can be traced and the theoretical framework of networks adapted and reworked to include the peculiarities of IS networks. Chertow et al. (2008) explore the relationship between agglomeration economies and industrial symbiosis, by broadening cluster theory and more, concretely the concept of agglomeration economies, to include environmental synergies and benefits derived from agglomeration. Within agglomeration economies, static economies, such as access to transport nodes, and dynamic economies, related to processes of knowledge generating and learning, are differentiated. The authors also distinguish basically between single sector and multi-sectoral clusters and explore the potential for industrial symbiosis to develop in different industrial cluster scenarios. The research looks at different industrial areas in Puerto Rico, analysing the development of localisation and urbanisation economies, including industrial symbiosis opportunities. The analysis concludes that agglomeration economies do not occur automatically, especially the dynamic ones, but require the active engagement of the actors in the process. The study also demonstrates that industrial symbiosis projects face a combination of different obstacles that can include technical, organisational, regulatory, motivational or economic barriers. Aspects such as stronger social bonds and willingness to cooperate seem to play an important role in the development of synergies, although they might not be sufficient for the symbiosis to realise.

Also exploring the potential for cross fertilisation between the research fields of industrial ecology and cluster theory, Deutz and Gibbs (2008, p.1313) argue that industrial symbiosis *"can be viewed as a distinct cluster concept"*. The authors identify three recurrent conceptual areas or meta-themes in cluster theory and regional development that can also be examined in the case of industrial ecology: a) economies of scale; b) networking and c) policy. The comparison between these three areas in the traditional cluster approach and its adaptation to industrial ecology offers some insights into the process of development of IE initiatives and onto the potential role of policy. Given this framework, the authors analyse different case studies of EIP in the US and conclude that even if there are similarities between more traditional approaches to clustering and IE, there are also important differences that should not be neglected. The most significant difference stem from the fact that by-product exchanges, unlike product/ service exchange, have a less relevant position within the company strategy, and therefore, this constitutes an important impediment to the successful construction of IS clusters ex-novo. The research stresses the importance of evaluating EIP initiatives cautiously, taking into account the barriers that are also present in the development of clusters. The difficulty in isolating conditions that make successful clusters possible and, more importantly, the limitation of policy to reproduce these conditions should also be considered. The authors though recognise the importance that the institutional framework can play in fostering these initiatives, by facilitating networking or collaboration. However, the ultimate development of a complex IS network will also depend on a number of preconditions such as the existence of a shared common interest and culture of cooperation.

2.7 Policy Aspects of IE and IS: Overcoming Policy Fragmentation

The policy component of IS covers three main levels of analysis. The first level refers to the wider institutional framework that influences the political decision-making process, knowledge, values and principles. The second level basically refers to the regulations that define the ground of industrial activity. Third, on a more applied level, policy also encompasses the use of public investment to promote initiatives that try to favour the further implementation of IS projects. This could be done through the funding of coordination bodies and/or systems, the provision of incentives for the attraction of companies or the development of infrastructures and championing of IS projects, among others. All three levels remain largely unexplored by the literature (Korhonen *et al*., 2004).

Although, as mentioned above, a thorough analysis of the policy facet of IE/IS is still missing, the need for policy intervention in IS projects has been a highly contested issue. The field is divided by two main positions (Korhonen *et al*., 2004): those who argue for policy intervention as a way to overcome the barriers to the implementations of IS projects and the need of a more active role of policy actors in fostering IS projects (see, for example, Boon and Baas, 1997) and those who argue against direct policy intervention as distorting the rational choice of economic agents (Desrochers, 2004). However, in most of the contributions, a certain degree of policy intervention is advised, at least to remove the obstacles and barriers that currently hinder the further exploitation of the potential benefits of IS (Van der Bergh et al., 2004).

Exploring the underlying assumptions of these positions is thus necessary if IE and IS are aiming to guide policy action, moving for the predominant descriptive approach to more challenging spheres of sustainable development. Opoku (2004) addresses the ideological positions behind different perspectives and approaches to IE. The author claims that the actual implicitness of ideological references in the IE literature inhibits a more open debate on policy action and its role in promoting IE. The author proposes four different ideological approaches to IE. While in "soft reformist" and "technocracy" approaches economic interests prevail over the environmental, the radical and the pragmatic approaches opt for the introduction of environmental principles at the core of decision-making processes. Therefore, the predominant ideological conception adopted by the main actors will lead to different policy objectives and instruments and thus different outcomes.

On a different scale, Andrews (2002) addresses the effect of planning practices and institutional frameworks in the implementation of IE/ IS projects. The author explores the role of planners in the promotion of IE development and investigates how different institutional frameworks choose different set of parameters in the planning processes and how this has an effect on the articulation of IE/ IS projects. In a planning context such as exists in Denmark and the UK, "*government planners tend to take a more active role in shaping urban form*" (p.480), and therefore, the vision of the planner and the incorporation of environmental and IE principles is key in moving towards more cyclical ecosystems. However, little evidence of changes in the planning process through the incorporation of IE principles exists. Although, in the UK and Denmark, environmental principles have in many ways pervaded the planning process (Rydin, 2003; Flyvbjerg, 1998), it is unclear that they have promoted a more integrated and cyclical design of industrial systems. Andrews calls for the need to temper the "grand visions of IE" by implementation experience, adapting its principles to the different physical and institutional frameworks in which they are embedded.

Powers and Chertow (1997) analyse the problem of "*policy fragmentation*". According to the authors, the body of environmental regulations has evolved incrementally, becoming a complex web of standards, practices, approaches, generated, in many cases, by different regulatory departments and responding to artificially isolated pollution problems. The problem of fragmentation is that it defines boundaries and divisions of pollution problems, overseeing the interconnection among them and therefore, losing the scope of the system as a whole. This generates a sort of specialisation, which accumulates a lot of specific knowledge about the area of speciality but at the expense of a greater disconnection with the system as a whole and the social and environmental consequences of the particular actions undertaken in the one specific area. The authors mention three different categories of fragmentation in environmental regulation: a) by type of pollutant, b) by life-cycle stage and c) by organisational characteristics. The interconnected divisions of environmental problems define an incomplete pattern of areas of intervention and areas that escape the control of regulation. The old artificial fragmentations and categorisations of pollution problems should then be replaced by a new integrated way of understanding the environment and human activities. These new practices, based on a systemic approach, "*become the fabric of a new environmental policy*" able to deal with the increasing complexity of the interactions between social and natural systems in a harmonising way (Powers and Chertow, 1997, p.33).

Van der Bergh *et al.* (2004) argue for a "*general dematerialization policy among national governments, as well as at the level of international governance*" (p. 374) that set objectives for dematerialisation and strategies for its achievement. The authors recognize that a "*clear and effective*" (p. 373) environmental policy that controls the impact of the use of materials and energy throughout the industrial process is insufficient to create adequate market conditions for the generation of the "*necessary adaptations, technological developments, and new applications*" (p.373), in a scenario characterized by imperfect information, bounded rationality and risk.

The call for more integrated policy approaches in the regulatory arena has been partly answered by the progressive implementation of the Extended Producer Responsibility (EPR) in many OECD countries (Gertsakis *et al.,* 2002, p.521-522). This approach extends producer responsibility over the life cycle of a product, including its disposal and recycling, and thus, provides the basis for more cyclical use of materials (Ehrendfeld, 2004). It has been argued that EPR can be "*an effective policy mechanism to promote the integration of the life cycle environmental costs associated with products into the market price for the product*"(Gertsakis *et al.*, 2000). To date, this policy approach has been implemented for a number of consumer products in the European Union, but there have also been successful examples of implementation, where EPR have resulted from voluntary initiatives undertaken by private companies, as is the case with Xerox.

The role of local and regional authorities in promoting IS initiatives as part of wider local and regional development strategies has also been addressed in the literature (see, for example, Dunn and Steineman, 1998; Brand and de Brujin, 1999 and Deutz and Gibbs, 2004). Local and regional spheres have actually attracted growing interest within the field as the realms for generating the necessary commitment and interaction between actors and driver of the change. However, ideological positions support contradictory arguments in regard to the role to be played by local and regional policy actors. While some authors have emphasised the self-developed character of IS networks, as is the case of Kalundborg, and have stressed potential obstacles posed by the intervention of local authorities (Eilering and Vermeulen, 2004), the alliance between public and private actors has also been identified as key in the process of developing IS projects, either as "institutional anchor tenants" (Burstrom and Korhonen, 2001) or as a facilitators and "knowledge banks" (Von Malmborg, 2004). Dunn and Steineman (1998) emphasise the role of planners in identifying potential IS opportunities by analysing resources needs and act as coordinators between different sectors and industrial areas. Similarly, Wallner (1999) points to the key role of government in providing suitable institutional conditions for IS development. Brand and de Brujin (1999) point to two main policy options for the promotion of IE/IS at the regional level, focusing on EIP: motivating policy and facilitating policy. Among motivating policy actions, the authors mention: a) the set up of an information office, which could provide examples of other projects, potential partners for IS exchanges and other relevant information; b) the introduction of a "sustainable team" that could initiate projects; c) the organisation of workshops that bring people together and facilitate the exchange of information. The authors also point to the need to provide financial support for the development of EIP. They point to three main options for facilitating policy that include: a) stimulating non-enforceable investments; b) stimulating company relocation according to IS compatibility and c) supporting the adoption of a management and facility system.

The case of the Netherlands, with a policy strategy for the development of eco-industrial parks, has been the basis of different research projects, which have empirically analysed different policy approaches and IS initiatives. Pellenbarg (2002) is the first of a series of papers that analyse the policy of development of industrial parks in the Netherlands, presenting an inventory of these initiatives and outlining potential factors of success and failure. The author refers to two main policy strategies: a) those aimed at sustainable production processes, which focus on physical exchange streams between firms and b) those aimed at sustainable site arrangements, such as more intensive use of space, provision of joint services and common facilities or multimodal transport options. The results are in line with other similar research and point to a wider implementation of the lower ambition strategy, that is, the one that focuses on what the author call sustainable site arrangements, although the exchange of materials, energy and water is present in a fair number of initiatives. The role of government should, according to this author, focus on an enabling position that creates the suitable conditions and delivers appropriate services but leaves the leadership of the project to the firms.

Van Leeuwen et al. (2003) examine planning methods for the development of EIP projects used in the Netherlands. They identify six different planning approaches for the evaluation of new and existing industrial estates in terms of IE/IS. The different methods are based on grading and classificatory schemes that evaluate the development against an "ideal" scenario. For assessment of the different planning options a theoretical framework is proposed that evaluates the level of ambition of the planning options against four main criteria: the concept of sustainability applied; the options that are considered, including industrial symbiosis, utility sharing and/or spatial planning and landscaping; the process for achieving cooperation and the steering instruments in place, such as park covenants, environmental tools such as environmental impact analysis or life cycle analysis or the set up of a park management organisation. Results seem to point to a limited success in terms of ambition of the planning approaches examined. In most cases the vision of sustainability is ambiguous or not clearly defined, symbiosis and utility sharing are options not fully explored, the participation of companies in the process is limited and the enforced steering instruments have only a modest environmental benefit.

This research is followed by Eilering and Vermuelen (2004) who address the results of the practical implementation of the Dutch policy to promote the development of EIPs, based on a combination of promotional instruments and funding schemes. While in the previous research Van Leeuwen *et al.* focused on the analysis of the different planning methods and the way the concept of EIP has been operationalised, here the authors focus on the identification of the elements that determine the degree of success of the initiatives. Eight case studies of EIP initiatives were selected from the most ambitious projects carried out under the umbrella of the funding scheme for EIP. Results from the research point to the relevance of complementarity between companies regarding their needs for energy, water and residual flows and the key role played by social aspects such as the existence of mutual trust, the presence of an anchor company and a pioneer and short mental distance between the companies interacting. Both physical and social factors were necessary for the successful development of the initiatives. An interesting finding is that the most successful initiatives seem to have been those in which the companies shared some kind of common background (they were in the past part of the same company) or cases where companies already interacting as member of a chain. The results also stressed the need for communication and involvement of stakeholders during the process. In the most successful initiatives a bottom-up approach was adopted, that is the companies are those leading the process, facilitated in some cases by local authorities. Administrative and policy support for the initiatives also contributed to their successful development. The research is inconclusive regarding the suitable mix of policy instruments that may help in the successful development of EIP projects. The authors consider specifically the following policy instruments: promotion and acquisition, facilitation, park management, financial incentives, company requirement and enforceable legislation. In the case studies analysed no direct relationship was found between the policy instruments used and the degree of success of the initiative. As a result of this, the authors question the relevance of the policy instruments in promoting EIP; however, they seem to fail to acknowledge that all the cases examined were to some extent the result of a direct policy action to promote IS and therefore, they may not have happened if this policy framework had been absent.

On a wider spatial scale, Gibbs (2003) and Gibbs et al. (2002) investigated a number of eco-industrial initiatives in the US and Europe. This research found that most of the initiatives labelled as eco-industrial developments, were either at very early stages in the planning process or show a substantial divergence between the proposed plan and the actual development. The authors conclude that eco-industrial development acts more as a marketing label to differentiate the projects than as a substantive IS strategy. Indeed, in most of the cases the level of ambition of the project was rather low and in most cases only involved some kind of green landscaping or building design, while initiatives based on material exchanges and cascading of energy were almost absent.

Similarly, Chertow (2007), partly drawing on a revision of Gibbs study, reviews a number of existing IS networks and proposed EIPs around the world. The author differentiates between two models of IS development: "planned EIP" and "self-organising symbiosis". The analysis reveals that "uncovering" existing industrial symbiosis has proved more successful that the attempts to create IS ex-novo. Chertow questions the effectiveness of policies that aimed to design industrial symbiosis from scratch and, drawing on the cluster theory and the lessons learnt from the existing IS case studies, argues that policy efforts should be directed to the promotion of existing kernels or exchange structures in order to foster their further development and complexity. More concretely, she points to three policy strategies to promote IS: 1) identify and map existing kernels of cooperative exchanges that are still hidden; 2) assist and support the further development of those starting to take off and 3) identify and assist "precursors to symbiosis" that may act as catalysts of new kernels. According to this, the role of policy should focus on the further assistance of existing symbiosis synergies that have emerged as a consequence of a business decision motivated either by potential cost-savings or by regulation and/or a company's voluntary commitment to improving environmental performance.

All these contributions point to the need for more research to clarify the role of policy instruments in the promotion of IS. The transition towards more cyclical industrial systems is a complex process not exempt of obstacles, as it requires a restructuring of the practices and operative principles of industry, and subsequently the principles that have guided traditional industrial policy. Policy can play a role in facilitating this process, but it does require a substantial change in the way industrial and environmental policy is conceived. As examined in this section, this change needs to cover all three dimensions of policy, from envisaging development strategies, through the design of new more integrated regulation to the introduction of instruments of direct intervention, facilitation and promotion. Thus, if new policies aim to guide the process towards more integrated industrial systems, guiding principles for policy making should accommodate the new approach offered by IE and IS. The table below shows the commonalities and disparities between the principles that guide traditional industrial practices and those proposed by IS.

Table 2.3: Comparison between guiding principles of traditional industrial policy and IS development.

Predominant values	IE/IS
Sector clustering	Diversity
Competence	Cooperation
Firm (organisation)	Community/network
Unconnectedness	Connectedness
Global	Local

\Source: author generated

2.8 Challenges to Eco-industrial Development: Barriers and Obstacles

Much attention has been paid to the potential benefits of eco-industrial initiatives, both in environmental and economic terms, in the specialised literature and policy proposals. However, the “win-win-win” situation has rarely been achieved and implementation of IS has resulted in a long and complex process (Gibbs, 2003). This has contributed to arguments questioning the benefits highlighted in the literature and, more globally, the validity of the approach. Desrochers (2002) argues that if the potential benefits existed, companies, led by rational behaviour, would have implemented IS options long ago. This position is based on the arguable assumption that the decision–making process is based on perfect information, where costs and revenues are easily identified and quantified. Most commonly, however, the slow uptake of IS has been attributed to the existence of a number of potential barriers and obstacles that face IS projects and that hinder its further development (Brand and De Brujin, 1999; Pellenbarg, 2002; Gibbs, 2003). A closer review of some of the initiatives carried out in the field of the eco-industrial and barriers reported in the literature seems to point to some main recurrent constraints that faces IS development. In this section, some of the main barriers and obstacles for the implementation of IS initiatives reported in the literature are critically reviewed.

2.8.1 Trust Building and Emotional Barriers

The industrial ecology approach is based on the collaborative and cooperative interaction between companies and between companies and local communities and authorities. In this context, the question of trust and consensus building poses important challenges to further development (Gibbs et al., 2005). Indeed, as mentioned previously, trust building is not a straightforward process and it requires time to develop. A crucial element in this process is the compromise of participating firms in a *"fair cooperation"* over time (Hassler and Schwarz, 2001). The trust-building process is sensitive to changes in the behaviour of any of the partners in the network. According to game theory, if any of the firms acts uncooperatively, it is expected that other firms act the same way, reducing the opportunities of achieving collective benefits. Another important element in the trust-building process is distance. Distance can be understood in spatial and emotional terms and both are crucial to secure trust and reach consensus. Geographical proximity is an asset for the development of eco-industrial systems not only because it reduces transportation costs, that can be determinant in waste exchange or energy cascading, but also because it contributes to raising the level of trust between companies, as exchange of information and informal monitoring becomes easier and cheaper. Emotional distance can also be related to spatial distributions, as companies co-located share a similar vision of the context and face similar conflicts. This shared vision can contribute to the reduction of emotional distance between firms and thus facilitate the trust-building process. As noted in the case of Kalundborg, the spatial concentration of activities and the emotional proximity between firms and local authorities have allowed the development of a complex network over time. However, it cannot be forgotten that the process of trust and network building has been evolving over more than 30 years and it has not been unproblematic.

2.8.2 Informational Barriers

Cooperation and networking are also dependent on the information flow between companies that enable synergies to be identified and linkages to occur. In many cases companies lack knowledge about the by-products and wastes generated by neighbouring companies, reducing the chances of establishing profitable linkages in this area. Information on the processes and products of co-located firms may actually be totally unknown. This lack of knowledge hinders potential cooperation in other areas. Web-based systems are relevant tools to overcome the **information barriers** that bar potential linkages and synergies. As noted by Harris and Pritchard (2004), industrial ecology can be seen as a learning process, where exchange of information, assimilation and application are phases of a whole process of cultural shift that can only be fostered by cross-company cooperation. Therefore, a readiness to communicate and exchange relevant information with partners is an important key to success. The value given by the recipient to the information is influenced by the perceived credibility of the informant, therefore the question of mutual trust is also important in removing informational barriers (Milchrahm and Hasler, 2002).

2.8.3 Regulatory Barriers

Regulation has been in many cases the main driver in enhancing environmental management in companies, contributing to the development of pollution prevention approaches and eco-efficiency strategies by changing the relative costs of pollution and cleaner production. However, regulation can also act as a barrier for IS when it is inspired by an individualistic approach to environmental management. Laws and regulations are usually addressed to individual companies and they often create disincentives to inter-company cooperation and exchange of potentially useful by-products and wastes. Although there are important differences in the regulatory framework of industries in Europe, and even more divergences in the way regulation is enforced, the European regulation has set a common framework for national governments and industries to address environmental problems. Related to eco-industrial development, one main problem derives from the definition of waste itself. The lack of distinction between wastes and secondary materials in EU-based regulations constrains the exchange, reuse and recycle of wastes between companies, as special permits and licenses are required to exchange materials classified as waste. The legal liabilities associated with waste management, reuse and recycling can also be seen as a barrier to the exchange and reuse of these materials.

2.8.4 Economic Barriers

Although potential cost savings and economic incentives in the adoption of IS solutions have been much emphasised, the case studies reported in the literature seem to point to a much more complex scenario, where the calculation of costs and savings largely depends on the institutional framework in which the organisations operate. Elements such as waste generation or disposal taxes, regulation and emissions limits or the broader concept of "*license to operate*" (Chertow, 2007, p.15) may greatly shape the relative costs of pollution and create incentives for waste exchanges. Cost of transport and other transactional costs may also help in understanding why the implementation of some *"win-win"* IS exchanges failed. The economic incentives of IS can also depend on the existence of a *"reliable market for the waste by-product"* (Brand and De Brujin, 1999, p.228).

2.8.5 Technological Barriers

Industrial ecology can actively promote innovation and technological change achieved by cooperation and dissemination of knowledge. Moreover, IS can also contribute to the development of technological and technical solutions for the transformation and exchange of waste. However, it could be argued that IS may contribute, under certain circumstances, to the problem of technological and institutional lock-in, as it may delay the adoption of cleaner technologies by reducing the cost or even valuing waste streams and it can create interdependencies between firms that hinder the process of innovation.

It is also necessary to note that the exchange of wastes and by-products is not an unproblematic technical question, and it may impose a barrier to the implementation of IS. Wastes often require adaptations and transformations before becoming raw materials in other processes. Given the wide range of wastes and their varied chemical composition, its transformation often requires complex and specialised technological solutions. In most cases, waste and by-products are complex chemical mixtures "*reduc(ing) the likelihood of any manufacturing plant to be able to account for the exact chemistry of their waste stream*" (Dunn and Steinemann, 1998, p.669), and thus, generating **technological challenges** for their clean-up or separation, before they can be reused or recycled. Moreover, this may also increase "*the risk of more toxic synergistic effects*" of the waste stream (Dunn and Steinemann, 1998, p.669). Further developments of the waste treatment sector and widespread use of new applications are first steps in the building of more complex exchange networks. However, these new technological developments do not escape from the dynamics of innovation. As noted by Huber (2000;2004) the dynamics of innovation point to some processes that can deter or even stop the process of adoption of new technologies, even when they produce potentially better economic and environmental results. Those barriers are related to the learning economies and inertias of the technological process itself. The lack of experience, of technology suppliers and of specialised technicians and the uncertainty of the outcomes of the research process, increase the risks, and, thus, the costs associated with the use of new technology. Also, in the first stages of development, an innovation lacks the supporting technical network required for its wider use. In this first stage, even though potential benefits of applying and developing the innovation are greater, the risks and uncertainties can discourage further adoption of the innovation until more experience and supporting networks, that guarantee its results, have been developed.

Moreover, the necessity of adapting the processes of the company to the new technology and training the workers in its use are factors that can deter its introduction. The dynamics of innovation help to explain why end-of-pipe solutions are often preferred to cleaner production techniques and procedures, even though the latter may provide better solutions in terms of cost/benefits generated in the medium and long term.

From a spatial perspective, it is also possible that the companies located in a region are not complementary in terms of potential to reuse waste streams (Brand and De Brujin, 1999).

2.8.6 Risk and Uncertainty

As has been emphasised, **risk and uncertainty** are also significant obstacles in the widespread of eco-industrial initiatives. This approach involves a new way of doing business and therefore faces some uncertainty regarding the results. Also, cooperation between firms implies higher levels of inter-dependency. Networking favours the diffusion of benefits throughout the network but it also poses risks due to the increasing complexity of the network and companies' dependency on each other (Gibbs, 2003). Moreover, networking requires higher degrees of flexibility and openness, factors that can make more evident the weaknesses of a company. In the case studies presented in this thesis, trust and commitment between companies have been key elements in reducing the perception of risk and uncertainty that accompany inter-organisational collaboration.

2.8.7 Cultural Barriers

Last but not least, there are **cultural barriers** that challenge the further adoption of an eco-industrial approach. The change from an individualistic perspective to an integrated industrial eco-system requires a great cultural shift for companies. Companies are expected to evolve from a culture based on competitiveness to a new context based on cooperation and collaboration. Cultural shift needs time and compromise to get settled. A good example of the time dimension of the approach is the Kalundborg case, where a long-term commitment between companies and local communities and authorities has led to a very complex and integrated eco-industrial symbiosis network.

The prejudices against the concept of waste are important too. The meaning of waste as something useless has been interiorised by company managers and even technical staff so that they may show some reticence about the use of waste as raw material. Knowledge transfer and demonstration projects can play a significant role in overcoming this kind of impediment. Resistance to change is also an important institutional barrier that may slow down the process of development of IS networks (Burstrom and Korhonen, 2001). This can require changes in the whole decision-making process and strategy definition.

2.8.8 Summary of Main Obstacles and Barriers to IS

The table below summarises the main barriers to IS development identified in the literature.

Table 2.4: Barriers to the emergence of IS networks

TYPE	ROLE PLAYED	REFERENCES
Absence of trust and emotional barriers	The absence of trust inhibits communication between actors and willingness to cooperate.	Cibbs (2003); Chertow (2007)
Informational barriers	Companies may lack information about other companies' by-products and waste flow	Schwarz and Steininger (1997); Brand and de Brujin (1999);
Regulatory barriers	Regulatory obstacles to the exchange of by-products or the creation of alliance (e.g. antitrust law in US)	Brand and de Brujin (1999); Fichtner et al. (2005); Chertow (2000)
Economic barriers	Divergences in investment cycles or uncertainty of the benefits derived from IS exchanges	Brand and de Brujin (1999); Fichtner et al. (2005); Chertow (2000)
Technological barriers	IS exchanges may pose some technological challenges as transformations and adaptations of the by-products before exchange need to be undertaken. Dynamics of technological change.	Dunn and Steinemann (1999);
Risk and uncertainty	IS exchanges may generate uncertainties regarding the outcome, performance or cost-benefit ratio. Increase inter-dependency and thus vulnerability to context changes.	Burstrom and Korhonen (2001); Fichtner et al. (2005)
Cultural barriers	Obstacles for the shift from competition to cooperation culture for companies. Conception of waste, as opposed to quality. Lack of environmental consciousness among companies; Resistance to change.	Ehrenfeld and Gertler (1997); Burstrom and Korhonen (2001); Fichtner et al. (2005)

\Source: author generated.

Although the identification of these barriers is crucial in progress to the implementation of IS, there is still little understanding of the mechanisms of the interaction among them and the social processes, rules and values that shape actor behaviour and network coordination. It is the focus of this thesis, to look closely at the subtle mechanisms that shape actor behaviour in interaction with the wider institutional context in which it is embedded. A deeper analysis of potential hindrances will be provided in the analysis and discussion chapters.

2.9 Key Factors in the Implementation of IS Projects

Although there is still limited evidence of the results of the practical operation of IS networks and EIP initiatives, an effort to identify and summarise the main requirements and factors that can determine the degree of success of IS projects has been attempted here.

Together with the identification of potential barriers some factors have been highlighted as key for the implementation of IS. These key factors have been considered a necessary condition for the success of IS initiatives. In many cases, these crucial aspects are the result of the absence of one of the barriers mentioned above. Gibbs (2003) refers to *"untraded interdependencies"* as key in the development of collaborative inter-firm relations. Untraded interdependencies consist of a combination of routines, practices and implicit rules that rely on trust and reciprocity among industrial actors and that allow the emergence of collaborative relations.

The importance of trust is also highlighted by Chertow (2007) and Pellenbarg (2002) among others. Reciprocity is also linked with trust and it plays a relevant role in assuring that collaboration is beneficial for all the parties involved (Gibbs, 2003). However, the process of creation of trust and reciprocity is still unexplored, as has been noted before. There remains a number of unanswered questions regarding the elements that may foster their emergence. Also relevant is the existence of short-term economic gains derived from the cooperation that may overcome the initiation costs and provide the basis for undertaking more ambitious projects (Pellenbarg, 2002). Another prerequisite is that the combination of activities at the local or regional level is to some extent complementary regarding resource needs and waste streams (Chertow, 2007).

An adequate regulatory framework and the introduction of pollution control instruments may also contribute to create the incentives for waste exchange, as it changes the relative costs of pollution and it imposes limits on emission levels. Involvement of stakeholders, self-organisation and the need for bottom-up approaches are all interrelated factors that seem to play a relevant role in IS networks. Gibbs (2003), Eilering and Vermeulen (2004) and Chertow (2007) point to the inadequacy of top-down approaches to promote the emergence of IS networks. Planning initiatives that have not taken into account key stakeholders show a much higher failure rate than initiatives that have been led by the companies themselves. Chertow argues that IS initiatives need to pass the market test to prove their feasibility. Another element emphasised in the literature is the existence of "*short mental distance*" among the actors involved (Ehrenfeld and Gertler, 1997). Interaction among actors who think alike facilitates communication and creation of trust. A more discussed issue is the role played by geographical proximity. Although it has been considered as a prerequisite for the emergence of IS networks by some authors (Graedel, 1996; Korhonen, 2002; Baas and Boons, 2004), it has also been recognised that IS networks can work at different spatial scales (Baas and Boons, 2004).

The table below indicates the physical and social elements that play a crucial role in the development of IS and that may constitute a necessary requirement for IS to develop.

Table 2.5: Key factors for the emergence of IS networks

KEY FACTOR	ROLE PLAYED	REFERENCES
Complementary activities	Industrial activities need to be complementary in their needs of resources	Lowe and Evans (1995); Pellenbarg (2002); Chertow (2007)
Suitable regulatory framework	A suitable pollution control regulatory framework may create the incentives for by-product exchanges	Ehrenfeld and Gertler (1997)
Trust	Trust among the involved partners reduces transaction costs, risk and uncertainty of IS exchanges and is key in the creation of collaborative structures	Gibbs (2003); Chertow (2007); Baas (2008); Ehrenfeld and Gertler (1997)
Reciprocity	Together with trust, reciprocity assures that cooperation is mutually beneficial for all the actors involved	Gibbs (2003)
Self-organisation/ bottom-up approach	The involvement of key stakeholders, and especially industries, in the process is essential for its further development.	Eilering and Vermeulen (2004); Chertow (2007);Baas (2008)
Short mental distance	Short mental distance assures convergence of goals and visions and facilitates communication.	Chertow (2000); Eilering and vermeulen (2004); Christensen (2006)
Spatial proximity	Transportation costs and other transaction costs are significantly reduced when companies are located in close geographical proximity. Distance may have a discouraging effect on the establishment of collaborative linkages.	Graedel, 1996; Korhonen, 2002; Baas and Boons, 2004

\Source: Author generated.

2.10 Conclusions

Over the past decade the field of IE has emerged as a new approach that focuses on the environmental restructuring of industrial systems so that they move towards closed-loop, cyclical systems. Within this approach, IS has focused on the development of inter-firm cooperation networks for the exchange of waste streams, transfer of knowledge and information and share of common facilities and services. Progress on the development of the scientific foundation of IE and IS (see, for example, Graedel and Allenby, 2003) has been combined with the "*discovering*" of existing IS networks (Chertow, 2007) and planning and prescriptive policies for the development of new IS projects. This has provided a growing body of literature and expertise and the basis for the critical review of the contribution of IE and, more concretely IS, to the greening of industry. However, as pointed by Gibbs (2003) and Chertow (2007), the number of practical examples of genuine IS networks is still rather low and the planning attempts to develop them relatively unsuccessful. As an emergent field of research, both from a theoretical point of view and from a more practical perspective, there are still major issues that need to be addressed and further understood.

As has been noted in this chapter, there is a lack of understanding of the social mechanisms that foster the emergence of cooperation in IS projects and how to manage them. Future research needs to address these issues and advance the understanding of the factors shaping a company's decision to cooperate by looking closely at its decision-making processes, discourse and networking dynamics. Contributing to the understanding of these social processes is the main focus of the research presented here.

Although in recent years a number of studies have tried to shed some light on the policy dimension of IS, its prescriptive realm remains relatively unexplored. Most of the analyses have focused on the descriptive analysis of existing initiatives and plans but the policy agenda is still rather ambiguous and unspecified. There is thus a need for a more defined policy framework and policy tools and instruments to foster IS. Although this is not the primary goal of the present research, this thesis also aims to provide some guidance on the design of policy and prescriptive actions.

B. METHODOLOGY

Presentation of the research design and description of the methodology used have been organised into two chapters. **Chapter 3** presents the main elements of the research design, provides an outline of the main methodological frameworks and clarifies the methods used for the data collection and analysis. The chapter concludes with a discussion of the potential limitations of the methodology proposed.

Chapter 4 presents the specific analytical framework designed for the evaluation of social aspects of IS networks. In an attempt to contribute to the gap identified in the literature review regarding the lack of comprehensive frameworks for the analysis of the social components of IS networks, this chapter presents the innovative analytical protocol adopted in this research. The framework designed builds on two main methodological approaches: Social Network Theory and Discourse Analysis. These two main methodological approaches are briefly presented and their adaptation to IS is discussed.

Chapter 3.
Methodology: Research Design

The methodological framework outlined in this chapter strives to capture the social aspects that surround the process of emergence and development of IS networks. The research focuses on the understanding of the social processes that govern material and energy exchanges. Therefore, due to the nature of the research question, the methodology designed takes a predominantly inductive approach, using a combination of qualitative methods. The chapter is structured in the following way. Firstly, the research question that guide the research is outlined. Secondly, the ontological premises and the epistemological foundations of the research are addressed. Thirdly, the process of selection of the case studies and the criteria used are explained. The fourth section addresses the design of the field research and other practical aspects of the research. In the last section, the main limitations of the methodological approach adopted are discussed.

3.1 Research Question

3.1.1 Research Question

The broad research area that frames this thesis engages in the analysis of industrial symbiosis networks and their potential contribution to the greening of industry and, more generally, to sustainable development. More concretely, the question that guides this research is: what are the key social processes behind the emergence and development of IS networks?. The theoretical justification of the question relates to the main gaps identified in the literature review (Chapters 1 and 2) regarding the insufficient understanding of the drivers and social processes governing material and energy exchanges in IS networks. Other theoretical concerns informing the research that constitute underlying research sub-questions are as follows:

- The impact of institutional, cultural and organisational frameworks on the development of industrial symbiosis and how this reflects on the structure of the network: what type of institutional frameworks may foster or hinder the emergence and development of IS networks?; Is the institutional framework shaping the structure of the IS network? And if so, how?; What is the strategic role of industrial symbiosis in the broader environmental policy context and what policy approaches may foster its development?

- The process of creation and the dynamics of operation of industrial symbiosis networks: What key elements may promote the emergence of IS networks? What main phases can be identified in the process of development of IS networks? What are the key elements in each of these phases?
- The discursive dimension of industrial ecology and IS networks: What roles are playing the narratives and discourses of the different actors in the phases of the development of the network, from its conception throughout its operation?; How is the industrial ecology discourse constructed?; Is the discourse dimension of IS having an impact on the material outcomes of the networks?

3.1.2 Specific research questions

Drawn from the literature, some more concrete research subquestions have been defined.

Related to the material basis of the synergies, the research aims to identify which key factors may favour the development of industrial symbiosis networks and, specifically, analyse the role of the following elements:

- The existence of complementary activities and waste/resource streams
- Quality specifications, volume and delivery requirements with regards to matching the needs of supplier and recipient organisations
- The availability of technologies to clean up or treat waste streams

Related to the social features that may act as drivers of actors' involvement and networking, the research looks into the role of the following factors:

- The presence of trust among the companies involved
- The involvement of an anchor company
- The involvement of a pioneering actor and leadership in the project
- The presence of short "mental distance" between the companies involved

- The presence of a certain level of commitment to environmental goals by the actors involved

3.2 Foundations of the Methodological Approach

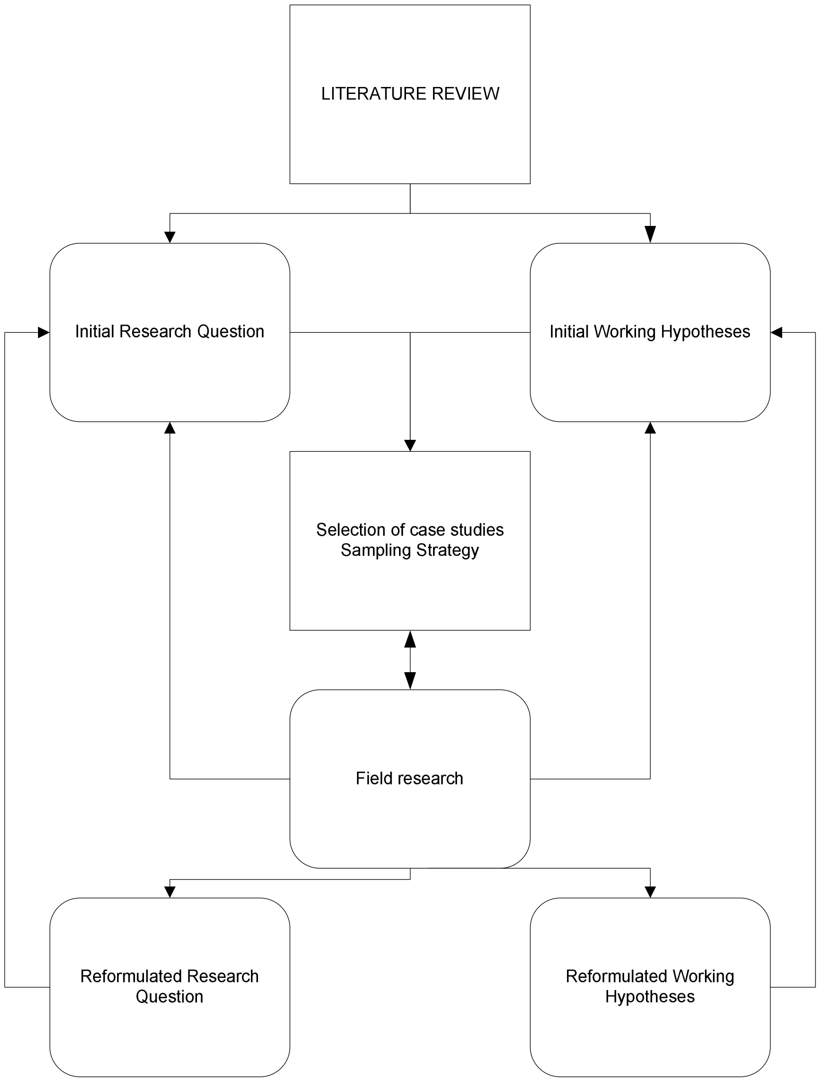
3.2.1 Introduction: Ontology and Epistemology of the Research

Two main ontological and epistemological approaches inform the process of knowledge creation in social sciences: the deductive and the inductive approaches. While the deductive method is generally linked to the positivist paradigm that assumes that the social world is an external, objective reality that can be observed and analysed through the scientific method, the inductive approach proposes a more flexible interrelation between knowledge/social world, where the emphasis is not so much in the description or understanding of an external entity or reality but on the dynamics of interpretation and co-creation of the social world. The research here presented departs from a fundamentally constructivist-interpretationist paradigm. Ontological and epistemological premises guide not only the selection of the research focus but also the methodology adopted and the outcomes expected. As noted by Denzin and Lincoln (2005, p.24), the constructivist paradigm assumes a "*relativist ontology (there are multiple realities), a subjectivist epistemology (knower and respondent cocreate understandings) and a naturalistic (in the natural world) set of methodological procedures*". Industrial symbiosis networks are thus examined as a social structure that is simultaneously constructed and reflected upon by the researcher and the actors involved. This approach does not deny the material basis of IS networks but understands that their identification first as a singular phenomena and then as a sustainable instrument is part of the process of co-creation of meaning and social interaction. This ontological and epistemological position explains the focus of the research question on the social processes behind the articulation of industrial symbiosis networks and the emphasis given to structural and discursive dimensions in the analysis. These ontological premises inform the research design described in the next section.

3.2.2 Research Strategy and Design

Due to the nature of the research question and the epistemological perspective stated above, the methodology proposed is based on a combination of qualitative approaches applied to the analysis and cross-comparison of different case studies. This methodology was designed in dynamic terms, so that, the initial research question established and the working hypotheses adopted, before conducting the field research, as expected, needed to be modified along the research process, leading to the redefinition or operationalisation of the initial questions and hypotheses, as illustrated in the scheme below (Figure 3.1).

Figure 3.1: Research design



\Source: author generated.

As an example of the dynamic conceptualisation of research questions and hypotheses and the changes operated in the research focus and scope as a consequence of the interaction with the case studies and data it should be noted that the research question initially focused on the potential contribution of eco-industrial parks in the sustainable planning strategy of the UK. Therefore, some initial hypotheses were adopted with regard to the drivers and obstacles that could foster/ hinder the process of development of eco-industrial parks. Thus, so-labelled eco-industrial parks were identified in the UK, based on literature reviews, planning documents, estate agents publications and an extensive Internet search, and initially assessed in terms of sustainability. However, the preliminary findings of the pilot study conducted pointed, in the best of the cases, to a very loose interpretation of the concept of eco-industrial park due to the limitation of the scope of the initiative and their debatable contribution to industrial ecology and industrial symbiosis. Some main problems were identified:

- As also highlighted by Deutz and Gibbs (2004) in many cases labelling new industrial developments as "eco-industrial parks" was the result of a "territorial marketing strategy" of regions competing for inward investment rather than a genuine commitment with a geographical approach of closing the material and energy loop of industrial systems.
- In many of the cases examined, there was a clear absence of innovative component or it was restricted to very small-scale projects (as in the case of the Eco-Tech Centre-Business Innovation Park in Swaffham, Norfolk)
- Many projected eco-industrial parks did not overcome the planning phase or were deferred and finally never carried out (see, for example, the East Manchester Eco-Industrial Park)
- In some cases the time horizon of the planning phase has extended so much that the context may have changed considerably compromising the viability of the project or leading to a complete reformulation of the goals and scope, led by the necessity of attracting investment, altering the original project (as it is the case of Sustainable Industrial Park of Dagenham Dock)
- In the majority of the case the attempts to establish material closed-loop networks have failed or have never been considered.
- Only in the best case, restricted green design or small-scale demonstration projects have been carried out. Generally the most challenging goals of the projects have in practice been limited to mere "environmental" design of green areas within the park.
- The main driver of most of the projects has focused on the regeneration of old industrial areas or economic development of rural areas, while environmental goals have only been added as a second-order element to differentiate the initiative from

other developments. The absolute predominance of the economic component, in its more traditional fashion of industrial investment and short term horizons, has led in most of the cases to the relegation of environmental objectives. Many projects were partially funded by governmental bodies as demonstration sites but their initial environmental goals were considerably distorted in their incapacity to attract investors (as is the case of Dyfi Eco-Park in Wales).

These preliminary findings challenged the initial assumptions of the research and called into question the potential contribution of eco-industrial parks in redefining the relationships between natural and industrial systems. This forced to the reformulation of the research strategy. This reformulation could be undertaken in two ways: (a) maintaining the research focus and analysing the barriers that the term of "eco-industrial parks" was experiencing in its practical application, based on the experience of eco-industrial parks in UK, or (b) redefining the research focus from eco-industrial parks to eco-industrial networks by broadening both the geographical scope of the study and its analytical framework. This research opted for the latter and thus, it changed its focus from industrial parks to networks and also its geographical locus from UK to EU, focusing on avant-garde projects of industrial symbiosis networks in Europe. The justification of this research option lies in the novel and innovative character of eco-industrial networks, whose contribution to industrial sustainable development needs to be critically examined. Moreover, as noted in the literature review, there is still a lack of understanding of the social dynamics that favour the successful development of these networks. In fact, a probable common reason of the "unsuccessful stories" of UK eco-industrial parks may have been rooted in the poor understanding of the dynamics of eco-industrial networks and their strategic role in sustainable development.

As already noted, a deeper analysis of inter-organisational collaborative networks may offer useful insights into the mechanism and drivers of industrial symbiosis and the key elements of "success". The analysis here undertaken may also help to ponder the potential contribution of these initiatives in a strategy of greening industry and the progressive integration of environmental and industrial systems. Therefore, the research aims at a critical examination not only of the drivers and barriers to industrial symbiosis, partly examined in the literature, but mostly the dynamics and social processes that lie behind the development of industrial symbiosis networks.

3.2.3 Grounded Theory and the Process of Building Social Knowledge

As noted above, the methodological approach taken in this research relies on a combination of qualitative methods. Grounded Theory (Glaser and Strauss, 1967) provides the methodological foundation for the research regarding issues such as data gathering and theory construction. Grounded theory (GT) methodological standpoints offer useful insights into how to address research in a field characterised by the lack of systematic "hard" sources of information or database and a disputable or problematic understanding and conceptualisation of the problem under study, due to the existence of alternative and even divergent perspectives and discourses converging in the field (see the discussion on different perspectives on industrial ecology and industrial symbiosis in Chapters 1 and 2). Moreover, GT allows a dynamic interaction between the researcher and the case studies so that knowledge is built along the process of the research, in interaction with key actors. Therefore, the boundaries of the research and the focus of study is redefined in interaction with the case studies and information is continuously reinterpreted in an iterative process of collection and analysis. The process of data collection is mainly based on in-depth interviews with main stakeholders, observation and site-visits and analysis of secondary materials. Where possible, this information is compared and contrasted with other sources such as policy statements, company reports, regulations and statistical data, aiming at the triangulation of findings.

3.2.3.1 Methodological Approach of Grounded Theory

Data gathering and theory building have been generally seen as consecutive stages in the research process. Glaser and Strauss (1967) challenged that idea of a two-phase process with their Grounded Theory method. This method of conducting qualitative research overcomes the traditional separation between the process of data gathering and theory building. The authors provided an "*idiosyncratic alternative to existing research methodologies*" (Dey, 2004, p.80), where the process of theory generation is stimulated by and "grounded" in the empirical research. In this methodology, analytical process and theory building is intimately interwoven with data gathering and interaction with the research context. Since its early formulation by Glaser and Strauss (1967), Grounded Theory has become a milestone within qualitative research and has become the basis for a wide variety of approaches, perspectives and interpretations. This process of "deconstruction" of the method provided a variety of versions of Grounded Theory (Dey, 2004). However, leaving aside the variety of perspectives, there are some common traits that characterise Grounded Theory-based research. First of all, the process of data gathering and collection of evidence requires from the researcher an open mind; special care should be taken not to distort or shape the data according to preconceptions and pre-existent theoretical structures, which may introduce a bias in the process of empirical research. In the early formulations of GT, hypothesis making was consciously avoided in order to eliminate its potential influence over the interpretation of empirical evidence. However, as many of the criticisms have pointed out, the lack of assumptions or explicit and/or implicit hypotheses is somewhat difficult (and arguably not desirable) to achieve in a research context, where the same definition of the problem is unavoidably shaped by previous knowledge and experience of the researcher and existing literature. Even though, in its extreme, this postulate is difficult and even undesirable to observe in a research project, the core idea behind it is worthy. It points to the precept of approaching empirical research with a flexible perspective, allowing ideas to be "discovered" during the research process and the theory to be built in parallel with the research, instead of "using" the data to test a previously conceived theory.

Another characteristic element of the methodological approach proposed by GT refers to the sampling process. Contrary to other research approaches, the sample is not defined a priori, but is based on the concept of "theoretical sampling". This involves an open process of sampling that builds incrementally, so that, the sample grows with the process of the research as new sites, actors or sources are sought to ratify, fill gaps or refine ideas. Thus, the original sample grows with the empirical research as more information is required to support the analytical process of theory building. Common to other qualitative research approaches, sampling procedures are not based on (statistic) representation and random selection but rather are guided by theoretical relevance (this issue will be further discussed in section 3.6 when addressing the limitations and problematic issues of qualitative research). As a qualitative method, Grounded Theory relies mainly, although not exclusively, on qualitative or soft data generated in observations inspired in ethnographic methods and qualitative interviews, which include a diversity of interviewing formats from informal dialogues to semi-structured interviewing. The process of theoretical sampling stops when the stage of "theoretical saturation" is achieved, which means when the input of new data does not add new ideas or does not alter significantly the “emerging theory” generated in the research process.

To achieve this “final” stage, data go through successive phases of codification. Codification is actually the critical analytical tool in the analysis of the data, within the framework of GT. The purpose of codification is to allow the “constant comparison” of data, through its classification into categories. The successive stages of codification the data go through denote different levels of analytical abstraction. In its interpretation of Grounded Theory, Strauss and Corbin (1990) distinguish three main phases in the coding process: open, axial and selective coding. Open coding is associated with the lowest level of abstraction. Codes in this phase are generally based on “in-vivo” terms, extracted from the data. This first analytical level is followed by the axial coding, where data are reorganised and reinterpreted on the basis of the open codes previously defined. In this phase relationships between the codes are sought. Connections among codes escape the univocal “cause-effect” relation, predominant in quantitative research, to build more complex relationships that include opposition, association or inclusion among others. Data are questioned and theory challenged by comparing and connecting categories. Selective coding goes a step further from axial coding by grouping codes into core categories as the theory “emerges”, offering a framework in which the research problem can be understood, while maintaining its complexity.

3.2.3.2 Adaptation of GT to the Analysis of Industrial Symbiosis Networks: Justification of the Methodology Proposed

The selection of Grounded Theory as the main methodological stance in addressing the potential of industrial symbiosis networks in contributing to a more sustainable path of industrial development can be justified from a double perspective: on the one hand, Grounded Theory offers methodological guidelines in approaching realities characterised by their complexity and low level of normalisation. As theory emerges while the empirical research is carried out, it seems to especially suit the necessities of the researcher faced with phenomena that lack a unifying theoretical framework, as is the case with industrial symbiosis networks. Industrial symbiosis networks still need to be understood, even though recently an increasing number of case studies have been reported in the literature, but still the social and organisational aspects that bring companies together in cooperative linkages still remain rather obscure. On the other hand, in GT, as in other qualitative methods, the description of the process acquires the same, if not more, relevance than the descriptions of the outcomes. This methodology recognises the explanatory capacity of the process in understanding a complex and ever-changing reality versus more static analytical perspectives, which focus only on outcomes and results. This seems to be crucial in understanding industrial symbiosis networks, as the "history" of the network and its "evolution" in time are critical to the results and outcomes achieved and its structural morphology. Apart from the elements mentioned above, there is also a practical bias in the selection of this methodology, which derives from the lack of "hard" data that document these initiatives. Grounded theory proposes the "creation" of data during the empirical research; in that sense, it addresses the constraint of dealing with a phenomenon for which sources of data are not available, but have to be generated by the researcher. However, as the focus of the research is not placed on the description of the energy and material flows but rather on the social processes that are actually deciding those links, "hard" data, even if available, would be insufficient and unsuitable to address the main research question.

3.3 Selection of the Case Studies

Selection of the case studies is a key element in the research design. Indeed it is a highly strategic process, designed in accordance with the scope and goals of the research, which aims to provide a comprehensive/in-depth understanding of the phenomena under study. Behind this process lies concern over the generalisation of the findings of the research. Even though the question of generalisability of the results is a highly polemical issue in the evaluation of qualitative research, as Flyvbjerg (2004, p.395) stresses, the potential "*Generalisability of case studies can be increased by the strategic selection of the case*s". Actually, when dealing with complex phenomena, such as eco-industrial networks, the "*random selection*" of cases, inspired in statistical methods, may actually offer a less representative picture of the phenomenon under examination. Moreover, the concept of "random selection" could hardly be applied to cases where the same borderline of what constitutes a "case study" becomes blur[1]. However, carefully selected cases may reveal

[1] As a new social innovation the same identification of "eco-industrial networks" becomes a highly arguable question. Moreover, the researcher is faced with the problem of "discovering" the cases, as the evidence is fragmented and scarce.

more information and may offer a more complex understanding of the problem investigated. The selective choice of cases also allows a deeper, richer and more complex evaluation of the problem under study, IS network in this case, by an investigation not only from the explicit but also from the subtle process shaping the operation of the network.

Flyvbjerg (2004) proposes a very interesting classification of strategies for the selection of "*information-oriented*" case studies. He defines four main strategies of case-study selection: extreme/deviant cases, maximum variation cases, critical cases and paradigmatic cases. Extreme/deviant cases are especially useful when the goal of the researcher is to stress some peculiarities by selecting very extreme or unusual cases that, as being problematic, offer a wider scope to analysis by pushing it to its extreme. Maximum variation cases strategy focuses on the selection of very different cases with the aim of analysing the significance of different elements or factors under divergent circumstances. With this strategy the researcher seeks to increase the variance between the cases, so that it stresses the differences between them in an attempt to explain the factors behind the observed dissimilarities. The critical case strategy aims to capture the essence of a process by focusing on cases that have key characteristics/factors. Critical cases contain elements that are essential in the understanding of a phenomenon and therefore allow a deeper investigation of dependencies and interrelation among key aspects or variables. Generally, this strategy focuses on those cases that show peculiarities that challenge the same conceptualisation of the problem under study. Therefore, according to this, a strategy based on critical cases is generally selected when the researcher is interesting in focussing either on those "*most likely*" or on those "*least likel*y" cases. This strategy is especially useful to reject theories or prove falsification hypotheses. "*Most likely" types* are especially appropriated to *falsification* propositions while "*least likely*" are more suited to *test or verification* (Flyvbjerg, 2004). Finally, the paradigmatic case strategy focuses on avant-garde, paradigmatic, innovative and/or attractive cases, which may be useful to develop a metaphor, model or to attract the attention of scholars and from which models are generally inspired. The significance of these cases goes beyond the particular situation they represent.

These strategies are not mutually exclusive. Indeed, in the selection of the cases of study, the researcher might combine criteria from all of these different approaches. Also, for this research the strategy developed for the selection of case studies follows a hybrid scheme. Industrial symbiosis networks, as social and organisational innovations, are at the early stages of development and they are far from being a standardised approach to waste and environmental management in industry. Thus, one of the criteria considered in the selection of cases has been an ability to provide lessons and models for the further development of industrial symbiosis. Therefore, one of the strategies has been the selection of a "paradigmatic case", which has performed especially well and rendered important outcomes, establishing a precedent and inspiring the mode of operation of IS networks. This was the dominant strategy when selecting Kalundborg as a case study. Being the most often referred example of industrial symbiosis in the literature, Kalundborg has acquired the status of model for IS networks. There have been attempts to replicate and emulate this experience in other scenarios, serving as an inspiration for the development of models in the field. However, in some aspects, Kalundborg might also constitute a "critical case" as the peculiarities of the context in which this network has developed point to the uniqueness of the case, reducing the likelihood of being successfully replicated ex-novo in other contexts.

Another consideration when selecting cases has been a willingness to increase the variance, so that a broader picture of the phenomena under study can be drawn. This strategy may also pose some risks to the outcomes of the research, as increased variability also reduces the possibility of extracting general patterns and therefore, general models and findings. To cope with this contingency, this research has opted to increase the variability of the cases but to limit the geographical approach of the study to Europe. This way, even when selecting significantly different cases regarding aspects such as goals of the initiative, process of development, strategies adopted, institutional framework or industrial structure, the limitation of the geographical scope has allowed for the control of the level of variance, so that comparisons are still possible and meaningful. In practical terms, this implies that cases selected are substantially different, both in internal and contextual aspects, but they are not extremely different, rendering any comparison useless. Because all the cases selected are based on European countries, they share to a certain extent a similar regulatory framework defined by EU environmental policy, business culture and industrial structure. However, significant differences can be observed related to business practices and organisation, operationalisation and enforcement of regulations and values and principles, among others.

The selection strategy has been completed with the selection of a deviant case. The aim of the deviant case is to look deeper at the barriers and obstacles for the full development of IS networks. An interesting case study in this sense is the industrial area of Sagunto in Spain, where, even though a favourable mix of industries exists, the level of development of IS projects and synergies is far from reaching its full potential. Identifying the factors that may be hindering those waste streams can actually contribute to a better understanding of industrial symbiosis networks.

In the table below a more detailed explanation of the criteria and strategy considered when selecting the sample of case studies is provided[2].

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[2] It is important to note, as has already been mentioned above, that the sample of case studies has varied along the research process, in accord with the necessities of the research and the requirements of the *emerging theory,* as *theoretical sampling* points. Theoretically, the process of sampling does not stop until the empirical evidence supports a comprehensive picture of the phenomena under study. According to this, saturation would be achieved when the evidence seem to support, proof and answer the initial research questions. However, in the practice, it is difficult to determine and justify when saturation is achieved, as more evidence generally could refine the findings of the research. Therefore, a sensible approach is to determine the inflexion point at which the frontier is drawn between the relevance of the findings provided by further research and the limited time and resources that constrain the research process.

Table 3.1 Selection of case studies

CASE STUDY	STRATEGY	CRITERIA
Kalundborg (Denmark)	Paradigmatic case	Most referred case in the literature Has emerged as model of eco-industrial parks and industrial symbiosis networks Long-term development Spontaneously company-driven process High levels of cooperation and integration between the companies Exchange of by-products and waste streams in continuous and profitable ways Collaboration of companies has extended to other areas apart from the exchange of material and energy flows
NISP (UK)	Critical case	Has achieved a wide recognition within UK industrial sector in a short period of time Focuses on the diversion of materials from landfill and the cut down of CO_2 emissions Operates as a national programme but has a network of support teams in each region of UK It is not geographically bounded Cross-sectoral and cross-regional exchanges are considered Central coordination exercised by a third-party
Sagunto (Spain)	Deviant case	Local area that combines heavy and lighter industry Has undergone industrial restructuring process Past history of waste stream exchanges between companies Unrealised potential for synergies and waste exchange

\Source: author generated

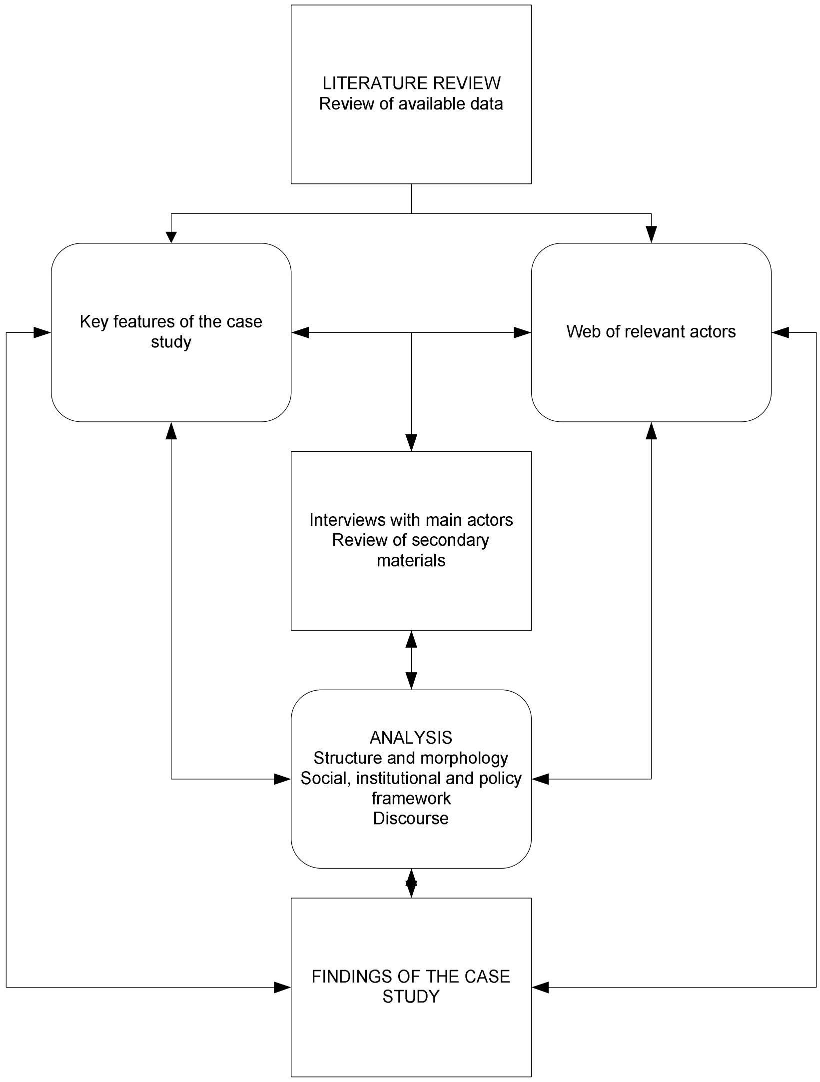
3.4 Field Research and Analysis of Case Studies: Methodological Issues

As already mentioned the case studies selected represent different types of industrial symbiotic networks. They respond to different processes, structures and are led by different goals. The degree of formalisation of the network also varies greatly between the different cases and this also influenced the availability of data and background information, the process of identification of main actors and even their willingness to participate in the research. All these elements were taken into account in designing the strategy to approach the case studies. As qualitative research, the emphasis is on social elements and structures by which processes are created, adopted and resisted (Hay, 2000), and how different elements interact in the development of IS networks.

The main source of information and data for each of the case studies has come from the in-depth interviews with main stakeholders. However, where possible, the findings from the interviews have been contrasted with data and information from other sources such as company reports, literature references, previous studies and projects, companies' policy statements and environmental reports among others. Triangulation of results aims to complement the information provided by interviews with other sources of data, offering a more comprehensive picture of the network, the discourses and the actors involved.

Case study methodology operates according to the following scheme:

Figure 3.2: Case study Research Methodology



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As already noted, the basic guidelines for the collection and analysis of the data are inspired by Grounded Theory. According to this, data will be examined, coded and categorised aiming at the identification of different key elements of the network structure, rules and tacit norms and predominant discourses. The analytical frameworks used for the analysis of networks will be discussed in Chapter 4.

3.4.1 In-depth Interviewing and "Creation" of Data

In-depth interviewing of key actors involved in each of the different case studies constitutes a crucial step in the methodological approach designed to address the research question. In-depth interviewing has been selected as a major method of generating data for various reasons: (a) first of all, the nature of the research question focuses on the processes, structures and discourses that lie behind the concrete outcomes of industrial symbiosis and explain the decision-making processes of the actors involved in these networks. Therefore, it needs to be addressed in qualitative terms, paying special attention to the way the different agents evaluate their engagement, potential outcomes and costs and how these elements are integrated into their discourses; (b) second, the novelty of the area under study and the fact that it develops at the edges of the policy agenda account for the lack of systematic, "hard", contrasted data on the outcomes of industrial symbiosis networks. Moreover, data about the concrete exchanges of materials and energy between companies are "commercial" information that the companies are generally not willing to share. Thus, the access to systematic, reliable data in the field is in most of the cases a very difficult task. In the cases where data is available, it will be a complement to the information obtained in the interviews, contributing to support, clarify or contrast some of the statements inferred from the interviews. However, as already mentioned, "hard data" cannot *per se* answer the research question; (c) in-depth interviewing allows the researcher to approach the complexity of the phenomenon under study by contrasting the perspectives and vision of the problem, creating a multi-choral picture of the phenomenon, integrating different voices and approaches.

In-depth interviews have taken the form of semi-structured dialogues, where some main issues and topics are outlined by the researcher, but around which there is flexibility by both interviewees and interviewer to alter the order and/or content of the interview, so that new themes, aspects and questions can be generated along the line. In this sense, the process of in-depth interviewing here proposed is closer to the approach of "interview-data-as-topic" rather than "interview-data-as-resource", according to the overview of interviewing's major traditions provided by Seale (1998). While the first approach treats "data" from interviews as reflecting the "reality" of the problem, "interview-data-as-topic" challenges the concept of "data" and analyse it as a "locally and collaboratively produced" reality. Hardly could interviews be seen as just "data" in the sense of an accurate reflection of the reality outside and independent from the interview. On the contrary, interviewer and interviewee are engaged in a process where they are given and represent different roles and positions, collaboratively constructing and defining the topic and the course of the interview. The topic is then constructed as a dialectic of the narratives of interviewer and interviewee. The interview is thus built as an interaction event, which is "*locally*" and dialectically constructed. As pointed by Rapley (2004, p.16) "*the interview talk, and hence the "interview data" that emerges from this, is the product of the local interaction of the speakers*". Under this perspective, interviews have been conceived as a co-constructed vision of the reality, which emerges from the interaction of interviewer and interviewee. This does not mean, however, that interviews are intentionally led or biased by the vision of the interviewer but that the researcher takes into account the cognitive limitations of the interviews and their role as constructed dialogues, so as Fontana (2002, p.166) notes, "*given the irremediable collaborative and constructed nature of the interview, a postmodern sentiment would behove us to pay more attention to the hows, that is, to try to understand the biographical, historical and institutional elements that are brought to the interview and used by both parties*".

The interview's designed strategy has combined neutral and collaborative approaches depending on the need to build rapport between interviewer and interviewee and the goals, dynamics and purpose of the interview. Every single interview has, therefore, been approached by a combination of interviewing strategies. Although it has been intended not to impose pre-conception or ideas directly or indirectly to the interviewee, by asking non-leading questions, avoiding overtly expressing the interviewer's own thoughts, so that the impact of the interviewer's perception on shaping the account of the interviewee is minimised, "neutrality" as such is very difficult to be achieved in a qualitative interview, where the interaction interviewer-interviewee is actually defining the context and the narrative constructed along the dialogue. Therefore, a more collaborative approach to interviewing was adopted allowing the contrasting of the thesis, hypothesis and ideas with the interviewee, so that agreed meanings could be created and discussed along the interview. In this sense, in-depth interviews required in most of the cases "*a greater involvements of the interviewer's self*" in the actual dialogue (Rapley, 2004, p.23), as a means of creating mutual trust and incentive cooperation, offering a sort of complementary reciprocity, that is, exchanging ideas, information and experiences. Moreover, this strategy has been proven helpful in the course of the research to help to uncover the "hidden voices", and to obtain a more reflexive understanding of the situation, perceptions and practices behind a more standardised account of the facts. Thus, interviews have been, for the purposes of this research, analysed as "*social encounters where speakers collaborate in producing retrospective (prospective) account or versions of their past (or future) actions, experiences, feelings and thoughts*" (Rapley, 2004, p.16), that is, as an interaction of identities, narratives and discourses.

In Appendix A can be found the outlines of themes proposed for the different interviews held. For each case study an open list of questions and themes was first produced, highlighting the issues the researcher considered of relevance to discuss with the actors. This initial list of questions or "*interview guide*" (Hay, 2000) was generated on the basis of relevant literature, the previous understanding of the case study and some initial working hypotheses. This general outline was rewritten later and adapted after some pilot interviews were conducted. Moreover, subtle modifications were introduced for each concrete interview, according to the position of the actor within the network and the role being played in the process. The interview outline served as a way to start the dynamic of the interview, but, the actual dialogue occurred generally in rather more open and flexible way, and questions were introduced following the course of the discussion. Thus, rather than a closed set of questions, the interview outline was more a list of relevant issues to be treated with the interviewee. Therefore, each of the interviews follows a different scheme and structure, although a central body of issues has been tackled in almost all of them, so that results can be contrasted, tested and complemented.

3.4.2 Recruitment of interviewees

Given the centrality of interviews in the methodology proposed, the selection and recruitment of interviewees has been considered very carefully. The interviewees' recruitment process was guided by four key principles (Rubin and Rubin, 2005):

- Getting a wide range of actors who hold different perspectives of the process under analysis

- Within the organisations involved, find knowledgeable and representative informants
- Testing emerging themes with new interviews
- Find new interviewees to extend and contrast the results ("*snowball or chain*" sampling)

According to this, a general recruitment strategy was designed. The strategy relies largely on the mapping of actors for each of the case studies (Chapter 4 provides a more detailed account of the process of actor mapping). Once the main actors involved in the different networks were identified, contact data were sought and an introductory email or letter was sent to each of them within the identified organisations. For each case study, actors have generally been divided into three main groups: Coordination organisations, companies and regulatory and governmental bodies. The recruitment strategy aimed at selecting some major players in each of these main groups (see Appendix A for the list of the actors that were contacted and the introductory letter sent to them by email). The introductory letter explains the purpose of the research and requests the collaboration of the actors by agreeing to be interviewed. After the introductory letter, allowing a reasonable margin of time for the addressee to respond, there were different types of reactions:

- Some organisations decided not to participate and attempted to divert the request to the coordination body or to other organisations that they consider more relevant for the purpose of the research
- Some organisations did not respond to the request
- Some organisations either agreed to be interviewed or requested more information about the project to decide on their participation

In order to increase the number of responses of key informants, subsequent emails/letters were sent (up to three letters) to each of the actors. From there, a preliminary set of potential interviewees was established. Before the interview, interviewees were sent an outline of the questions and issues to be treated in the interview. The interviews were also a good way of contacting other relevant actors who might not have been identified before, expanding the number of potential interviewees.

3.4.3 Triangulation of results

It has already been mentioned that only relying on information gathered in the interviews might be highly problematic. Interviews account for different narratives of a limited and sometimes biased perspective on the problem held by a single actor, so they need to be contrasted and re-examined in the light of other narratives and data available aiming at triangulation of the findings to offer a more consistent and comprehensive picture of complex industrial symbiosis networks. Triangulation has been undertaken at two different levels: a) triangulation in the methods of data gathering by using other sources of information, mainly secondary material about the network and actor; and b) triangulation in the selection of informants, by contrasting and cross-comparing the information given by different actors or stakeholders.

3.4.4 Analysis and treatment of information gathered in interviews

The information generated in the interviews has been analysed following the methodological guidance of Grounded Theory, as explained above. Therefore, interviews have been transcribed and coded, allowing the emergence of relations between codes. Cognitive maps, offering a wider and deeper understanding of industrial symbiosis networks and the decision-making processes behind them, have been elaborated plotting the inter-connections between codes. The codification of interviews has also contributed to comparison of the results of the different case studies, by emphasising similarities and divergences among them, while helping in the process of tracing the connections between network structure, institutional framework and discourse.

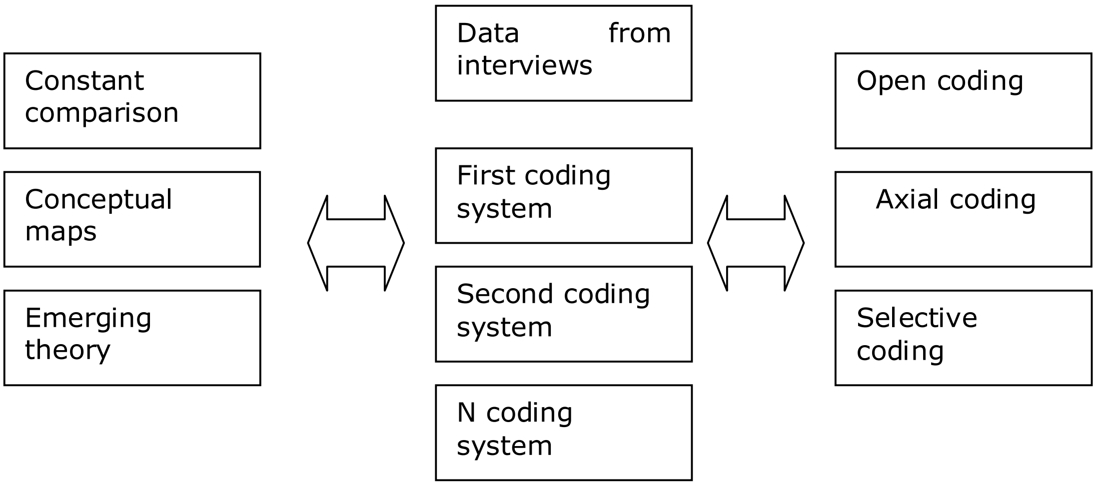
3.4.4.1 Coding and content analysis

As Grounded Theory proposes, a coding system has been used for sorting, analysing and retrieving data from the interviews. The coding process begins with the analysis of the transcripts of the interviews. A preliminary coding system may emerge from the information of the interview and may be refined and re-examined during the process of analysis. As already noted, the coding strategy entails different stages of theorisation running from the descriptive to the analytical level through subsequent phases of analysis. Codes are generally ascribed to text in the first stages of the analysis, but as the analytical process progresses, it is expected that new codes emerge, such as axial and selective codes (Strauss and Corbin, 1990), which result from the analysis of other codes and their relationships. Glaser (1981) proposes different families of codes in which “open codes” can be grouped (cited in Dey, 2004, p.85):

1) ***Causality***. This family encompasses causes, contexts, contingencies, consequences, co-variances and conditions.
2) ***Process***. This denotes codes that refer to the process, stages, progression, phases and periods of the phenomena under study.
3) ***Classification***. All kind of sorting categories related to the types, classes, kinds and different groupings can be aggregated under this code family.
4) ***Strategy***. Codes referred to strategies, lines of action, rules, and covenants can be grouped under this family.

The coding system helps in the analytical and theorising phase by offering a base for the constant classification, sorting and analysis of the data. The coding process has been supported by the use of the software ATLAS.ti. The software, which is inspired by Grounded Theory but also support other forms of content and discourse analysis, facilitates the process of coding of the data and retrieving information, so that the theorising process can be reconstructed from the raw data to the emerging theory, keeping track of the connections between the evidence and the theory. The figure below shows this connection between evidence and theory in the process of coding. Coding schemes generated for each of the case studies analysed are provided in Appendix B, C and D.

Figure 3.3: Coding process: keeping track of the connection between evidence and theory



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3.4.4.2 Constant comparison and theory building

Comparison is at the core of the methodological approach proposed by Grounded Theory (Dey, 2004). Data are constantly compared so that they can be coded and categorised. The comparison allows "discovering" the patterns of similarity and dissimilarity and the analysis of the causes that lie behind the shared and divergent elements. As noted by Dey (2004, p.80) through "*constant comparison* (...) *relations and properties can be identified and refined*". Constant comparison of data and categories contributes to the analysis of complex causality relations where the nature of causation is considered "*multiple and conjectural*". It examines structures and captures the explanatory capacity of the process by comparing different discourses, different perspectives and different cases.

Notwithstanding the centrality of "comparison" in social inquiry, some aspects of this method of analysis may turn problematic. One crucial limitation is the difficulty in establishing the direction of the causality. This problem, however, is common to almost any research methodology and area of research within social sciences. The directions of causality may remain obscure and may only be addressed under the guidance of the theoretical framework. Aware of this limitation, the causality of the relations derived from the analysis of the data have been conceptualised within the theoretical framework of eco-industrial networks. Moreover, as qualitative inquiring overcomes simplistic causality (A leads to B) by introducing multiple causality (a1, a2, a3, a3 may lead to B) this limitation can be partly addressed. In the research of industrial symbiosis network, a softer "view" of causality in the line of Sayer (1992) and Dey (2004) has been preferred, where causality is placed within the power relations and discourse structures that shape the experience of the researcher; that is, causality might be perceived in different ways by different actors.

The final purpose of the method of constant comparison is to develop a theory that allows integrating the concepts and relationships "discovered" during the analysis of the case studies of industrial symbiosis networks, so that an "emerging theory" or framework is constructed along the process of the research, offering a better understanding of the key elements influencing decision-making processes in industrial symbiosis networks and how this relate to structural, contextual and/or discursive elements.

3.5 Limitations and Problematic Issues of Qualitative Methodology

Some of the limitations of the qualitative approach have already been mentioned. In this section, some of these problematic issues and the way they have been addressed in this research project are discussed.

3.5.1 Context-dependent Knowledge and the Problem of Generalisation

It is claimed that qualitative methodology generates "context-dependent knowledge". This has traditionally been seen as one limitation of qualitative approaches. However, as noted by Gobo (2004), context dependent knowledge can indeed provide a more explanatory picture of complex phenomena, as "e*pistemic theoretical construction"* in social systems is necessarily context-dependent. This links with the philosophical debate on the limitation of analytical rationality of context-independent knowledge versus the potential of explanatory capacity of context-dependent knowledge. Thus, while context independent knowledge can only generate a general understanding of the problem, only context-dependent knowledge can provide the ground for the analysis of the relations and structures behind the more apparent causations providing a more complex picture of social phenomena. Moreover, regarding the question of "generalisability" of the results, it is useful to distinguish between two types of generalisation: that which generalises about a population or group and that which generalises about the nature of a process (Gobo, 2004). In the present research, the focus is on structures and processes rather than the concrete characteristics of populations, and, thus, general “patterns” are likely to emerge from the context-dependent knowledge derived from the case studies.

Dependency on the context has been in some cases associated to the impossibility to generalise findings. However, as Gobo (2004) emphasises, context dependency does not imply that findings cannot be generalised. On the contrary, context dependent knowledge can shed some light on the causes that make a social phenomenon operate in different contexts and thus provide a deeper understanding of the “general” pattern. As Giddens (1984, p.328) states some kind of generalisation of “*hermeneutic*” problems can be elucidated when looking across “*a wide range of action-contexts*”. In the context of industrial symbiosis networks, the examination of different initiatives and cases may also help to provide the basis for understanding the operation of these networks and critically analyse their contribution to a more sustainable path of development. By selecting a range of case studies, it may be possible to avoid the limitations of context dependent knowledge while maximising its potential. In this research the comparison of industrial symbiosis networks under different social, economic, cultural, regulatory and institutional frameworks, allows the identification of similarities and divergences, from which some general patterns can be drawn. However, it also has to be noted, that each of the cases provides in itself a complex and rich understanding of the process of industrial symbiosis, and thus, it is in itself a source of “general” findings and conclusions. As has been argued by other scholars (Flyvbjerg, 2004), it is possible to generalise from a single case-study when this is strategically selected.

Moreover, as Flyvbjerg (2004) argues, generalisability may have been overrated as the unique source of scientific progress. According to this author, context-based knowledge can contribute to the accumulation of knowledge in a field or area and can support or help to refute more generalised models and theories. This is especial true for the method of “falsification” proposed by Popper (1963), according to which if just one single case/observation does not fit within the theoretical framework analysed this theory can be automatically refuted. However, the task of falsification and testing is not exempted from problems, as the complexity of social systems reduces the possibilities of isolating the factors to ratify or refute a theory and even the research method or metrics used can be easily challenged, resulting in different “possible worlds” or paradigms. Indeed, the research aims to explore this "possible worlds" in industrial symbiosis, analysing different types of networks and discourses, concurring in the field of eco-industrial networks.

3.5.2 Sampling, Representativeness and Generalisability

As emphasised by Gobo (2004) generalisation about the nature of a process can hardly be based on statistical logic but rather on what Glaser and Strauss (1967) described as "theoretical sampling". According to the concept of "theoretical sample", the sample is constructed on the basis of being theoretically meaningful, that is, relevant for the analytical process of testing and proving the theory. Thus, "*the selection of the cases is driven only by their relevance and not only by the need of representativeness*" (Gobo, 2004, p.417). The generalisations derived from this kind of non-statistical sampling have been described by some authors as "analytical generalisation" (Yin, 1989. P.15), "extrapolation" (Alasuutari, 2004, cited in Gobo, 2004, p. 406) and "moderate generalisation" (Williams, 2002, p.131). The theoretical sampling is a cumulative process. Information and data are gathered, refining the previous findings or relations until "theoretical saturation" is reached (Strauss and Corbin, 1990). Therefore, as noted by Gobo (2004, p.418), "*representative samples are not predicted in advance but found, constructed and discovered gradually in the field*". This points to "sampling sequentially", so that the sample is shaped in constant dialogue with the analytical process and the particular incidents/events/contingencies of the research process.

Even though the process of sampling in social contexts may not follow statistical logic, it has to follow an equally rigorous process, by which sampling is decided strategically according to the goals of the research. The question of representativeness cannot be avoided when applying qualitative methodology. Sampling is indeed central to guarantee the representativeness of the findings and conclusions. "*The heuristic of representativeness*" (Kahneman and Tversky, 1972, cited in Gobo, 2004, p.407) indicates that strategic sampling is in fact the main cognitive strategy to generalise based upon a few observed events. In this research, representativeness is sought along the process of field analysis in "*dialogue with field incidents, contingencies and discoveries*" (Gobo, 2004). To explore the representativeness of the sample, it is important to refer to the "*sociological relevance*" of the cases selected (Gobo, 2004). Therefore, the strategy of selection of the case studies previously explained has taken into account the problem of representativeness. Thus, in the sampling process special attention has been paid to the extent to which the sample (or cases selected) are representative of whole population, that is, to what extent the case studies selected are representative of industrial symbiosis networks. By focusing in a strategy of variable, critical and paradigmatic cases, I have tried to increase the representativeness of the findings by providing a basis for the comparison and the identification of common patterns.

Another important element in selecting the sample has been to take into account the variance of the phenomenon under study. It is generally argued that if the variance is low, the number of cases selected can remain low too but if the variance among cases is high, a larger sample may have to be selected. As already noted above, the selection of different types of eco-industrial networks contributes to widening the scope of the analysis and providing a more comprehensive picture of the phenomenon; on the other hand, the restriction set on the geographical scope of the cases keeps the variance within a sensible range.

3.5.3 Bias of Non-response

As interviews are essential for the generation of data, another important limitation that arises is how to account for the bias of non-response. Those who agreed to be interviewed generally corresponded with pioneers or leaders. In the case of the companies contacted, a higher number of responses were obtained from big companies, most of them already having an organised structure to deal with environmental issues, such as an environmental department or environmental manager and, in most cases, a certified Environmental Management System. Although this potential bias is recognised, the findings of the research are not likely to be challenged by this, as the "bias" is actually intended to be used in a strategic way. IS initiatives can be considered as avant-garde initiatives within the realm of sustainability, therefore, examining the perspectives of the pioneers and leaders of the process is of utmost interest. Their experiences offer insights into the challenges and potential outcomes of industrial symbiosis. Although industrial symbiosis is not a pervasive phenomenon, it does involve environmental and social innovations. Therefore, most of the companies involved in the process already have an environmentally advanced position. By addressing the pioneers it is possible to draw some conclusions about the potential scenarios and ways by which industrial symbiosis may become a pervasive phenomenon and the challenges it may encounter in the process.

3.5.4 The Bias towards Verification

Selection of the cases and of interviewees and the analysis of the "data" have been undertaken carefully in an attempt to avoid a possible "bias towards verification". This bias is, however, not exclusive to case study methodology but also affects quantitative methods of research. Moreover, as it is generally the case, the analysis of the data of the case studies selected has challenged rather than verified the prior assumptions of the researcher (Flyvbjerg, 2004). To avoid the bias happening, there has been an on-going process of revision and reformulation of working hypotheses readapting and readjusting to the contingencies of the field work. Feedback has been favoured between the researcher and the different actors involved in the various industrial symbiosis networks, both in the interviews and through follow-up brief communications, so that hypotheses, meanings and theories have been challenged and discussed. In that sense, day-to-day interaction with the actors and involvement in the case studies dynamics (such as participation in informal meetings) has allowed the unveiling of information encapsulated in the narrative of the quotidian, also questioning of preconceptions, by examining and paying special attention to the "*complexities and contradictions of real life*" (Flyvbjerg, 2004, p.400).

3.5.5 Case Study Boundaries and Selection of Unit of Analysis and Observation

Another aspect considered in the design of the methodology that might be problematic is the definition of the boundaries of the case studies, that is, the delineation of what is going to be evaluated as an integral part of the case and what is going to be left aside. Boundaries of industrial symbiosis are generally blurred and fuzzy. The same definition of the structures, actors and institution that constitute the core and "relevant" background of the actual networks implies in itself a decision. The researcher has tried to make this decision explicit by offering a detailed description of the elements that have been considered "relevant" in the analysis of each case study on the basis of the framework provided for analysis.

Another aspect that has been considered while undertaking the field research is the problem of correspondence between the sampling unit and the observational unit. For each of the case studies, the unit of analysis has been twofold: 1) the whole network and 2) the actors that are part of the network. Therefore, for the interviews, the sampling unit selected was generally companies and organisations already involved in an industrial symbiosis network. Within these organisations, I have contacted the person directly involved in the negotiation of the synergies and coordination activities, or, in the case of regulators and institutions, those individuals responsible for industry and environmental issues. Therefore, in some cases, there might be discrepancies between the unit of observation, that is, the interviewee, and the unit of analysis, the organisation. However, the identification of potential divergences between the two units constitutes in itself part of the research task and analysis. In that sense, the triangulation of results and the contrast between discourse and practices were examined more closely so that a deeper understanding of the relationship between discourse and practice could be traced. On another level too, there is some discrepancy between the two units when addressing the network as a whole. The network has been examined on the basis of the aggregation of individual companies (as units of observation) and complemented, where possible, with information given by central and coordination nodes. Also here, differences in the individual and aggregate level have been examined closely.

Chapter 4.
Analytical Framework: SNA and Discourse Analysis

Once the general methodology of the research has been outlined, this chapter focuses on the specific analytical framework adopted to analyse the data and generate the theory. The chapter has been organised in three main sections. The first section provides an overview of the framework designed for the cross-comparison of the case studies. This framework proposes three main dimensions of analysis: structural, contextual and discursive. The next section deals with the first two dimensions, structural and contextual. The analytical framework proposed for the analysis of these dimensions relies largely on Social Network Analysis (SNA). A protocol for the adaptation of SNA to the study of the structural and social mechanisms in IS networks is proposed. The last section deals with the discursive dimension, and proposes a framework for the application of discourse analysis to the field of IS.

4.1 Cross-comparison Framework

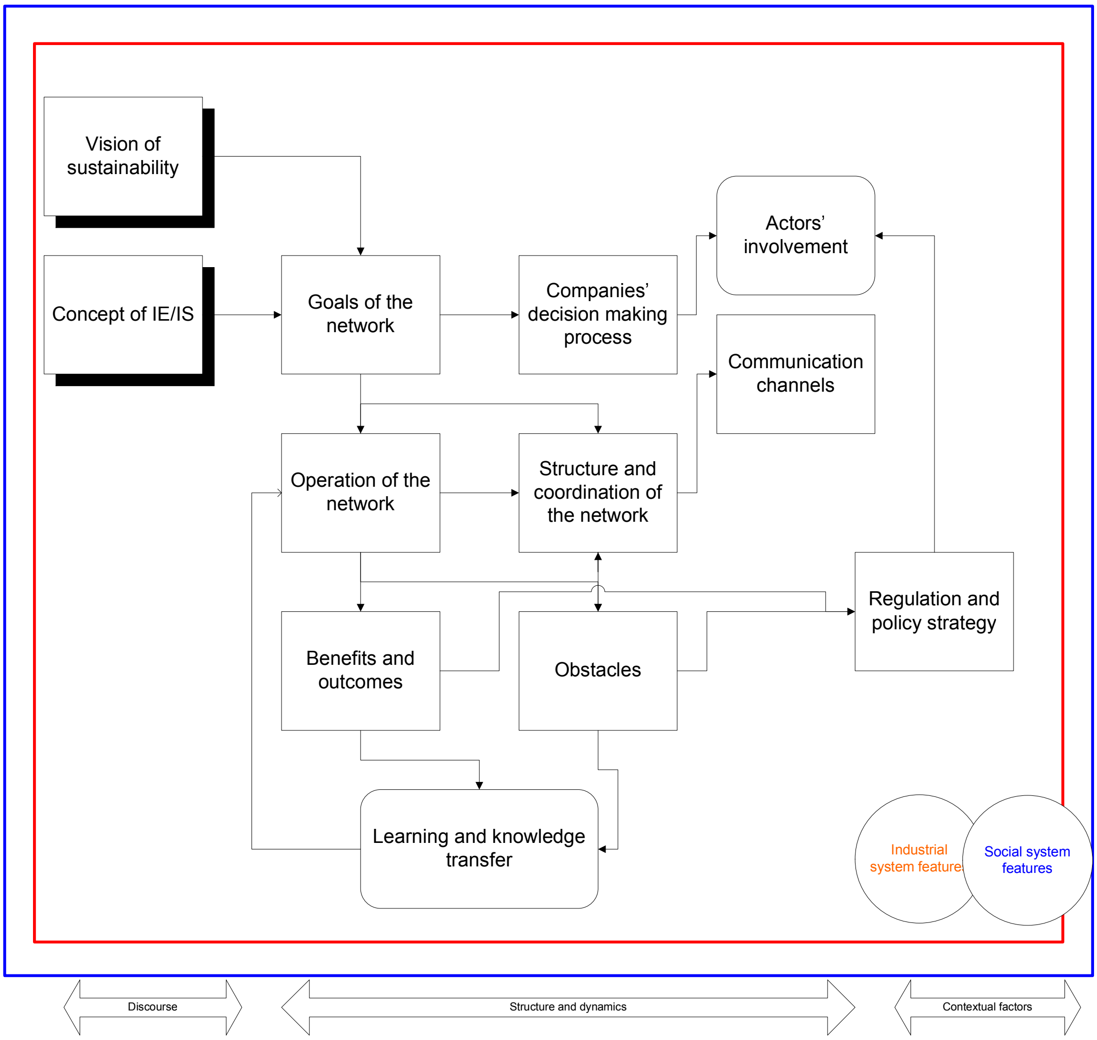
The analytical framework for the comparison of the case studies is based on an expanded adaptation of the evaluative framework proposed by Eilering and Vermeulen (2004). The focus of the framework is the analysis of the dynamic and adaptive process of creation and evolution of the network rather than more static appraisal of the benefits or the achieved state. This allows identification of the factors that are shaping the ever-changing structure of the networks and analysis of aspects such as learning and trust that evolve along the process and influence its progress.

As already noted, the proposed analytical framework for the cross-comparison of the different case studies selected identifies three interacting dimensions:

1) Structure and dynamics of the network;
2) Contextual elements, rules, norms and behaviours;
3) Discourses and visions.

These dimensions are in continuous interaction shaping the process of the formation and development of the network and influencing its outcomes. This dynamic process has been represented in the figure below.

Figure 4.1: Interaction between the different dimensions of IS networks



\Source: Author generated

4.1.1 Discourse, Vision and Goals

The vision of sustainability underlies the scope of the network and the goals it is aiming to achieve. This vision permeates the whole process, from creation to implementation. Moreover, the actors' involvement and relationships are mediated by their environmental discourse and vision of sustainability. The same concept of industrial ecology and its principles and imperatives are influenced by the sustainable vision in place. The discourse and vision dimension is also closely interwoven with the socio-institutional context, mutually defining the rules, values, practices and action patterns in a given situation.

4.1.2 Context of the Network

Economic and social system features also define the framework in which the vision of sustainability and industrial ecology is implemented, the perception of the potential benefits and the social and economical feasibility of synergies and symbiotic exchanges. An important element being influenced but also defining this socio-economical framework is the regulation and policy strategy in place. Different degrees of enforceability of the regulation may be impacting on the feasibility of the exchanges, acting as drivers or barriers in their implementation, thus influencing the performance and outcomes of the network. On the other hand, the industrial features of the system related to the mix of industries and processes taking part in the networks, set the conditions for the material and energy basis of the system and thus the emergence of potential exchanges and synergies.

4.1.3 Structure, Dynamics and Operation of the Network

All these elements defining the context of the network converge and determine the concrete practical structure of the network. The structure refers to the actual morphology of the network but also to the cooperation dynamics in place. Elements such as the mix of actors and industries participating in the process and other elements such as communication channels, coordination and learning, contribute to shape the structure of the network. It has also to be noted that the structure of the network may have an influence on the degree of achievement of benefits and also in the obstacles to IS projects. Obstacles might in some contexts become opportunities to challenge the goals, scope and measures implemented favouring the adaptive capacity of the network through learning.

4.2 Application of SNA to the Understanding of the Structural and Social Dimensions of IS Networks

This section proposes the adaptation of the core concepts and theories of SNA to the field of IS. It is argued that SNA can contribute to the understanding of structural and networking dynamics of IS networks in interaction with institutional conditions. A full account of the adaptation of SNA to IS has been recently published by the author of this thesis in *Progress* *to Industrial Ecology: an International Journal* and included in Appendix E. This section summarises the main elements of the analytical framework proposed.

4.2.1 Networking Component of IS

As argued in the literature review (Chapters 1 and 2), although the importance of social aspects in the emergence and operation of IS networks has been increasingly recognised in the literature (see, for example, Eilering and Vermeulen, 2004; Korhonen et al., 2004), there is still a lack of comprehensive frameworks for the evaluation and the understanding of the dynamics of collaboration in IS networks.

The analysis of IS networks needs to acknowledge that networking has implications that differ from other market-based waste management solutions. Understanding these differences may also help to distinguish between IS initiatives that are genuinely operating as networks from those that only consist of market exchanges of material and energy by-products. Indeed, these two forms of governance have different implications and may lead to divergent results. Therefore, the strategy to promote one or the other necessarily differs. IS literature has generally emphasised in its discourse the 'cost-based' approach as a main driver for the emergence of IS networks (see, for example, Lowe and Evans, 1995). However, when doing so, they are assimilating IS networks to atomistic market conditions, overlooking the 'structural' conditions that might actually set the basis of IS networks and that can better explain the emergence of IS networks. Binder et al. (2004) provides an example, applied to the wood flows in a Swiss region, of how structural conditions ('rules' and 'resources') can foster or hinder progress to more sustainable scenarios. In this thesis, it is argued that IS networks are closer to the theoretical construct of networks rather than market-based exchange conditions and therefore, even though the potential for IS networks to reduce the costs associated with environmental management is recognised, I contend that the central elements in explaining the network exchanges challenge a narrow 'costs-view' (Larson, 1992), falling closer to the 'heuristics' approach (Lewis and Weigert, 1985). According to the latter, the decision-making process of companies interacting in a network would not only be influenced by cost but other rather more 'qualitative' factors, such as trust and information, which would have a primary influence (see also Begré and Hadorn,2002; Hadorn et al., 2002).

4.2.2 Core Concepts of SNA

Social Network research has steadily grown in recent years and has been applied to many disciplines and social contexts. Social network analysis introduces a new perspective in the examination of social environments and processes, by focusing attention on relational information, that is, the relationships among interacting social units, rather than in the units themselves. From this exploration, some patterns or regular traits can be identified, giving rise to the 'Structure' (Wasserman and Faust, 1994). This approach encompasses a multiplicity of theories, models and methods of analysis that put the emphasis on the relational content and the linkage structure between different organisational units.

Table 4.1 briefly present some of main concepts of Social Network Analysis that can be applied to the study of IS networks. A comprehensive review of the concepts, methods and applications of Social Network Analysis can be found in Wasserman and Faust (1994) and Scott (2000).

Table 4.1: Main concepts of Social Network Analysis

Concept	Definition	Applicability to IS
Network	Larson (1992, p.77) offers a definition of networks as "*distinct from market and hierarchical arrangements in their heavy reliance on reciprocity, collaboration, complementary interdependence, a reputation and relationship basis for communication, and an informal climate oriented toward mutual gain*" Even though there is no unified concept of network, some general characteristics of networks can be inferred from the literature: Interactions are based on cooperation Informal arrangements are preferred to formal contracts Exchange relations tend to be long term and recurrent There is frequent and reciprocal communication between network members Shared rules and (tacit) agreed norms govern the operation of the networks Reciprocity and mutual gain is pursued Interactions rely on close social relationship and trust	Most of these general characteristics apply to IS networks. Yet, some peculiarities should be taken into account. IS networks focus on a single aspect of company performance, that is, environmental issues, which have not traditionally formed the core of the business strategy. Therefore, the culture of the company will condition the predisposition of the firm to engage in IS networks. Moreover, the participation of the firm in IS networks might influence its overall strategy, if the collaborating culture permeates other areas of the activity. However, it should be noted that not all IS exchanges are organised as networks. IS exchanges based on market mechanisms consist of one-off exchanges, formally arranged by purchase contracts and regulated by prices. These "*arm's length ties*" imply that there is no recurrent interaction between companies and therefore no space for reciprocity. In this scenario cost/price would be the main coordination mechanism (Uzzi, 1997). On the contrary, IS based on network governance is characterised by recurrent interaction between the companies, informal arrangements (although might be also formalised by contracts), reciprocity and trust. In this scenario, though cost is still an important aspect, it might not act as the main coordination mechanism. Cost is evaluated in a global way, taking into account not a single transaction but the overall interaction.
Nodes, ties and dyads	Actors are represented by nodes that are linked by lines "*representing the direct ties between a pair (dyad)*" (Yang and Knoke, 2001, p.286). The ties between the nodes can be either directed/ asymmetric or either undirected/symmetric ties. The later imply the reciprocity of the interaction, while direct ties represent one-way relations between the actors.	In the case of IS, the organisations linked by IS exchanges represent the "nodes" and the exchanges the "ties" between them.

Concept	Definition	Applicability to IS
Path distance	The "path" can be described as the distance between two nodes, represented by the set of nodes and lines that connect them. The shortest path between two nodes, that with the smallest length, is referred to as the "*geodesic"* path (Yang and Knoke, 2001). The optimal connection "*involves a combination of the fewest intermediaries with the most intense interactions*" (Yang and Knoke, 2001, p.287).	The concept of path distance can be fully applied to IS networks, based on the number of lines to connect two organisations.
Centrality	The simplest indicator of centrality can be measured through the number of ties that a network member has to other members of the network (Shan et al., 1994). However, different measures of centrality have been developed to try to capture the importance of a node in a network.	This measure is an indicator of the position of different nodes in the network and the relevance of the role played by each of them.
Characterisation of network structure	A multiplicity of other factors might in fact also influence network structure: Openness/ closeness of the network. This refers to the entry of new members to the network in a certain period of time. Open networks promote the integration of new members while closed networks tend to establish "barriers for entry" that discourage the engagement of new members in the network Weak versus strong bonds, depending on the continuity, frequency and quality of the interaction between the members Trust and past history shared. This links with the notion of stability, which refers to the evolution of network's pattern over time Geographic distance: local versus extent networks	All these aspects are of relevance in the analysis of the structural aspects of IS networks.

Concept	Definition	Applicability to IS
Reciprocity	The term reciprocity in Social Network Theory has been used to refer to mutually beneficial arrangements considered in a global and long-term perspective (Shan et al., 1994). This implies taking into account: a) direct gains involved in a transaction b) a generalised sense of reciprocity, in which the linkage is not compensated in concrete terms or as a result of a specific transaction but it may be compensated in future transactions or with some other kind of support and c) network balancing, where the repayment may come from the network as a whole as a reward from a concrete network member contribution to the network or to one of its members (Shan et al., 1994)	This notion of reciprocity fully applies to IS networks. IS literature has emphasised that companies in IS networks are engaged in mutually beneficial exchanges. However, when analysing concrete IS dyads, cooperative links also seem to occur when no direct pay-back is attached to them, analysed on a single transaction basis. In this last case, the rationale of the behaviour has to be linked to more subtle and inter-temporal framework as the one presented above, taking into account generalised reciprocity and network balancing.
Trust	Trust lies at the core of the network form of governance and stands as a major coordination mechanism in network-based transactions. According to Lewis and Weigert (1985) certain conditions allow trust to emerge: All participants must believe that action is aimed at common values These common values have to be translated into common goals There must be a shared sense of solidarity in accordance with participants expectations Trust must be reinforced by empirical evidence and past action Some contextual aspects such as the homogeneity of the group and the level of connectedness between members might actually positively affect the levels of trust. Lewis and Weigert (1985) also point to the size of the network as an aspect negatively influencing the levels of trust. Moreover, the process of building trust seems to be directly linked to the sharing of a common history. Baker (1990) shows the influence of pre-existing ties between companies and the interpersonal ties between managers and employees in subsequent cooperative relationships in the network.	Lewis and Weigert's (1985) concept of trust brings understanding to the conditions that might foster the process of building trust in IS networks and its role in network development.

Concept	Definition	Applicability to IS
Embeddedness	Uzzi (1997) analyses the performance of embedded networks and its implications for efficiency and company performance and defines embedded networks as characterised by three main features: 1) trust, 2) fine-grained information transfer and 3) joint problem solving. These three features would allow companies engaged in embedded ties to be more flexible and adapt more quickly in environments characterised by complexity and continuous change. As a result of this, companies engaged in embedded networks can gain advantages in comparison to other forms of governance (Uzzi, 1997).	When characterising IS networks, attention must be paid to the level of embeddedness of its ties, as it might be a good indicator of the performance of the network.

\Source: author generated

4.2.3 Network Governance Theory and the Emergence of Networks

As already noted, social network analysis constitutes a collection of analytic tools and techniques focused on the linkages among interacting units. However, as argued by Cook and Whitmeyer (1992, p.115), social network analysis needs to be combined with other theories to provide "*theoretical underpinning for network conceptions of structure*", allowing progress from a descriptive to a prescriptive dimension. In an attempt to generate a *'Network Theory'* (Cook and Whitmeyer, 1992, p.115), that is, a comprehensive theoretical framework for the application of social network analysis, Jones et al. (1997) proposed the General Network Theory. This theory tries to identify the conditions under which 'network governance' tends to 'emerge and thrive'. This aspect is of crucial interest to IS initiatives, as it may help to understand under what structural conditions the exchange of by-products can succeed, or, from a policy view, what conditions should be favoured to promote intercompany cooperation in environmental issues.

According to this theory, and, assuming that "*social mechanisms influence the cost of transacting exchanges*" (Jones et al., 1997, p. 913), network governance is likely to emerge in environments characterised by "*the need for high adaptation, high coordination and high safeguarding*" (p.913). In the proposed theory, Jones et al. (1997, p. 913) also show how structural embeddedness "*provides the foundation for social mechanisms to appear such as restricted access, macrocultures, collective sanctions and reputations*".

In the case of IS networks it is necessary to identify under which contexts and conditions structural embeddedness appears, providing the ground for social mechanisms to develop, reducing the transaction costs, and thus favouring the operation of the network in a highly competitive and rapidly evolving environment.

4.2.3.1 Exchange Conditions for Network Governance

Jones et al. (1997) distinguish between different kinds of interfirm governance: hierarchies; market solutions and network governance. Network governance stands as a distinctive form of interfirm organisation characterised by informal social structures to coordinate complex products or processes 'based on implicit and open-ended contracts' to adapt to uncertain and competitive environments. In their proposed theory, the authors point to three main exchange conditions which would determine the form of governance adopted: 1) uncertainty; 2) asset specificity; 3) frequency of contact.

These conditions, however, need to be adapted to the specific context of waste-flow exchanges. From the analysis of the cases reported in the literature of IS and the empirical research undertaken in this thesis, some main conditions seem to characterise the contexts where IS develops:

- Stringent and rapidly evolving regulatory frameworks with regard to waste management and environmental performance that require high adaptability from companies. In this context knowledge dissemination becomes a crucial aspect.
- Waste-flow exchanges require customised, nonstandard, applications or involve an innovative component or approach, and, therefore, carry uncertainties with regard to the outcome and process. Customised solutions generally require the development of routines, team works and protocols, enhancing cooperation and the transfer of tacit knowledge between the parts. Having developed a cooperative culture with one or more partners makes it easier to generate multiple projects in what Jones et al. (1997) refer to as 'relationship-specific capital'.
- As a result of the need for customised solutions, high coordination is required, which implies frequent interaction between companies, favouring the transfer of tacit knowledge, 'learning by doing', and the creation of a shared culture or 'macroculture' (Jones et al., 1997). Having developed 'relationship-specific capital',

frequent exchanges reduce the transaction costs between partners that have learnt 'to speak each others' language'.

The fact that companies are faced with the uncertainty of an increasingly stringent regulatory framework and the need for coordination and integration that derives from the customised solutions, pushes companies to find forms of governance in the environmental area that foster cooperation while maintaining the independence of the firm in other areas. Network governance emerges then as a suitable form to face environmental challenges in a cost-effective way.

4.2.3.2 Social Control Mechanisms

Structural embeddedness provides the basis for the development of social control mechanisms that regulate transactions in network structures. Jones et al. (1997) mention the following social mechanisms, which contribute to the emergence of the network form of governance:

- restrict access to exchanges
- macroculture
- collective sanctions
- reputation

These social mechanisms help reduce the costs associated with the coordination and safeguarding of the exchanges. Exploring the presence of these mechanisms in operative IS networks may help to understand the role played by them in favouring the emergence and development of this type of network.

Restricted access occurs through 'status maximization strategy', that is, avoiding partners with lower status and through 'relational contracting'. Both strategies emphasize the importance of past interactions; by reducing the number of partners a company interacts with, it reduces the costs associated with coordination and negotiation as well as guaranteeing quality standards based on previous experience. Moreover, restricted access and recurrent interaction reduce the chance of opportunistic behaviour among partners (Tutzauer et al., 2006). However, very severe exchange restrictions would reduce the opportunities and synergies, thus an "*intermediate level of restriction*" would be optimal (Jones et al., 1997, p.929).

The macroculture defines a common understanding that includes knowledge, values, approaches and patterns of action. The higher the degree of structural embeddedness, the more network members identify with a macroculture. The dissemination of a macroculture enhances coordination and integration as a result of three mutually reinforcing processes (Jones et al., 1997):

1) by creating 'convergence of expectations'
2) by defining a common language to 'summarise complex routines and information'
3) by generating 'tacit rules' and norms for the interaction of actors

It is also important to note that the content of the macroculture can be an element fostering or hindering cooperation. Thus, the development of a culture that stresses the value of intercompany interaction and the positive impact of cooperation may be a crucial factor in further integration among parties. In this sense, and with regard to IS, the development of a broader 'macroculture of cooperation' between companies in other areas of business can set the basis for the cooperation on environmental management and exchange of waste flows. Similarly, IS can be the first step into the definition of cooperative patterns in other areas of the company.

Collective sanctions, whether tacit or explicit, condemn deviating behaviour and the violation of norms and rules of network operation. The sanctions generally affect one's reputation, reducing the changes of further interaction and can even lead to detachment from the network. Collective sanctions are generally supported by 'meta-norms' that also punish "those who do not punish devian(cy)" (Jones et al., 1997, 932), increasing the social control of 'offenders'.

Connected to collective sanctions, reputation stands as an important mechanism to reduce the uncertainty of exchanges. Reputation refers to an overall picture of skills, reliability and capacity to meet specifications, based on past experiences. Reputation reduces the risk associated with the exchange by providing information of past capacity and performance. Opportunistic behaviour or failure to meet specifications have a negative impact on reputation and involve social sanctions with economic consequences. As more of these social mechanisms are put in place, the likelihood of a network form of governance to develop rises. These mechanisms "*favour cooperation in the face of collective or social dilemmas*" (Jones et al., 1997, p. 934). Companies when faced with the decision to cooperate or to defect would have more incentives to cooperate, achieving a better social (economic and/or environmental) outcome (Tutzauer et al., 2006). Social mechanisms are used in network governance as a way to deal efficiently with highly uncertain scenarios, characterised by customised exchanges and complex tasks.

4.2.4 Embeddedness and Development of Networks

While the section above focused on the conditions that may foster the emergence of networks and the social mechanisms that may play a role in their development, in this section the concept of embeddedness is introduced. This concept provides the basis to understand why under certain conditions network structures can provide better outcomes that other network governance structures. More concretely, the concept of embeddedness (Uzzi, 1997) explores the mechanisms through which social structure, cognitive processes, institutional arrangements and cultural contexts determine the action of economic and social agents. According to Uzzi (1996, p. 674), embeddedness refers to "*the process by which social relations shape economic action in ways that some mainstream economic schemes overlook or misspecify when they assume that social ties affect economic behaviour only minimally or, in some stringent accounts, reduce the efficiency of the price system*".

Following Uzzi (1997), embedded networks are characterised by three main features: 1) trust, 2) fine-grained information transfer and 3) joint problem solving. These three features would allow companies to be more flexible and adapt more quickly in environments characterised by complexity and continuous change. As a result of this, companies engaged in embedded networks can gain advantages in comparison to other forms of governance (Uzzi, 1996, 1997). Table 4.2 explores the role of trust and other main elements of embeddedness in the case of IS networks.

Table 4.2: Main features in embedded networks

	Mechanisms/ conditions	Outcomes
Trust	Size of the network Past-history and shared experience Common goals and values General reciprocity Emotional contractual ties Frequent interaction	Reduce the risk associated with transactions, by preventing opportunistic behaviour Reduce access barriers and learning costs Promotes willingness to collaborate
Fine-grained information transfer	Learning by doing and close interaction facilitate deep understanding of the organizations dynamics Generation of tacit knowledge	Flexibility and rapid response and adaptability Reduces the risks and costs and increases the effectiveness of coordination.
Joint problem solving	Routines of negotiation and communication. Development of a "common language"	Rapid identification of problems, due to implicit feedback mechanisms Cooperative approach
Multiplexity	Diversity of roles that a pair of nodes can represent Embedded ties are a combination of business relation, friendship and other social/cultural attachments	Multiplexity promotes trust and willingness to cooperate Minimise opportunistic behaviour It confers stability and flexibility to the connections

\Source: author generated

4.3 Protocol of Implementation of SNA to the Analysis of IS Networks

Building on the elements outlined in the previous sections, an analytical methodology has been designed, combining elements from Social Network Analysis and Network Theory (Uzzi, 1996, Uzzi, 1997 and Jones et al., 1997) to contribute to the understanding of the social dimension of IS, by examining the relationships occurring between all members of the network and the structures that are supporting or hindering those relations (Binder 2007b). The approach described here has been structured as a four- step method consisting of (Schensul et al, 1999):

1) Mapping of the main participants of the network;
2) Identification of the boundaries and a core-periphery structure for the network. Potential local bridges are also identified;
3) Evaluation of the structural characteristics of the network;
4) Examination of the exchange conditions and degree of embeddedness

Although the process is presented as sequential, in practice all the phases are interrelated and in the process of implementation, phases can merge or change the proposed order, as part of an iterative process. Indeed, step 1 and 2 are generally undertaken together as one initial phase.

4.3.1 Research Methods and Data Sources

Although chapter 3 provided a general outline of the main data sources used in the research, the table below summarises main methods, data sources and actors involved in each of the four analytical steps described above:

Table 4.3 Data sources and methods of research

PHASE	METHOD	DATA SOURCES	ACTORS INVOLVED
Mapping of actors	Social Network Analysis (Wasserman and Faust, 1994 and Scott, 2000)	Literature review Expert interviews Snow-balling Informal and expert meetings Ethnographic fieldwork	Entrepreneurial organisations Network coordinators Institutional actors Researchers
Definition of core/periphery structure	Social Network Analysis (Wasserman and Faust, 1994) core/periphery structure (Laumann and Pappi, 1976, Laumann et al., 1983)	Structured interviews Questionnaires Expert interviews Ethnographic fieldwork	Entrepreneurial organisations Network coordinators Companies
Identification of the structural characteristics of the network	Social Network Analysis (Tichy et al., 1979)	In-depth interviews Expert interviews Questionnaires	Network coordinators Companies
Analysis of exchange conditions and structural embeddedness	General Network Theory (Jones et al., 1997) Discourse analysis (Dryzeck., 1997)	In-depth interviews Expert interviews	Network coordinators Companies Institutional actors Researchers

\Source: author generated

4.3.2 Step 1: Mapping of Actors and Establishing the Boundaries of the Network

A crucial question in analysing IS networks is to define the boundaries of the network by tracing a border between the companies and organisations belonging to the network and those outside it. The mapping of the (direct and indirect) actors (Binder, 2007b) that constitute the network is thus the prerequisite or pre-phase that allows the drawing of the boundaries of the network. Based on the literature review, a first map is designed that is then complemented by the input data from: a) expert interviews and 2) research and expert meetings. Through "snow-balling" (Clarke, 2002), other interacting agents are identified. Although an agent map is drawn at the early stages of the process, the number of actors and boundaries are modified as new actors are incorporated and new linkages found.

4.3.3 Step 2: Identification of the "Core/periphery" Structure

The definition of the boundaries is not an unproblematic issue, as in many cases the boundaries of the network remain blurred and fuzzy, even for the actors involved. The core-periphery model (Laumann and Pappi, 1976; Alba and Moore, 1978) supports this process by distinguishing between core/periphery structures within a network. According to this model, networks would have a core group formed by "*densely connected actors in contrast to a more loosely connected class of actors forming the periphery of the system*" (Garcia Muniz and Ramos Carvajal, 2006, p.442).

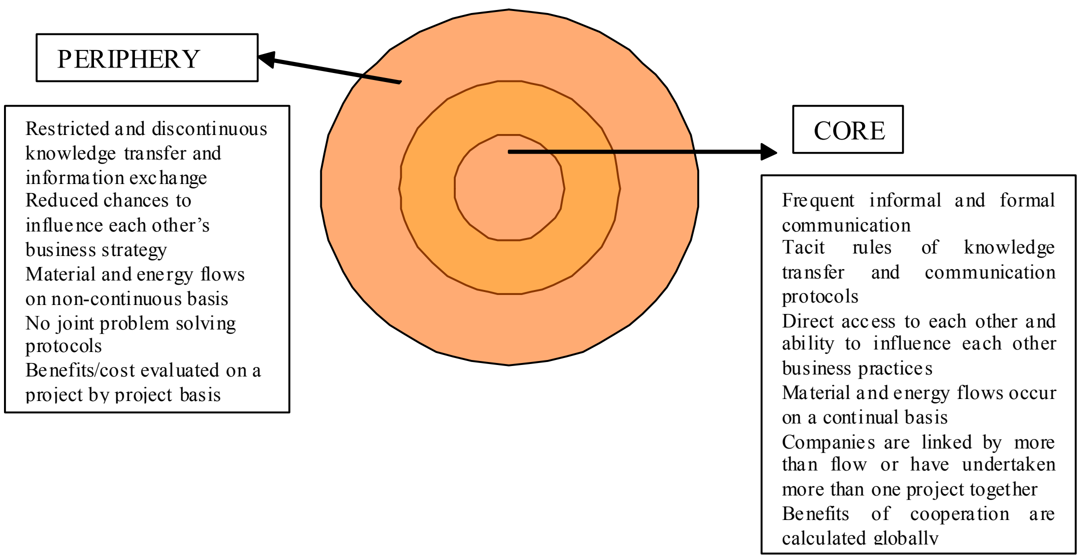
Drawing on this, some main guidelines can be given to identify the core-periphery structure in an IS network (see Figure 1). The core of the network will be formed by organisations within which:

- There is very frequent informal and formal communication;
- Information flows and knowledge transfer is a common practice and has led to high levels of interconnection, including tacit rules of knowledge transfer and communication protocols;
- Companies and companies' representatives have direct access to each other and can influence each other's business practices;
- Material and energy flows occur on a continual basis;
- Companies are linked by more than flow or have undertaken more than one project together;
- Benefits of cooperation are calculated globally.

The periphery of the network, on the other hand, will be made up by those nodes within which:

- Information and knowledge transfer only occur in certain periods of time or linked to a concrete exchange or transaction;
- Communication does not occur on a regular basis and tacit rules have not been established;
- There is little scope for companies to influence each others' business strategies;
- Material and energy flows occur only at certain periods and not necessarily as long-term agreements;
- Joint problem solving is not a common practice and only occurs under specific circumstances or in particular projects;
- Benefits of cooperation are calculated on a project by project basis.

Figure 4.2: Core/periphery structure



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4.3.4 Step 3: Identification of the Structural Characteristics of the Network; Typologies of Networks

Once the actors have been identified and a tentative core/periphery structure has been defined, the next step in the proposed methodology consists of an examination of the structural characteristics of the network and the nature of the linkages. Following the scheme provided by Tichy et al. (1979), networks can be analysed according to three main areas: Transactional Content, the nature of the links and its structural characteristics (see Figure 4.3).

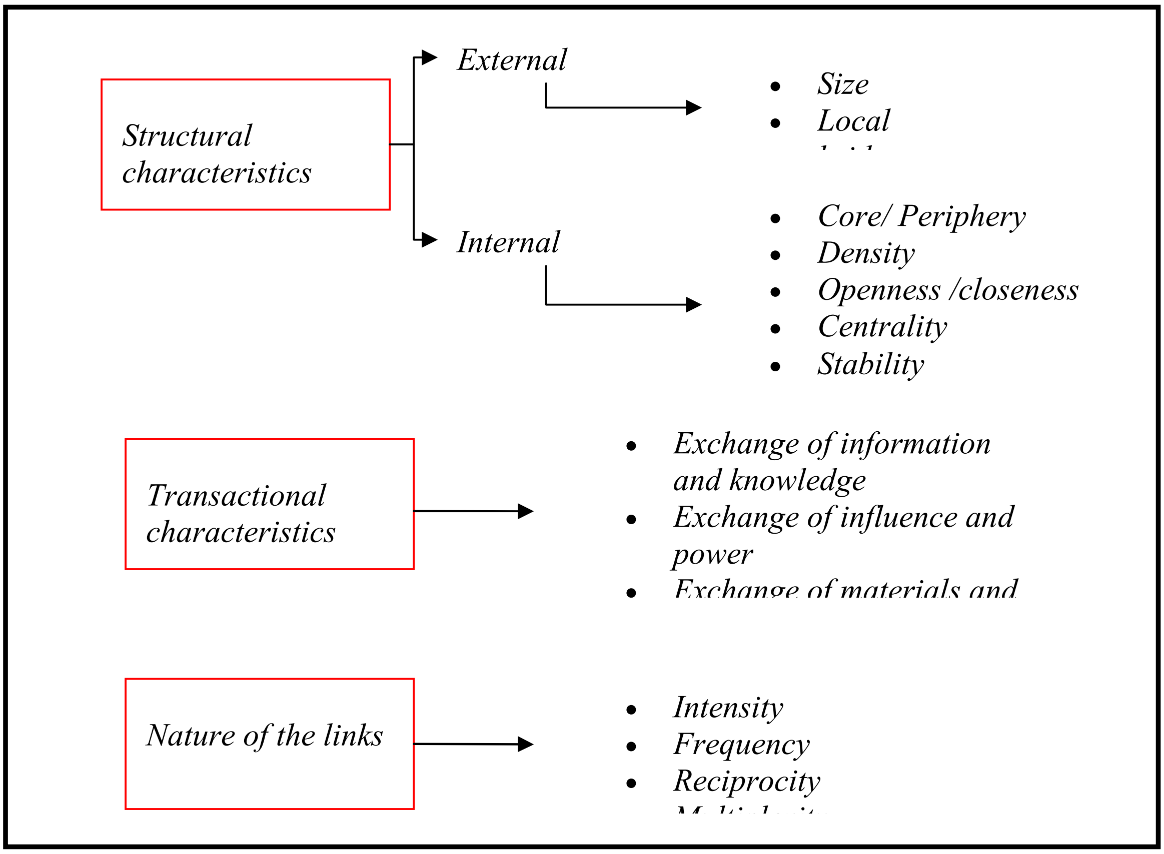
The first area refers to what is exchanged or shared within the nodes of a network. Tichy et al. (1979) identify four types of transactional content: 1) exchange of emotional support, 2) exchange of influence or power, 3) exchange of information and 4) exchange of goods and services. In the case of industrial symbiosis, networks will generally involve transactions of types 2, 3 and 4. Social networks can be redrawn for each of these content types, so that the same network can be structured in distinctive ways depending on the content that is being analysed. Therefore, an industrial network could have a structure when informational and knowledge content is examined, and a rather different one when material flows are observed. Different levels of analysis would then be needed to analyse complex IS networks.

Secondly, the nature of the links occurring between the nodes that form the network requires the study of different dimensions: 1) the *intensit*y of the relationship, which can be a measure of the frequency of contact in a unit of time or a proxy of the content value of the exchange, 2) the degree of *reciprocity* of the relationships; this dimension permits to distinguish between symmetric (non-directive) relationships and asymmetric relationships, 3) degree of formality of the relationships, which can vary from informal to formally institutionalised relationships and 4) the *multiplexity* (Tichy et al., 1979) or the diversity of roles that a pair of nodes can represent.

Finally, the study of the structural characteristics of the network should also be undertaken at different levels: 1) the external level, which focuses on the definition of the boundaries of the network and the interaction of the network with other networks, isolated nodes or the environment; at this level, local bridges can be identified. The concept of "bridge" is that of a "*line in a network which provides the only path between two points*" (Granovetter, 1973, p. 1364). Bridges act as the "gate" for the connection with other groups or networks, and in most cases it can actually be the "only" way to possibly connect two nodes. Thus, even though networks characterised by strong and dense ties may be more cohesive, in the absence of weak ties acting as local bridges, this system could lead to overall fragmentation

(Granovetter, 1973) and 2) the internal network, which basically captures the patterns of the relationships and structure of the network in itself. Core-periphery structure can be analysed at this point together with the patterns of communication and exchange. At this level, the structure of the network can be characterised as the result of a combination of different properties, such as density or connectedness, openness, stability and centrality.

Figure 4.3: Areas of analysis of IS networks



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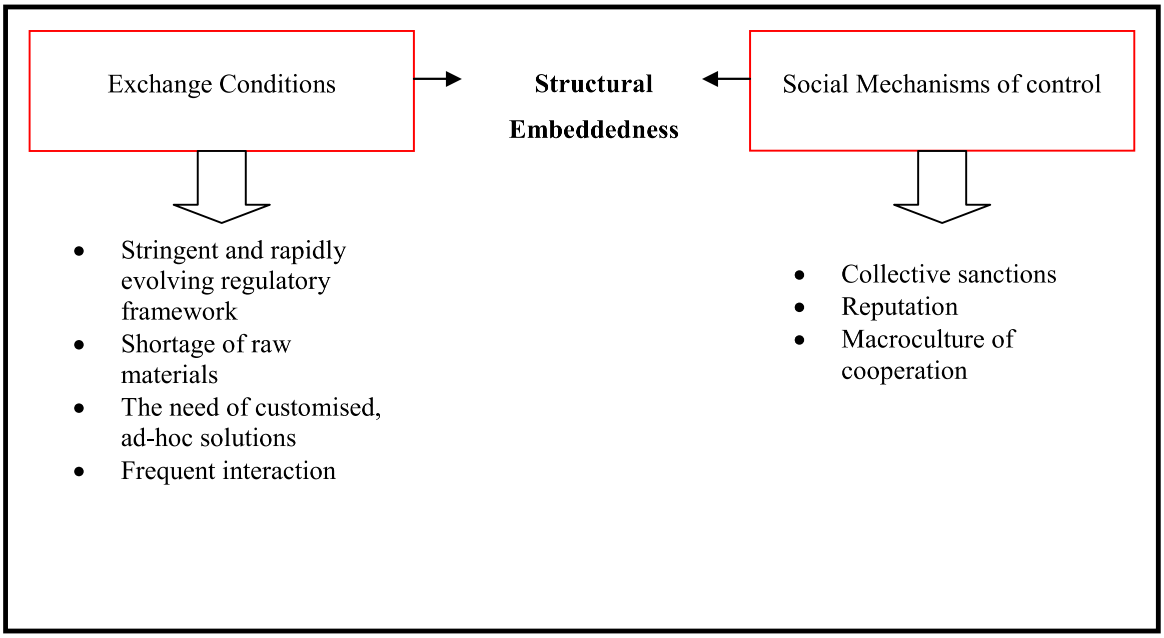
4.3.5 Step 4: Identification of Exchange Conditions and Structural Embeddedness

The next step would be to identify, following the theoretical framework of Jones et al. (1997), the conditions that have favoured the emergence of the network. It would be necessary to examine both the exchange conditions as well as the social mechanisms in place. Exchange conditions that are likely to be found in IS networks are: 1) stringent and rapidly evolving regulatory frameworks, 2) shortage of raw materials,3) the need of customised, ad-hoc solutions[3] and 4) frequency of contact. These conditions increase the need for coordination and flexibility, favouring the emergence of network-related governance forms. At the same time, social mechanisms develop to support the operation of the network. Among the social control mechanisms, the existence of a macroculture and tacit collective sanctions foster collaborative behaviour. An analysis of the culture of cooperation and the tacit rules that govern the network is needed for a better understanding of its dynamics, potentials and threats (see Figure 4.4).

Figure 4.4: Exchange conditions and Social Mechanisms of control



4.4 Analytical Framework for the Analysis of the Discursive Dimension of IS Networks

Together with the structural and contextual dimension of IS networks, their discursive dimension has been analysed in an attempt to shed some light upon the predominant narratives and discourses that inform the operation of IS networks. The discursive dimension of IS is continuously shaping and being shaped not only by the discourses of the

[3] Note that the 3rd condition, relates to what Jones et al. (1997) specify as "*task complexity*" and "*human asset specifity*". In highly competitive contexts, uncertainty and need of adaptation are central problems for the organisation of the industrial system. Under these circumstances standard solutions may fail to address contextual challenges and "unique" solutions, referring to equipment, knowledge or processes, lead to the need of customised, ad-hoc solutions. In this sense, although the need of customised, ad-hoc solutions can be partly interpreted as a consequence of the previous two exchange conditions (uncertainty of rapidly evolving regulatory framework and shortage of raw materials) it is also to be related to the existence of competitive drivers that involve innovation and task complexity.

actors involved but also by the material and structural conditions of the network. This section proposes a protocol of the analysis of the discursive dimension of IS networks and the evaluation of its impact on the network structure and operation. Section 4.3.1 briefly summarises some of the main contributions to the analysis of discourse in the environmental field. Section 4.3.2 provides some insights into the discourse classification proposed by Opoku (2004) for the field of IE. All these contributions provide the theoretical and methodological basis for the analytical protocol proposed in section 4.3.3. A more comprehensive account of the application of discourse analysis to IS networks has been explored by the author in a recent publication in the *International Journal of Environmental, Cultural, Economic and Social Sustainability*, included in Appendix E.

4.4.1 Discourse Analysis: Classification of Environmental Discourses

The discourse analysis framework has been applied to a variety of social disciplines and areas of study that range from organisational studies (Alverson and Kerreman, 2000; Cheney, 2004), communication (Van Dijk, 1995), anthropology (Bloome et al., 2005; Briggs, 1996), cultural studies (Barker and Galasinski, 2001), politics (Fairclough, 2001; Riggins, 1997), social psychology (Potter and Wetherell, 1987) to planning (Rydin, 2003), among others. Within the field of sustainability, discourse analysis has also been used to study the cognitive and representational changes introduced in social structures of modern societies in relationship with the natural environment.

The "construction" of the environmental crisis has been studied by Hajer (1995) in the *Politics of the Environmental Discourse*. Using the concepts of storylines and discourse coalitions, the author discusses the origin of environmentalism and its progress towards inclusion of the environment in the core of public (and private) policies. Weale (1992), in his discussion of the "new politics of pollution", examines the emergence of a new discourse on the environment and identifies three dimensions in the characterisation of the "new politics": 1) change in the scale of the problem, the shift from local/regional problem to global threats; 2) new dynamics of interaction and power among policy actors, and 3) reformulation of pollution problems and solutions. Benton and Short (1999) identify two main meta-discourses in environment: the ecological and the technological meta-discourses. These meta-discourses frame distinctive ways of understanding time, space, causation and propose different understandings and beliefs in the way the relationships between society and nature are constructed. The typology proposed by Dobson (1998) of "environmental sustainability conceptions" is also an attempt to identify different discourses to understand the relationship between human societies and natural systems. Although the author does not specifically refer to discourse, he looks to the different assumptions, causation, goals and scope of different theories of environmental sustainability. Rydin (2003) analyses the discourse embedded in environmental planning from a critical perspective. The author explores the process of "discursive construction" of legitimacy, the notion of "rationality" and the dynamics of conflict and consensus in defining and constraining environmental problems as well as the policy strategies to address them. The method used by the author to analyse discourse is "rhetoric". This method focuses on the latency of explicit lines of argumentation in a discourse and the way these are created. Rhetoric assumes a persuasive nature of language and discourse and, basically, it focuses on three main devices in the process of argumentation (Rydin, 2003): 1) the "ethos", or representation of the "credibility of the speaker"; 2) the "pathos", that defines the "mood music" of the discourse; and 3) the "logos", or "path of argumentation", sustained by the use of tropes.

In *The Politics of the Earth*, Dryzeck (1997) proposes a classification of the main environmental discourses along two dimensions. The first dimension differentiates between reformist and radical discourses. For this author, all environmental discourses derive from the discourse on industrialism. Environmental discourse therefore constitutes a critique of industrialism, but its degree of contestation is variable, ranging from reformist to more radical formulations. The other dimension used by Dryzeck to classify environmental discourses differentiates between prosaic and imaginative approaches to the environmental crisis. Prosaic approaches look at environmental challenges as problems they have to deal with, by using the instruments and maintaining the "political-economic" institutional structure of the industrial society. On the other hand, imaginative approaches interpret "environmental problems as opportunities rather than troubles" and propose a new organisation of the industrial society, with environment at the core of the socio-political systems. The combination of these dimensions gives rise, according to Dryzeck, to the environmental discourses as seen in the table below:

Table 4.4: Classification of environmental discourses

	REFORMIST	RADICAL
PROSAIC	Problem solving	Survivalism
IMAGINATIVE	Sustainability	Green radicalism

\Source: Dryzeck (1997)

Within these discourses, Dryzeck also identifies variations that have generated different sub-discourses, as shown in the following table:

Table 4.5: Classification of Sub-discourses within the environmental discourse

Problem Solving	Sustainability	Survivalism	Green radicalism
Leave it to the people: democratic pragmatism Leave it to the experts: administrative rationalism Leave it to the market: economic rationalism	Environmental benign growth: sustainable development Industrial society and beyond: ecological modernisation	Looming tragedy: survivalism	Save the world through new consciousness: green romanticism Save the world through new politics: green rationalism

\Source: based on Dryzeck (1997)

Among the sub-discourses, ecological modernisation discourse calls for a reconciliation of the environmental preservation goals with economic growth and development. This vision aims to overcome the conflict between economy and nature and define a new path of development in which both dimensions co-evolve in a harmonic way. There are different definitions and approaches to ecological modernisation. Weale (1992) uses the term in a pragmatic fashion to refer to environmental policy and politics in western economies. Hajer (1995) emphasises the relationship of the term to the cultural and philosophical realm of modernity, representing an attempt to "green" the traditional concept of development and progress. This author also points to the possibility of transcending the mere "technocratic" approach to the environment in moving towards a more "reflexive" ecological modernisation, that deepens democratic practices and explore the possibilities of social and institutional change in accordance with environmental challenges. For Dryzeck (1997) ecological modernisation is an attempt to restructure the political economy through the introduction of ecological principles. As this author points out, this discourse does not challenge the pillars of the industrial society, but just reformulates the core criteria that guide political and economic activity. In doing so, it is assumed that the intervention of the state in changing the parameters of economic activity is required to introduce the necessary changes. This intervention, however, is introduced in close collaboration with industrial agents, avoiding confrontation and resistance.

4.4.2 Prevalent Discourse in IE

Within the field of Industrial Ecology, discourse analysis has been used for examination of the relationship between the policy and pragmatic levels of IE developments. Opoku (2004) identifies four main policy perspectives in industrial ecology: the radical approach, the pragmatic approach, the soft reformist approach and the technocracy approach. The soft reformist approach "*conflates largely with the ecological modernisation discourse*" (Opoku, 2004, p.322), which focuses on technological progress as a way of reorganising production and consumption systems and eco-efficiency as a main parameter of action, guiding policy decisions based on economic rationality. The technocracy approach presents industrial ecology as an engineering system, where social and cultural and psychological issues are generally neglected in the analysis. According to this, industrial ecology is interpreted as an "*objective field of study, (which) (...) relies on traditional scientific, engineering, and other disciplinary research for its development*" (Opoku, 2004, p. 324). The radical approach connects with a stronger view of sustainability where industrial and consumption systems have to undergo a process of paradigm shift leading by the principles of "connectedness, community and cooperation". This philosophical standpoint is to a certain extent integrated in the pragmatic approach, which proposes more concrete measures to integrate industrial and environmental issues in mutually supportive ways, and a co-evolution of industrial and natural systems, as the "consistency" strategy proposed by Huber (2000) points to.

These different policy discourses within the field are embedded in the rationale of the actors involved in symbiotic networks. Thus "*different conceptions of industrial ecology will lead to different objectives*" (Opuku, 2004, p. 330) and therefore, to different policy programmes and measures. Identifying the policy standpoint or dominant discourse of main actors involved in symbiotic networks may contribute to a better understanding of the purposive and latent objectives of the network and the way programmes are designed and articulated. The discourse rationale can be identified at three different policy levels: the system level, which relates mainly with the objectives, the structural level, which basically focuses on how the network is organised and a more macro level or institutional level, which refers to the "*playing field created by policy means*"(p.331).

4.4.3 Protocol of Implementation

All the contributions reviewed above confirm the growing importance of discourse in analysing environmental problems from a social constructivism point of view. Although the scope, methods and analysis proposed may vary greatly between authors, they all represent a more critical and reflexive standpoint to analyse the environmental crisis in relation with the system of ideas and belief that defines society. The protocol of implementation of discourse analysis proposed in this thesis for the study of IS networks, builds on the combination of methodological approaches stated above and, especially, in the methodological instances defined by Dryzeck (1997) and Hajer (1995).

For the analysis of the discourses interacting in IS networks, some key elements are examined:

- **The "storyline" or main narrative construction of the emergence and development of networks –**
  This provides a cohesive articulation of the history of networks and the key aspects that prompted its development. Aspects such as the analysis of benefits and costs, the communication with other network members and the sense of shared goals and vision are of especial relevance in the definition of the storyline.
- **Basic conceptions and assumptions** –
  Another crucial element in the understanding of the discourse prevalent in networks is the examination of the basic assumptions and conceptions that hold different actors regarding issues such as the relation between industry and the environment, networking or cooperation.
- **Main actors and motives** –
  As already has been noted, networks are not homogeneous entities but a combination of heterogeneous organizations. This explains the existence of co-occurring discourses within a network and divergences in the drivers that bring companies together.
- **Recurrent metaphors and tropes** –
  The study of recurrent metaphors and tropes is closely connected to the basic assumptions and the storyline of the networks. These elements allow a better

understanding of the way knowledge and meaning are created and to the pre-existing assumptions that lie behind.

- **Principles –**
  Principles act as a guide for action by defining the boundaries between what is accepted and what is considered a deviant behaviour. Main principles leading the dynamics of interaction in the network contribute to understanding of the discourse in place and the way social mechanisms of control operate.

- **Legitimised course of action –**
  Finally, connected with the principles, is the legitimised way of action that defines the frame of cooperation in the network. This refers to identification of the course of action that is preferred or accepted as (socially, economically) viable.

On a practical level, the analysis of the discourse has been done in parallel with the SNA. The analysis of these elements has been based on the content and contextual analysis of secondary and primary data sources.

In the next chapters the framework here explained is applied to the case studies selected.

C. ANALYSIS

The next chapters present the findings from the analysis of the three case studies selected. Chapter 5 and 6 present the findings for Kalundborg and Sagunto respectively. Both chapters are structured in a very similar way. Some background of the case is provided, main actors are mapped, the structure of the network is analysed and the exchange conditions, social mechanisms of control and predominant discourses identified. Chapter 7 presents the main findings from the analysis of NISP. In this case, the structure of the analysis differs from the previous two chapters, due to the characteristics of the network and the lack of available detailed information on the realised IS exchanges. Chapter 7, thus, focuses on describing the methodology of implementation of the programme and analysis of the role of NISP as coordinator. This is of the utmost relevance for the design of policies to promote IS. Aspects such as the structure of the network, exchange conditions and social mechanisms of control are also analysed although the availability of data has limited the possibility to conduct a graph analysis and provide measurement of the structural characteristics of the network.

Chapter 5.
Kalundborg IS Network

Kalundborg is considered the paradigmatic model of industrial ecology networks (Jacobsen 2006; Chertow, 2007). Over more than four decades the companies in the area have developed a complex web of material and energy exchanges, including substitution of virgin raw materials for waste products and cascading of energy, that has reduced the environmental impact of the industries located in the area. Many attempts have been made to replicate this model in other locations all over the world with different degrees of success but still the complexity of Kalundborg has been rarely achieved. What is so unique about Kalundborg? What are the key elements that have contributed to the development of the industrial symbiosis in Kalundborg? Even though great emphasis has been put on the complementary character of the activities located in Kalundborg, it seems difficult to argue that the development of Kalundborg has been the result of a "lucky" coincidence. Indeed, similar combination of industries has not led in other contexts to processes like those developed in Kalundborg. Therefore, beyond the feasibility of the exchanges favoured by the combination of activities, there are some more subtle elements that have conditioned the evolution of the network. The aim of this chapter is two-fold. On the one hand, it provides an excellent case for testing the analytical framework proposed in this thesis and, on the other hand, it contributes to the understanding of a case that has been adopted as a model of IS development by focusing on the soft elements and structural characteristics of the network, and helping to shed some light upon the mechanisms that have favoured its emergence and development. By building on the existing body of knowledge about this experience, the chapter provides new elements of analysis and a systematic approach to the study of the social dimension of IS in Kalundborg.

5.1 Introduction

5.1.1 Selection of the Case Study

As stated in Chapter 4, the main criterion for the selection of Kalundborg as a case study has been its paradigmatic character within the field of IS. Outlined below are some of the main characteristics that justify the theoretical and practical transcendence of this case study:

1) Kalundborg provides a model of operative industrial ecosystems where recycling exchanges and cooperation have emerged spontaneously between the companies, without direct external subsidies or intervention
2) Kalundborg IS is based on economically feasible solutions that have been developed and negotiated by the companies themselves, proving that IS exchanges may pay off
3) Kalundborg has been able to evolve and adapt over the years

5.1.2 Data Sources and Methodology

The main data for undertaking the analysis of Kalundborg have come from: 1) a site-visit to Kalundborg and in-depth, face-to-face interviews with some of the key actors, and short communications with other relevant agents involved in the network; 2) examination and analysis of secondary sources such as company sustainability reports, company environmental policies and programmes, environmental records of emissions, waste and energy; 3) analysis of the environmental regulatory framework and environmental institutional organisation in the region through secondary documents and site visits and informal talks with civil servants and governmental officers; and 4) review of the existing prolific literature on the case.

During the visit, observations were made about the community, the role of the IS institute and its collaboration with other local actors, such as the Local Agenda 21 or the regional environmental agency as well as about the physical and infrastructural layout of the system, such as the pipeline network and other facilities.

The application of the methodological framework, as outlined in chapter 4, has been structured in the following phases: 1) the main participants of the network were identified; 2) dyads were established between the actors, specifying transactional content and intensity (evaluated taking into account the value of the exchanges and frequency of the interaction); 3) a core-periphery structure for the network was proposed and potential local bridges identified; 4) the exchange conditions were examined, paying special attention to the provision of main raw materials and the regulatory and institutional framework in place; 5) Discourses within the network were studied to identify tacit rules of operation that govern the network, the content of the macro-culture and the formation of social mechanisms of control, which provide the basis for the realisation of the IS exchanges.

5.1.3 Literature Review

As a paradigmatic case, the reference to Kalundborg as a practical implementation of the concept of IS and industrial ecosystem is almost omnipresent in IS literature (see, for example, Cote and Rosenthal, 1998; Esty and Porter, 1998; Hardy and Graedel, 2002; Chertow, 2007). However, deeper analyses of the case of Kalundborg and a more detailed examination of the process, evolution of the symbiosis projects and institutional arrangements that characterise this case, are much less common.

Ehrenfeld and Gertler (1997) were among the first to examine closely the evolution and the forces that have driven the development of the IS network in Kalundborg. The authors considered that this network had been the result of "*a sequence of independent, economically driven actions*" (p. 67), that "*sought to make economic use of the(ir) by-products and (to reduce) the cost of compliance with a new, ever-stricter environmental regulations*" (p. 69). After examining the main IS projects developed in Kalundborg, the authors discuss some of the factors that may foster or inhibit the development of IS networks. They emphasise that despite the complexity of the system, the symbiosis in Kalundborg has been achieved without any direct public intervention or "grand plan". The existence of a socially tight community together with cultural pressures that call for environmentally responsible actions and the emergence of organisational arrangements between companies that contributed to a lowering of the transaction costs (information gathering, discovery, contracting, etc.), have favoured the development of a web of IS exchanges. These IS exchanges are based on economic rational choices. The authors, however, argue that this has only been possible due to the flexible and participatory character of the Danish regulatory framework. The regulatory framework has fostered innovative solutions to pollution problem, favouring in this case the cooperation between companies. Notwithstanding the possibilities opened by Kalundborg, the authors believe that the case is not always possible to replicate as it would need "*two or more firms that produce and consume a continuous stream containing useful by-products*" and "*such process industries are only a small fraction of the typical manufacturing firm*" (p. 76). The "evolutionary path" contributed in the case of Kalundborg to gradually generate the conditions for the industrial ecosystem to develop. Similar conclusions are found in Ehrendfeld and Chertow (2002), where also the relevance of evolutionary approaches, such as “green twinning” or by-product synergy and the “anchor and tenant model”, are recognised as critical to IS.

Jacobsen and Anderberg (2004) have also investigated the preconditions that have favoured the development of the network in Kalundborg, with the aim of understanding the role played by IS in sustainable development. The authors direct their attention to the study of the “local dynamics behind IS networks” and design an analytical framework that focuses on three main aspects: 1) “the physical preconditions” and the complementarities between activities; 2) the environmental and economic benefits derived from the networking activities and 3) “*the central conditions and mechanisms behind the development of symbiotic networks*” (p. 317), covering aspects such as technological, institutional, organisational or mental conditions. The authors conclude that a combination of all these factors (technological, institutional, organisational, economic and mental), which are closely interlinked, have contributed to the successful development of Kalundborg. The environmental legislation and the social demands are highlighted as major drivers in the process, as they contributed to the creation of the conditions that made cooperation among companies an economically viable response. However, this alone does not explain the adoption of symbiotic solutions. Cooperation is, according to the authors, deeply rooted in the web of social relations and interactions, favoured by a flexible institutional framework, characterised by negotiation rather than confrontation between companies and regulators, and the existence of fluent communication, also described as a short mental distance, between the different actors. All these elements have led to the progressive institutionalisation of the concept of IS, that has turned into an “action-guided framework” to foster sustainability.

The role of Kalundborg as a model of industrial eco-system and the diffusion of the idea of IS is explored by Boons and Janssen (2004). In explaining the development of Kalundborg, the authors also place special importance on the gradual development of cooperation, which has been mutually supported by the development of social capital. The dynamics of trust building, reciprocity and communication, together with the development of social norms and sanctions have been central in this process.

Sterr and Ott (2004) also consider that the singularity of Kalundborg relies on the combination of factors that have developed over the time and have favoured the emergence of inter-company cooperation and material and energy exchanges. The authors identify three different categories of factors: a) those related with the "historical and systemic" evolution of the network; b) those related to the "economic, technical and political" elements of the case and c) those related to the "spatial" size of the network. In the first category, they emphasise the existence of a "short mental distance" among the main actors, as a crucial element in building trust and favouring "long-term oriented output-input decisions" and the gradual process of institutionalisation of the network that has allowed time for learning and adaptation to develop. When looking to the economic, technical and political factors, the authors highlight as the key pillar for the successful implementation of the waste exchange projects, the fact that they are based on viable economic solutions that are driven by economic rationally, in an attempt to "*diminish or compensate the cost effects resulting from new or stricter environmental regulations"* (Sterr and Ott, 2004, p. 950). This has been possible thanks to the pro-active attitude of actors towards innovation that has resulted in cost-effective and innovative solutions as a response to changes in the context and the relative costs of pollution. Finally, in reference to the spatial component of the network, Sterr and Ott argue that the evolution of the network has resulted in a local nucleus of exchanges that have been gradually expanded to the implementation of regional and supra-regional material flows.

A more detailed analysis of the environmental and economic benefits derived from the water and steam-related projects is provided by Jacobsen (2006). The author focuses on the quantification of the effects of the IS symbiosis at Kalundborg, concluding that through substitution, water and energy cascading and utility sharing, quantifiable environmental and economic benefits are achieved. The author, however, points to different stimuli in the case of the water-related and steam-related projects. In the first case, while the direct economic gains, from a corporate perspective, may seem minor, indirect economic and environmental benefits associated with a more global, long-term strategic perspective play a significant role in driving the IS exchanges. The steam-related projects, however, as a high-value by-product, seem to be motivated more by direct economic benefits. This conclusion raises the question whether economic incentives are enough to explain IS exchanges and points to the importance of social factors as preconditions to IS development, a question that has been further examined by the author in a subsequent paper (Jacobsen, 2008).

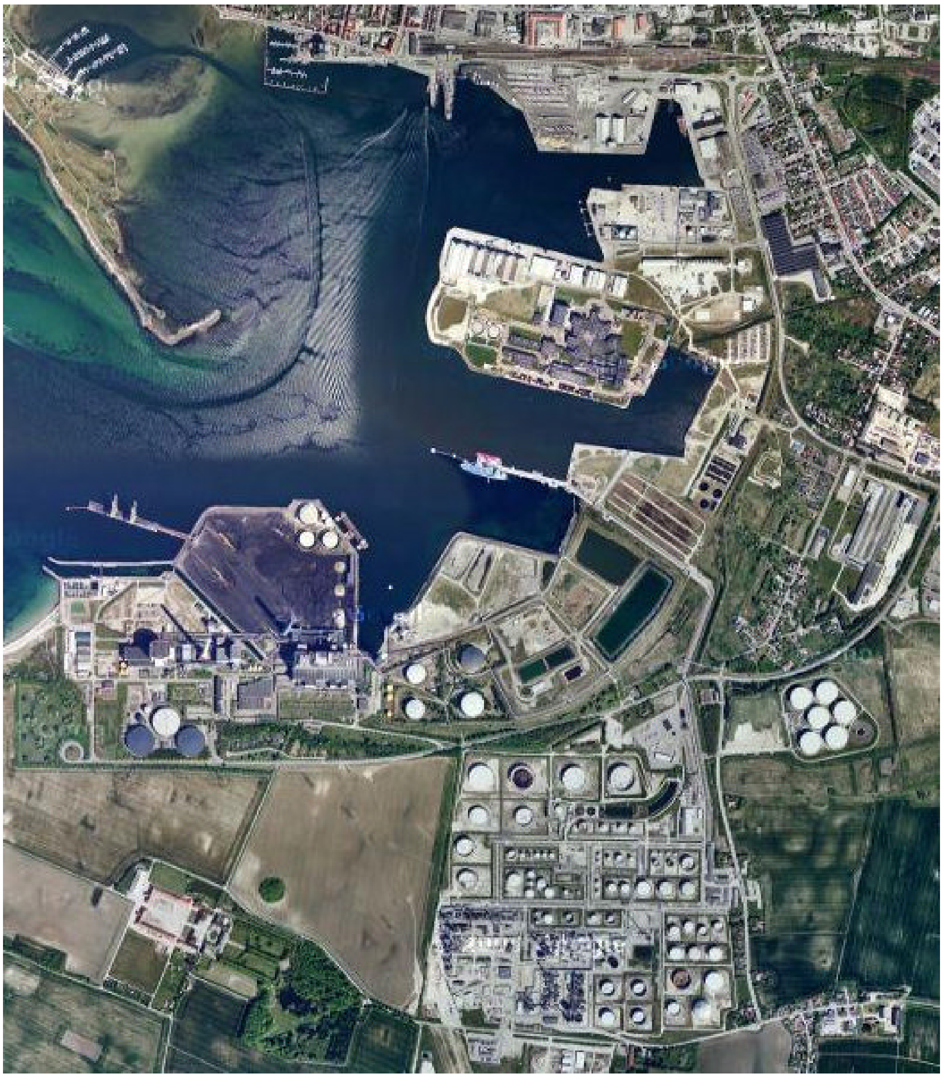
All these contributions, together with more fragmentary or schematic descriptions of the symbiosis in Kalundborg, which can be found in the IS body of literature, offer the basis for the analysis here presented. This chapter, however, introduces an innovative methodological approach to the study of the IS network in Kalundborg by focusing on the structural characteristics of the network, and the impact structural elements have in the development and operation of the network. This is complemented by a discourse analysis that focuses on an examination of the predominant discourses in place and how these are embedded in the network, providing the cognitive basis for the development of the exchanges.

5.2 Description of the Network: Overview and Evolution

5.2.1 The Municipality of Kalundborg

Kalundborg is situated in the West Zealand County, on the west coast of the island of Zealand (Sjælland), in Denmark. As a result of the "Municipality Reform" (Kommunalreformen), in January 2007, the municipality of Kalundborg has been merged with the former Gørlev, Hvidebæk, Bjergsted, and Høng municipalities, covering an area of 598 km², and with a total population of 48,697 (2005).

Figure 5.1: Aerial map of Kalundborg IS



Source: Google Maps

According to the data on the labour market (that still refers to the previous municipal distribution), the industrial sector in Kalundborg has an important weight on the economic structure of the town. Special relevance within the industry has the chemical and plastic sector, where just one company group, Novo Nordisk and Novo Enzymes, accounts for more than half of the employment in the sector. This industry, together with the production of electricity, gas and water supply, play an important role in the IS network, as will be described in the next section.

Table 5.1: Kalundborg Municipality 2006

Sectors of Activity	Employed
0109 Agriculture, horticulture and forestry	190
0500 Fishing	19
1009 Mining and quarrying	2
1509 Mfr. of food, beverages and tobacco	109
1709 Mfr. of textiles and leather	0
2009 Mfr. of wood products, printing and publishing	75
2309 Mfr. of chemicals and plastic products	3356
2600 Mfr. of other non-metallic mineral products	150
2709 Mfr. of basic metals and fabricated metal products	342
3600 Mfr. of furniture; manufacturing n.e.c.	12
4009 Electricity, gas and water supply	220
4500 Construction	1106
5000 Sale and repair of motor vehicles sale of auto. fuel	295
5100 Wholesale except of motor vehicles	266
5200 Re. trade and repair work exc. of m. Vehicles	843
5500 Hotels and restaurants	249
6009 Transport	408
6400 Post and telecommunications	189
6509 Finance and insurance	123
7009 Letting and sale of real estate	143
7209 Business activities	802
7500 Public administration	441
8000 Education	716
8519 Human health activities	621
8539 Social institutions etc.	1592
9009 Associations, culture and refuse disposal	430
9800 Activity not stated	17

\Source: Denmark Statistics (2006)

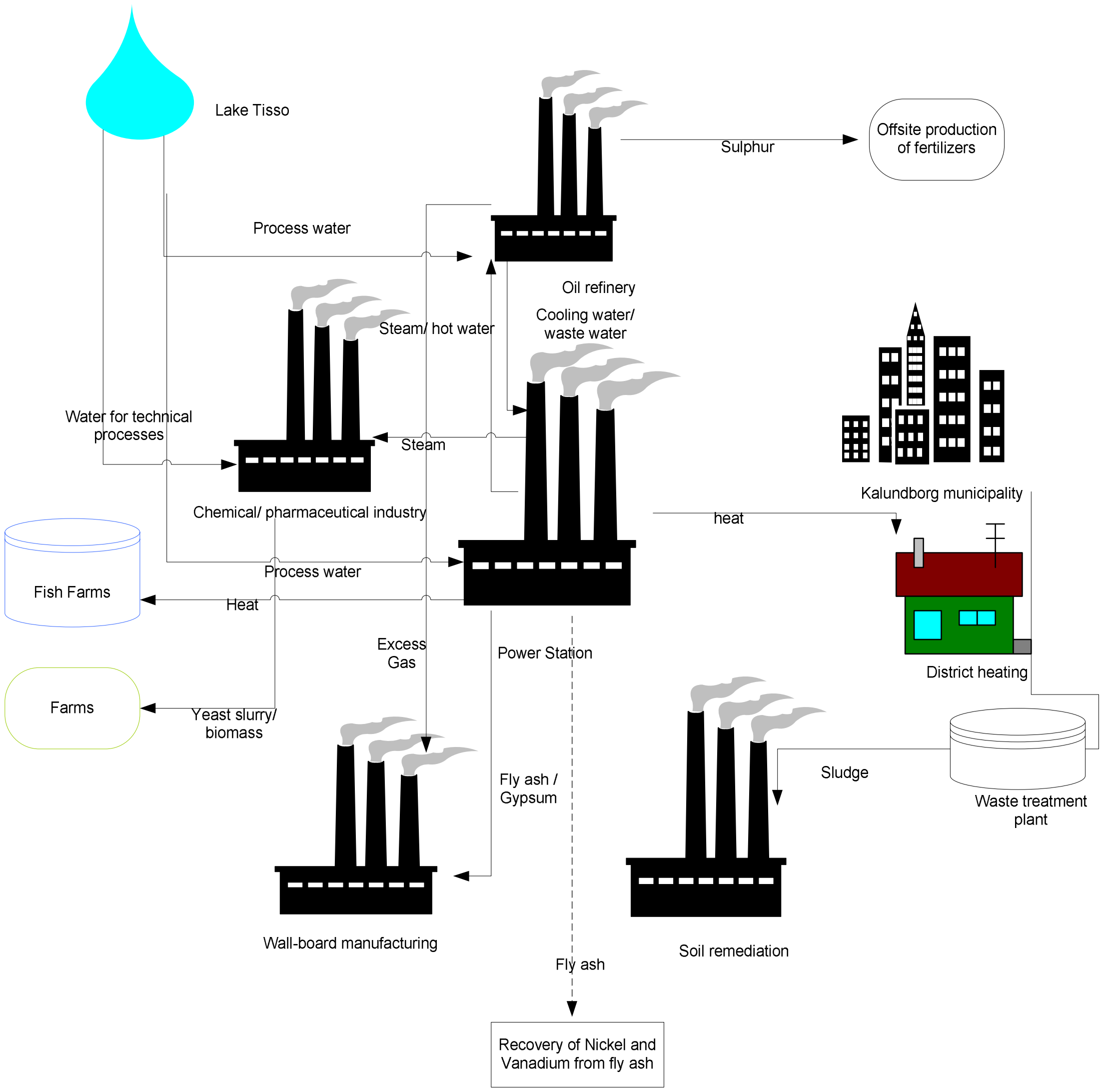
5.2.2 Description of the Symbiosis Projects: The Process of Building the Industrial Eco-system

Retrospectively, the symbiosis in Kalundborg can be described as a process of development of collaborative linkages between different industries located in near proximity to each other. This process has been the result of the material and social conditions that characterise the area. From bilateral exchanges, the collaboration gained in complexity, led to a dense network of IS exchange. The process of cooperation has had an impact on the structure of relative costs of the companies and global environmental impact of the industrial area.

The first "symbiotic" projects emerged in the 1960s just after some of the major players of the network located in the area. In the beginning, the projects were not framed as environmental solutions; they were initiated by the companies, in a combination of alliances and commercial agreements. The institutionalisation of the symbiosis came only long after. The projects included in the symbiosis, as described below, comply with three main criteria: a) allow the reutilisation of waste flows as inputs for other processes; b) entail both environmental and economic benefits compared to the business as usual scenario and c) require companies to work "across the fence".

Figure 5.2 below provides a graphical representation of the IS ties developed in the network of Kalundborg. A more detailed description of the main actors that configure the network and the evolution of the projects developed within the network is given in the next sections.

Figure 5.2: IS network of Kalundborg



\Source: author generated

5.2.3 The main players

The Kalundborg Symbiosis network is made up of six companies belonging to different sectors of activity: a power station, two major chemical companies, a plaster board manufacturer, a soil remediation company, a refinery and the municipality of Kalundborg, which acts not as an authority, but as a supplier/demander of material and energy flows and utilities. There are also some other peripheral actors including farmers from the region, a fishing factory and some material recycling companies that act as a recipient of some of the material flows. The analysis has included all the actors that have at least one exchange with another actor within the network. There are other actors, such as Novoren, an urban land field and recycling company, that although are formally part of the symbiosis institute, do not contribute with a tangible exchange to the network. A more detailed description of the main players, based on data obtained in company policy documents and personal communications, is provided below.

Dong Energy Asnaes Power Station is the largest power plant in Denmark, with three active units supplying a total of 1,057 MW of electricity and up to 502 MJ/s of heat. This plant provides around one third of Zealand´s total power consumption. The power plant uses coal as its main fuel, oil being the reserve fuel at all three active units. The plant currently belongs to the group DONG Energy and has around 155 employees. Although the employment generated by the plant has decreased significantly, the company still plays a major role in the economy of the region. The first production plant, Asnæs Power Station's Unit 1, was commissioned in 1959, and in 1981 Asnæs Power Station's Unit 5 was put into operation. In addition to electricity, the Asnæs Power Station produces district heating for the Municipality of Kalundborg and process-steam for neighbouring enterprises (Statoil, Novo Nordisk and Novozymes). In 2006 the Asnæs Power Station generated a net quantity of 4,439 GWh of electricity and a net quantity of 2,263 TJ of district heating. In 2003-2004 Unit 5 of the power station, supplying 640 MW, underwent a major renovation that will extend its life by 15 years.

Statoil A/S refinery at Kalundborg processes up to 5.5 million tonnes of crude oil a year. It refines crude oil and condensate to petrol, jet fuel, diesel oil, propane, heating oil and fuel oil. The refinery was first built in 1961. In 1995 it underwent a major expansion, so that it could increase the fraction of condensates, which has proven along the years a very profitable area of business. Moreover, it allows the production of petrol with lower content of benzene. As a result of changes in the legislation and the restrictions on the emissions of sulphur and nitrogen oxides, the plant designed a completely new facility that converts sulphur and nitrogen from the desulphurization process of oil products, into an agricultural fertilizer, of ammonium thiosulphate (ATS). The fertilizer began to be produced in 2000. In 2002, a synflex facility started to work, generating up to one million tonnes of sulphur free diesel. The refinery also produced low-sulphur diesel oil (with less than 50ppm of sulphur content). Statoil has been a main player of the IS network, collaborating in a number of water, steam and materials projects.

Novo Nordisk was established in the area in 1969 as an enzyme production plant. It was not until the 1970s that the company extended its operations to the production of insulin. Although both processes shared the same technology (permutation technology) the conditions and requirements of the production were quite different. Therefore, the company decided in 2000 to split its operations into Novo Nordisk, the pharmaceutical section, and Novo enzymes, the industrial enzyme producer. Novo enzymes at Kalundborg is the world's largest single enzyme factory, with around 600 employees. Novo Nordisk also has a strong competitive position in the pharmaceutical sector, offering a wide range of insulin products. The plant in Kalundborg has grown considerably and currently has around 2,500 employees. Both companies have a very proactive profile in the environment field. Green accounts are published online and detailed information about the main environmental effects of their activities is also publicly available.

Gyproc A/S is also an active member of the Kalundborg IS. The company belongs to the transnational group Saint-Gobain, and it has become the leading producer in Scandinavia of plasterboards and plasterboard-based systems for the construction industry. The factory in Kalundborg has around 165 employees.

RGS 90 A/S, also known as Soilrem, is a soil remediation company. The company has developed patented technologies for the decontamination of soil and sludge. The plant in Kalundborg specialises in the remediation of soil contaminated by oil, chemicals and heavy metals. It processes around 500,000 tonnes of contaminated soil a year and has approximately 65 employees.

The **municipality of Kalundborg** is another of the partners in the industrial symbiosis network. The municipality has a population of around 50,000 (after the municipality reform) and has engaged in different energy and water projects within the network. The main project the municipality is involved in the recovery of waste heat and steam from the power station for the district heating.

Kara/Noveren I/S is also a partner of the industrial symbiosis institute in Kalundborg, although it does not directly engage in any of the waste flow streams exchanged in the network. The company operates an inter-municipal waste treatment system, covering nine West Zealand municipalities. The company has its own waste treatment facilities as well as contractual agreements with other plants on waste treatment. At Kalundborg, the company operates a transfer station for household and industrial waste. This facility handles approximately 350,000 tons of waste per year, with a high percentage of recycling and heat and energy recovery.

There are also actors that receive and reuse waste flows generated by the above mentioned companies, although they are not formally members of the industrial symbiosis network. These actors, however, have been taken into account in the analysis of the network, as they also contribute to the recycling flows of materials. Among these actors, the analysis has considered the following: cement companies that receive fly ash, farmers that are offered fertilizer and fisheries that benefit from the waste heat from the power station.

Based on the data gathered in interviews and site-visits, and the analysis of secondary materials, the table below has been constructed to offer a summary of the characteristic of the main players of the IS at Kalundborg. Aspects such as the environmental profile of the actor and attitude towards IS have been analysed using a grading system. For the evaluation of the environmental profile and I+D component of the activities, a simple 3-level classification has been proposed here, which rates these aspects from * (low) to *** (high). Therefore, for example, an organization with a certified Environmental Management System (EMS) and an ambitious environmental policy would be rated *** in the column environmental profile. It should be noted, however, that one characteristic of the companies involved in the network in Kalundborg is the high level of corporate commitment towards environmental issues and a significant R&D content, so it is expected that they would rate high in these aspects. For analysis and evaluation of these dimensions the competitive position of the company within its sector of activity, the budget in R&D activities and the number of registered patents have to be taken into account. The attitude towards IS has been classified using a 2-dimensional system. First, it distinguishes between active (A) and passive (P) players, depending on their level of engagement in the network and, secondly, it is stated whether they have a positive (+), neutral (/) or negative (-) attitude towards the network, that is, if they support, are indifferent or oppose to the network. In the case of Kalundborg, due to its characteristics and process of development, it is unlikely that some actor could develop a negative attitude towards the network.

Table 5.2: Mapping of main actors in Kalundborg IS network

Name	Size (num. employees)	Sector	Environmental profile		R&D	Streams to IS network		Attitude towards IS
			Certified Environmental systems (ISO 14,001)	Leadership/ environmental position		IN	OUT	
Asnaes	155	Energy Production	Yes	**	**	Cooling water Waste water	Steam Heat Fly ash Gypsum	A+
Statoil	330	Oil refining	Yes	***	***	Steam	Sulphur Waste water Cooling water (Gas)	A+
Novo Nordisk	1500	Pharmaceutical/ chemical	Yes	***	***	Steam	Biomass Yeast slurry	A+
Novozymes	650	Chemical	Yes	***	***	Steam	Biomass Yeast slurry	A+
Gyproc	165	Construction materials	Yes	***	**	(Gas) Gypsum		A+
Novoren	-[1]	Waste management	Yes	**	*	-	-	P+
Kalundborg Municipality	20, 000[2]			**	-	Heat Waste water	Sludge	P+
RGS 90, Jordrens (Soilrem)	65	Soil remediation	Yes	**	***	Sludge	-	A+
Farmers	-[1]	Agricultural	-	-	-	Fertilizer	-	P+
Fisheries	-[1]	Fishery	-	-	-	Heat	-	P+

\[1] - Unspecified
\[2] - 20,000 (town of Kalundborg), 50,000 (municipality)

\Source: Author elaborated based on data from interviews and company reports.

5.2.4 Evolution of IS Projects

As has already been mentioned, the IS process has developed gradually over the years. Genesis of the IS network is generally traced back to 1960, with the commissioning of the power plant (1959) and the refinery (1961). The refinery's processes had a large requirement for cooling water and the municipal water supply was insufficient to cover this demand. The solution found was to source the water from lake Tisso by running a pipeline about 13 km long. The cost of this investment could not be assumed by the municipality, so the refinery financed the project and the cost was paid back in water. If considered in isolation, this can hardly be considered an IS project; however, it represents the beginning of the process of cooperation that resulted in the complex IS network. The next project developed as a result of the location of a plasterboard manufacturer, Gyproc, in the area. In the production of plasterboard, gypsum has to be burned, decalcinated, suspended in water and the drain so that excess water evaporates. The drying process requires a lot of energy and an agreement was signed between Gyproc and the refinery to use the excess gas from the refinery. This project eventually died as the refinery found a more efficient use of gas and Gyproc changed to alternative sources (butane and then, natural gas).

The expansion of the power station in 1973 increased its water requirement, which was sourced from lake Tisso by using the existing pipeline. As a consequence of the strengthening of environmental regulations, introduced in the early 1970s, Novo industry was forced to separate the effluents and find a solution for the waste biomass generated in the enzyme production process. The most cost-efficient alternative was in this case to apply a heat treatment to kill potential microorganisms, so that it could be used as fertiliser and be distributed free of charge among adjacent farms (around 80,000 tonnes a year), through a network of pipelines and trucks.

The next IS project developed within the network, involved the use of fly ash, from the power station, in different cement companies in Jutland. Other IS linkages were generated in order to reuse lost heat from the power station. The power station used sea water as cooling water. This water is recirculated and returned to sea, although at a higher temperature. This proved to be an excellent medium to grow fish and it spawned an entrepreneurial project generated by the IS network (first as part of Asnaes and later as a small private company).

Also changes in the regulatory framework this time affecting energy production favoured the development of another IS project. The new regulation stated that power stations became not only suppliers of electricity but also suppliers of energy, such as heat for district heating. This fostered the introduction of a cogeneration system in the power station, generating three additional flows: 1) heat to be used for district heating, 2) steam to be used in Novo industry (covering all its demand) and 3) steam to cover part of the requirements of the refinery (around 15% of total needs).

The scarcity of water in the area was again the origin of two new IS projects. Novo industry replaced ground water for surface water for cooling purposes. The other project consisted in reusing the cooling water from the refinery as raw boiler feed water for Asnaes.

As some of the biomass generated by Novo was yeast slurry, a valuable by-product from the insulin production, the company separated this fraction and sold it for animal feed (in the pig industry).

In 1990, the refinery built a desulphurisation unit to remove the sulphur from the gas and transform it into liquid sulphur that was sold and shipped to a company in Jutland for the production of sulphuric acid. However, as the market value of sulphur dropped, the refinery decided to produce ammonium thiosulphate that could be sold directly as fertiliser, and generated better revenue.

The construction of a waste water treatment plant for the refinery also allowed reuse of the treated water by the power station as second or third-class water, to be used in less demanding processes. The next project also involved the refinery and the power station. The refinery piped excess gas, once desulphurised, to be used as supplementary fuel by the power station. Regulatory requirements also forced the power station to desulphurise its emissions. Among the alternative methods, they selected a sulphur dioxide scrubber that generated calcium sulphate, or gypsum, as a by-product. This by-product could be used as an input material by Gyproc, covering most of the gypsum needs. In 1995, also the power station constructed a water basin, to reuse the drain water and use it as third-class water.

In 1996 the Symbiosis Institute was formed. This can be considered another IS project, although of a different nature. Among the aims of the institute was: a) favouring interaction between companies, b) generating new ideas and projects for the IS network and c) to publicise and give information about Kalundborg IS network so that it could be used as a referent for further developments somewhere else.

At the end of the nineties, a new company located in the area and joined the symbiosis network. Former Soilrem (now called Jordrens), a soil remediation company, started to use the sludge from the municipal wastewater plant to speed up the process of aerobic digestion of contaminated soil.

For some years, the power station used ori-emulsion as fuel. The fly ash generated by this fuel was of a different composition and had important concentrations of oxides of nickel and vanadium. This made the fly ash unsuitable for the cement industry, but it was possible to recover and reuse the content of nickel and vanadium, so it was sent to a company in England that recovered those metals. This, thus, generated a new exchange, in this case with an external actor. The ori-emulsion is not used anymore and therefore this tie has also been stopped.

The power station requires a fraction of water of high quality for the boilers. This water needs to be treated by decarbonisation and osmosis to make it suitable for this purpose. The refinery also requires a small fraction of pure water for some of its processes. Instead of investing in the equipment for the purification of the water, they reached an agreement with the power station and run a pipeline to use some of its high quality water.

More recently, in 2004, another project to save ground water was undertaken by Novozymes and the municipality. To reduce the pressure over ground water resources, which are scarce in the area, Novozymes decided to treat surface water up to drinking standards, so that it could replace ground water in some technical processes. A water works was built together with the municipality for this purpose, allowing Novozymes to use one extra million m^3 of surface water.

The last project of the network consists of a bilateral collaboration between the power station and the refinery. As a result of the extension of the refinery they required more cooling water. They studied the possibility to use sea water for cooling, but this required a high investment. The power station already had one sea water installation and therefore, they reached an agreement to share the use of the installation at the power station and construct a pipeline to the refinery.

The table below, summaries the chronology of the development of the IS network in Kalundborg.

Table 5.3: Chronology of the network in Kalundborg

Year	IS Project
1961	Surface water from Lake Tisso is pumped to the refinery
1972	Excess gas from the refinery is piped to Gyproc
1973	Power station uses surface water from lake Tisso by using the pipeline from the refinery
1976	Novoindustry starts to deliver sludge as fertiliser for farmlands
1979	Fly ash from Anaes to be used in the production of cement
1981	Heat is provided from Asnaes to the municipality for district heating
1982	Steam from Asnaes is supplied to the refinery and to Novo industry
1987	Novo industry starts to use surface water for cooling purposes
1987	Cooling water from the refinery is used in Asnaes for boiler feed
1989	As a consequence of the use of sea water for cooling, waste heat retained in the water is used in Asnaes for the production of fish, in a fish farm
1989	Novo separates the yeast slurry from the biomass, which is sold to pig farms
1990	The refinery sells the sulphur, obtained as a by-product of the pollution control technologies, to a company in Jutland.
1991	Treated waste water from the refinery is reused in Asnaes for non demanding processes
1992	Excess gas refinery, after being treated, is sent to Asnaes.
1992	Statoil starts to sell the liquid sulphur as fertiliser, replacing the ties with the company in Jutland.
1993	Gypsum from Asnaes, generated as a consequence of the desulphurization treatment, is supplied to Gyproc
1995	Re-use water basin was constructed at Asnaes.
1996	Symbiosis institute was created.
1998	Jordrens reuses sludge from municipal waste water plant for its processes
1997	As the power plant introduces ori-emulsion as fuel, fly ashes are sent to a company in England for the recovery nickel and vanadium.
2002	Statoil to use sea water for cooling purposes. An agreement is reached with power station to use its sea water installation.
2004	Use of surface water (treated up to drinking standards) to replace ground water at Novozymes.
2008	Shared use of sea water treatment installation for cooling between the power station and the refinery

\Source: Author generated based on personal communications with main network members.

5.2.5 Types of Projects

From the description of the projects outlined above, it is possible to distinguish three types of projects: a) minimisation, recycling and cascading of water, b) exchange of energy and c) recycling of solid waste products. Apart from all these material and energy exchanges, there is a complex web of knowledge and information flows, which have provided the ground for the development of the network. This aspect will be addressed later on in more detail.

Table 5.4, shows the number of project of each type. Up to date, around 22 IS projects have been developed in total within the network. Most of these projects are still operative, although there are some of them that have either been stopped or replaced by other IS exchanges. For example, the recovery of vanadium and nickel was stopped once ori-emulsion was discarded as fuel at the power station. Instead, fly ashes have been sent to cement companies. There are also a number of projects that were tested but for a number of reasons did not work. An example of this was the project to install a central cooling system. The system proposed would have allowed production of cooling water more efficiently by designing a cascading system in order to cope with the requirements of temperature set up by different companies. It was an economic and technically viable project, but most of the companies had already cooling systems that were paid for and this would require a new investment. The costs of investment discouraged, in this case, the potential IS project.

Projects related to the reduction, recycling and cascading of water are the more important in number. The environmental conditions of the area, with a scarcity of natural ground water resources and, the nature of the activities located in the area, with high requirements of water, explain the primacy of this type of projects. Although, the proximity of lake Tisso makes surface water more abundant, the industries still suffer restrictions in the volume of water available for their activities. It has been estimated that an annual water intake of around 5 mill m^3 is sustainable for the area (Jacobsen, 2006). The water projects can be divided into: i) projects that replace ground water by surface water and ii) projects that minimise the consumption of water, especially ground, but also surface water, by cascading of water and recycling (such as reuse of cooling water, recycling of waste water and cascading of water for less demanding processes).

Energy projects are related with the cogeneration of electricity, steam and heat at the power station. Steam-related exchanges connect the power station to the neighbouring facilities of Statoil, Novozymes and Novo Nordisk. Heat is distributed by the municipality through the district heating system.

Finally, the third category of projects consists of the exchange of material or solid by-products that are recycled and reused, either by neighbouring companies or external recyclers. Most of these projects are directly linked to the introduction of stricter regulatory limits to emission of contaminants and effluents and pollution control technologies, which have generated a diversity of by-products and waste flows that need to be dealt with. Examples of this are the exchange of gypsum, between Asnaes and Gyproc, as a consequence of the de-sulphurisation process or the distribution of biomass among farmers by Novo Nordisk and Novozymes.

Table 5.4: Number of IS projects in Kalundborg by type

Type of project	Number
Recycling water	11
Recycling/ reuse of energy	6
Reuse/ recycling of solid waste	7
TOTAL	**22**

\Source: Author generated based on Christensen (2006): personal communication.

Another possible categorisation of the projects differentiates between internal and external projects. Internal are those projects where all the actors involved belong to the network and external projects comprise those exchanges that take place between an actor of the network and an external organisation (see Table 5.5). An example of the latter would be the reuse of fly ash by cement industries, located in Jutland. In the case of Kalundborg, most of the projects are internal, as they occur within the boundaries of the network.

Table 5.5: Internal vs. external projects in Kalundborg IS network

Type of project	Number
Internal	17
External	5
TOTAL	**22**

\Source: Author generated based on Christensen (2006); personal communication.

5.2.6 Benefits Derived from the IS

Although Kalundborg has become a milestone in IS development, quantitative analyses of the economic and environmental benefits derived from this experience are still scarce. The most comprehensive attempt to quantify such benefits has been recently published by Jacobsen (2006). This analysis builds on previous contributions (especially, Christensen, 1998) and detailed information provided by some of the main players involved in the network. In this chapter, a revision and update of this analysis is proposed, based on data published by the companies, such as green accounts and environmental reports, as well as other data gathered in the interviews conducted by the researcher. Rather than an exhaustive account of the benefits generated by the projects, the aim of this section is to provide an overview of the main network outcomes and an idea of their magnitude.

One of the main difficulties in evaluating economic and environmental benefits of IS projects, is to define the baseline scenario to which compare the IS initiatives. As noted before, all of the IS projects developed in Kalundborg are business projects, in the sense that they have been selected by the companies as the best solution or option given the alternatives and all were considered “profitable” projects. The decision criteria are a mixture of economic and strategic motives, defined by a multiplicity of factors such as the business context, the institutional framework or the economic conjuncture. These factors are difficult to isolate and evaluate retrospectively, and therefore the quantification here provided is based on assumptions regarding the most likely scenarios and alternatives to IS projects. They account for the savings (and revenues) generated by the IS projects, both in environmental and economic terms, in comparison to the most likely alternative scenario. This may refer to the business as usual scenario or to the most likely alternative when selecting between different options. Table 5.6 provides a summary of the main exchanges of the network and an estimation of the quantities/volumes exchanged[4].

A quantification of the main IS exchanges is provided in table 5.6.

Table 5.6: Quantification of main IS exchanges in Kalundborg

Exchange tie	**Since**	**Status**	**Quantity per year/ units**	**Transaction type**
Surface water to refinery	1961	Operative	1,6 mill m^3	Sold
Excess gas from Statoil to Gyproc	1972	Stopped	8,000 Tn	Sold
Biomass Novoindustry to farmers	1976	Operative	210,000 m^3 (Novo Nordisk) 109,000 m^3 (Novozymes/ Novogro 30)	Free
Fly ash shipped to cement companies (Aalborg Portland)	1979	Operative	Approx. 120,000 Tn	Sold
Heat from Asnaes to district heating	1981	Operative	569,784 GJ	Sold
Steam from Asnaes to Statoil	1982	Operative	197,000 GJ	Sold

[4] The quantities here are estimations based on calculations provided by main actors during interviews undertaken by the researcher and previously published material.

Exchange tie	Since	Status	Quantity per year/ units	Transaction type
Steam from Asnaes to Novo industries	1982	Operative	829,000 GJ	Sold
Use of surface water for cooling at Novo industries	1987	Operative	491,000 m^3	Sold
Cooling water from refinery to Asnaes for boilers	1987	Operative	700,000 m^3	Sold
Salty cooling water is piped to the fish farm to reuse the waste heat	1989	Operative	23 mill. m^3	Free
Yeast slurry generated by Novo Nordisk	1989	Operative	42,500 m^3	Sold
Sulphur generated by the refinery	1990	Stopped	2,800 Tn	Sold
Treated waste water from the refinery to Asnaes	1991	Operative	9,000 m^3	Free
Liquid sulphur (fertiliser) from Statoil	1992	Operative	20,000 Tn	Sold
Gypsum	1993	Operative	170,000 Tn	Sold
Waste water from Novo industries to treatment plant	1995	Operative	2.3 mill m^3	----
Reuse of sludge from municipal waste water plant by Jordrens	1998	Operative	-----	Free
Upgrade of surface water to drinking water standard for Novozymes	2004	Operative	1 mill m^3	Sold

* Includes the production of three factories of the group: Kalundborg, Copenhagen and Bagsværd

\Source: Christensen, personal communication 2006; Jacobsen, 2006; Chertow, 2001; Novo Nordisk green accounts; Statoil environmental report; Novozymes green accounts; Dong environmental report; Interview data. Base year for the data varies, although most data has as base year either 1998 or 2002. It is assumed that as exchanges occur on a continuous basis, quantities linked to the exchanges remain stable over the years.

5.2.7 Environmental analysis

Environmental benefits have been calculated as a reduction in consumption of resources or emissions and effluents released to the environment. Table 5.7 summarises the main environmental benefits generated by the IS network in Kalundborg, on a yearly basis.

Table 5.7. Annual environmental benefits of Kalundborg IS network

Resource/ emission flow	Savings per year
Ground water	2,9 mill m^3
Surface water*	1,0 mill m^3
Liquid sulphur	20,000 Tn
Biomass	319,000 m^3
Biomass (yeast slurry)	42,500 Tn
CO_2 emissions**	64, 460 Tn
SO_2 emissions***	53 Tn
NO_x emissions***	89 Tn
Waste water ****	200,000 m3
Gypsum	170,000 Tn

* Surface water substituted by sea water at Asnaes
** Reductions in emissions are calculated as an estimation of the reduction of heavy fuel oil derived from the combined heat and power generation (20,000 tn heavy fuel oil * 3,223 conversion factor CO_2).
*** SO_2 and NO_x are based on 2002 data, Jabobsen (2006). These values are expected to be a bit lower, since unit 5 from Asnaes is no longer fuelled with oriemulsion; CO_2 emissions may, on the contrary, be higher, as a result of the fuel substitution (coal for oriemulsion);
**** This value is calculated as an estimation of waste water recirculation at Asnaes;

\Source: Christensen, personal communication 2006; Jacobsen, 2006; Chertow, 2001; Novo nordisk green accounts; Statoil environmental report; Novozymes green accounts; Dong environmental report; Interview data.

5.2.8 Economic Analysis

Together with environmental benefits, IS projects have generated important annual savings and in some cases revenues (as in the case of the exchange of some by-products such as steam or liquid sulphur). Many of the IS projects generated in the network have been the direct or indirect consequence of changes in the regulatory framework, that have imposed new requirements to the industries. However, in all cases, the IS projects, as mentioned earlier, were the best business option given the context, that is, that they were considered the most profitable (or less costly) alternative. As noted before in the quantification of the IS flows, the evaluation of the economic benefits is based on the relative savings this option has generated when compared with other likely options.

Up to 1998, the total investments calculated as a global figure for all the 18 projects developed until that date, amounted to over $75 million. Since then the only big investment carried out within the network has been the waterworks to treat surface water up to drinking water standards. A relevant investment of around US$3.5 mill. (DKK 21 mill.). Annual savings for the whole network have also been established at around US$ 15 mill.

(Christensen, 2006, personal communication), a figure presumably higher now. According to this, a simple payback period of the network evaluated globally is around five years. Across the projects, however, the payback periods are very different and may vary between projects that pay back in less than a year or projects with long pay back periods, such as the district heating system. The accumulated savings are now over US$310 million.

Table 5.8: Economic parameters of the IS network

Investment/ savings	**Amount (in US$ millions)**
Investments	78.5
Annual savings	15
Accumulated savings	310

\Source: Author generated based on Christensen (2006): personal communication.

Table 5.9: Financial indicators of the IS network

Simple payback	5 years
Return on Investment (not discounted)*	295%

* - The value of ROI given here is just a global estimation for the whole network. Note that ROI between projects may have been very different.

\Source: Author generated based on data from interviews.

More than the magnitude of these benefits, these figures show that IS exchanges are both economically and environmentally beneficial compared to the business as usual scenario or stand-alone solutions in the face of changes in the regulatory framework and strict environmental requirements. Moreover, although more difficult to quantify, there are other important social, environmental and business benefits derived from the IS network. Aspects such as reduction of the risks (associated to environmental investments), minimisation of innovation costs (as they are shared by more than one actor), improvement of the corporate image of the companies involved, integration in the local community or increase in the level of staff satisfaction, should also be taken into account as positive outcomes generated by the network.

5.3 Structural Analysis of the Network

The structural analysis of the network follows the protocol of implementation presented in Chapter 4, where the rationale of the methodological approach has been explained. The analysis of the data has been supported by the Social Network Analysis software UCINET, version 6. Complementary information, detailed calculations and graphs are provided in Appendix B.

5.3.1 Assumptions

The analysis is based on directed graphs, where ties are not assumed to be reciprocal but they have a direction (from node A to node B, but not from B to A, for example), as they provide a better representation of the relationships within the networks where an IS exchange can be originated in one company but it does not necessarily imply a flow back. Even when IS exchanges generate revenue, money has not been represented as a tie. Due to the specific characteristics of IS networks, the main focus of the research was to study the material and knowledge exchanges between industries and thus the consideration of money flows in this case might have introduced changes in the morphology of the network that would not be related to changes in the environmental impact of the industrial system. When considering the flows related to knowledge and information in most cases reciprocity has been assumed (Von Hippel, 1987). Even though in some cases the knowledge was originated by a single actor or a pair of actors, the protocols of communication within the companies belonging to the Industrial Symbiosis Institute made it likely for the knowledge to permeate the whole network, leading to innovation and transfer of know-how. However, knowledge and information flows have been considered unidirectional in the case of "external" nodes, as for example, the flow of fertiliser from Novo industries to the farmers, where the knowledge has been originated by a single actor, Novo industries in the example, with little or no input from the other, in this case, the farmers.

The analysis include the actors that formally composed the institutionalised network, as well, as other actors, that although not formally part of it, are playing a role as recipient of flows generated within the network, and have been here referred as "external actors/ projects".

5.3.2 Mapping of Actors

A summary of the main actors that constitute the network has already been provided in Table 5.2. As noted above, all actors that have at least one exchange with another actor within the network have been considered. Other actors, such as Novoren, formally part of the Symbiosis Institute but that does not contribute with a tangible exchange, have not been included in this analysis.

The level of commitment and relevance also varies among the actors of the network. The role played by different actors is examined more closely when referring to the core-periphery structure of the network in section 5.3.4. In general terms, companies within the Kalundborg network have a high environmental and I+D profile and are medium to large size.

5.3.3 Transactional Content

As has been noted before, in the IS network of Kalundborg, it is possible to distinguish between four types of transactions: i) exchange of material waste flows; ii) exchange and cascading of water; iii) cascading of energy and iv) exchange of knowledge. While the first three types of content denote a tangible component, the exchange of knowledge refers to an intangible exchange of know-how, potentially leading to innovation. Different matrixes have been elaborated to individually study the different content exchanges. A general matrix has also been generated that encapsulates all the different flows of the network.

5.3.3.1 Kalundborg IS Network: Matrixes

The matrix shown in Table 5.10 corresponds to the general structure of the Kalundborg IS network and therefore considers all the exchange flows taking place among the actors of the network, independently of their transactional content (exchanges of information and knowledge have not been considered in this matrix, as emphasis on the material exchanges is generally stressed on IS; these type of flows would be analysed separately). It is a binary matrix, where 1 denotes the existence of an exchange flow between a given pair of actors and 0 the absence of link.

Table 5.10: Kalundborg IS network matrix

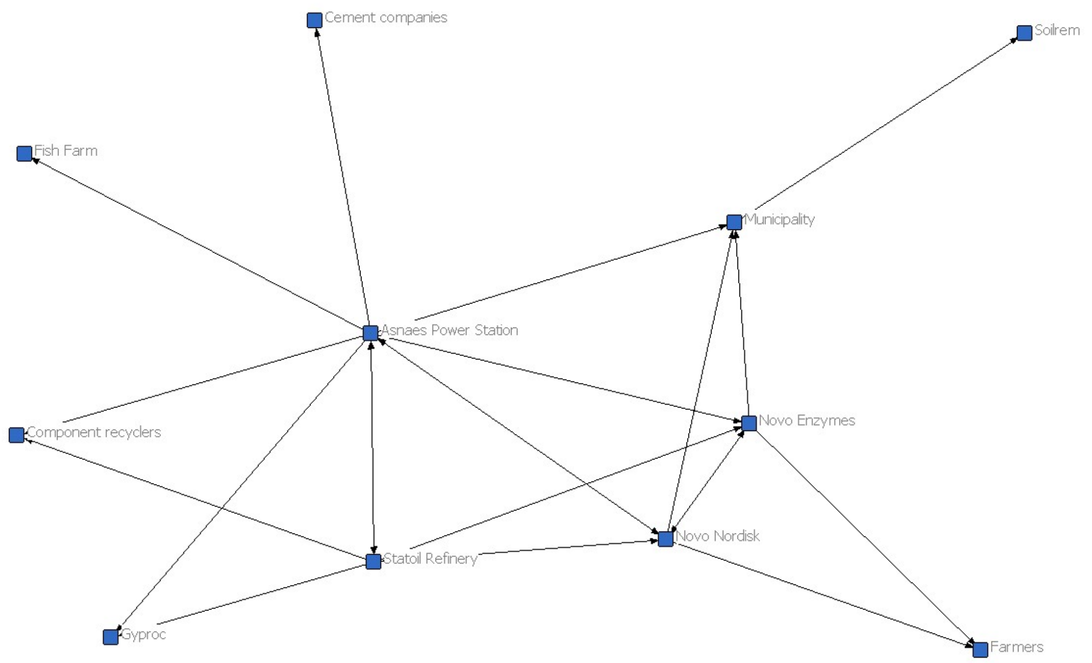
	Novo Nordi	Novozymes	Asnaes Pow	Statoil refin	Gyproc	Soilrem	Municipalit	Farmers	Fish farm	Cement con	Component
Novo Nordisk		1	1	1	0	0	1	1	0	0	0
Novo Enzymes	1		0	0	0	0	1	1	0	0	0
Asnaes Power Station	1	1		1	1	0	1	0	1	1	1
Statoil Refinery	1	1	1		1	0	0	0	0	0	1
Gyproc	0	0	0	0		0	0	0	0	0	0
Soilrem	0	0	0	0	0		0	0	0	0	0
Municipality	0	0	0	0	0	1		0	0	0	0
Farmers	0	0	0	0	0	0	0		0	0	0
Fish Farm	0	0	0	0	0	0	0	0		0	0
Cement companies	0	0	0	0	0	0	0	0	0		0
Component recyclers	0	0	0	0	0	0	0	0	0	0	

The matrixes created specifically for the different transactional exchanges are included in Appendix B.

5.3.3.2 Kalundborg IS Network: Graph

Fig. 5.3 shows the graphical representation of the network. It is a directed graph, as the linkages in the network are not necessarily reciprocal, and hence it is made up by directed arches, that indicate the direction of the link. The graph, as a representation of the structure of the network, already sheds some light upon its properties, offering some approximation to the idea of centrality and density. Including knowledge exchanges would result in a denser network, as can be appreciate in complementary graphs included in Appendix B.

Figure 5.3: Graphical representation of the Kalundborg IS network



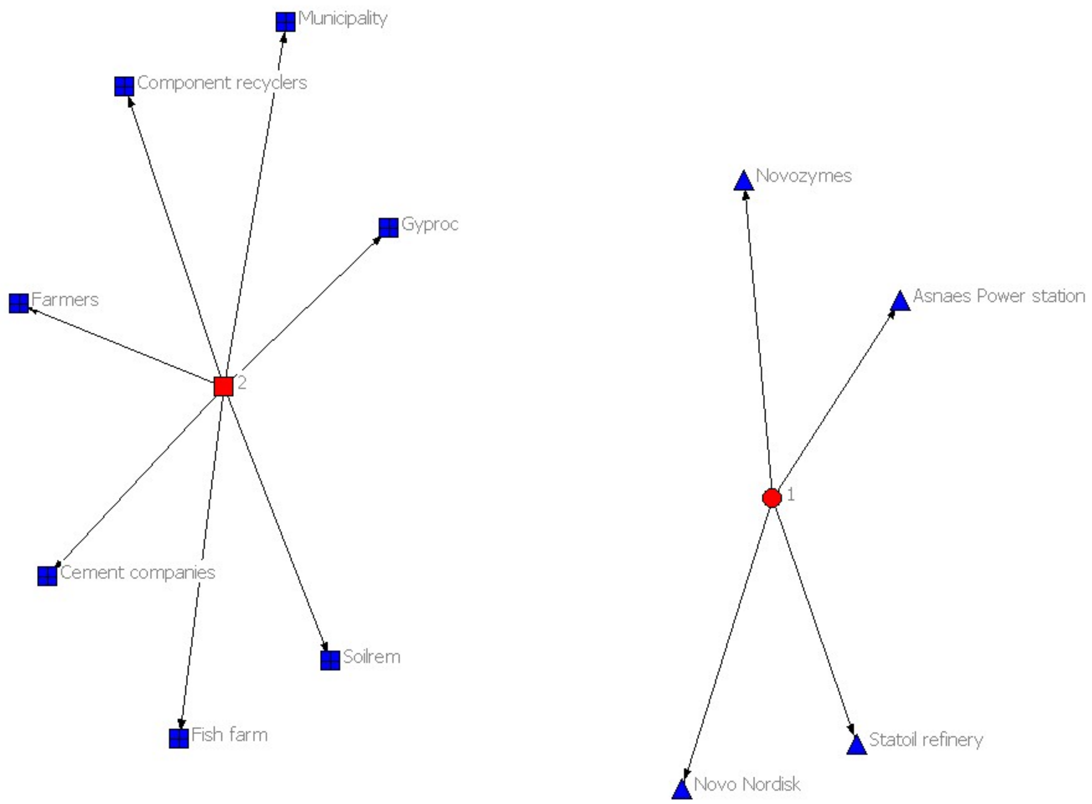
5.3.4 *Core-periphery and Size of the Network*

As already mentioned, Kalundborg is a small network, made up by six main nodes and a number of secondary nodes, that act as recipients of some of the IS exchanges generated in the network. The network size is a critical element in determining the structure of the network. In smaller networks, such as the one study here, actors are more likely to be connected. The size, thus, has an impact in aspects such as density and connectivity.

The analysis of the core periphery structure of the network defines two types of memberships (class 1 and 2). Class 1 denotes actors at the core of the network, while class 2 includes nodes in the periphery (see Appendix B for the output of the core-periphery analysis). In the network in Kalundborg the distribution of actors among class 1 and 2 is shown below and graphically represented in Figure 5.4:

1) Novo Nordisk Novozymes Asnaes Power station Statoil refinery
2) Gyproc Soilrem municipality farmers fish farm cement companies component recyclers

Figure 5.4: Core-periphery structure of the Kalundborg IS network



Similar results are obtained when calculating the coreness values for each node performing a k-core partitioning. The k-core decomposition consists of the recursively removal of all the nodes of degree smaller than k, so that actors with larger values of coreness remain. These are associated with larger degree and more centrally positioned nodes. According to this measure, the core of the IS network would be composed by all the nodes identified above as class 1 plus the municipality. On the other hand, Soilrem, the fish farm and cement companies present lower coreness values.

The calculation of the core/periphery structure is based on mathematical algorithms, which distinguish between the more densely connected actors and those with less dense connections. Nodes on the core share a number of characteristics that may explain this higher density of connections: i) they have frequent formal and informal communication; ii) they were the first members of the network and therefore have a longer history of interaction and cooperation, which has contributed to the development of formal and informal protocols of communication and created emotional linkages among the actors; iii) cooperation over the years has contributed to high levels of reciprocity and trust and iv) in many cases, companies are linked by more than one exchange flow on a continuous basis. On the other hand, some common elements that characterise nodes in the periphery are: i) there is less frequent communication among peripheral nodes and with the core; ii) the exchange of information is generally only attached to concrete projects or exchanges; iii) in many cases peripheral actors act just as recipients of waste flows, and their relations are mainly regulated by market mechanisms leaving no room for embedded relations to develop. A more detailed account of this will be given in section 5.4.3, when qualitatively analysing the characteristics of the network.

Appendix B contains the core-periphery structure for the different transactional contents of the Kalundborg IS network. Only significant changes can be appreciated when considering the exchange of information and knowledge. In this case, the core is more populated, being composed by the actors that formally belong to the institutionalised network. This can be explained by the fact that the Symbiosis Institute has contributed to the formalisation of the exchange of information and knowledge among the actors, increasing the density of the connections.

5.3.4.1 Local Bridges

Due to the small size of the network, local bridges could be relevant for the connection to other potential networks through peripheral actors, increasing the opportunities for creation of new linkages. However, in this case, local bridges have not been identified. This may actually compromise the ability of the network to connect to other nodes and thus may limit its opportunities of exogenous innovation.

5.3.4.2 Structural Equivalence

The analysis of structural equivalence provides a mathematical foundation for identification of the position played by different actors in a network. Structural equivalence refers to the degree to which two nodes have overlapping neighbours, and therefore, may be redundant with regard to adjacency and distance (Bogartti, 2006). Here the measure of structural equivalence is calculated as Euclidean distance (Wasserman and Faust, 2007). The larger the Euclidean distance between two actors, the less structural equivalent the nodes are. Since the content of the transactions in the IS network of Kalundborg varies and they are not mutually interchangeable, the study of structural equivalence needs to be specific to the different types of transactional contents. Annex B contains the structural equivalence matrixes for each of the transaction contents considered. Each entry in the matrixes measures the structural equivalence between a pair of nodes.

For all the content networks, Asnaes and Statoil show lower structural equivalence to the other nodes and, therefore, their disconnection would impose a higher risk for the network. Only in the case of the water-related network, the position of Asnaes and the refinery could be considered structurally equivalent with regard to the IS network, being redundant in adjacency and distance, as they are connected to the same pairs of nodes for the same transactional content[5]. In the case of Kalundborg it is difficult to evaluate the consequences of the disconnection of individual nodes, but it seems clear that the position of the power station in the network is crucial for the operation of the whole network and the consequences and risks associated with a potential disconnection should not be overlooked. Analysis of the measures of centrality, addressed in the next sections, also contributes to the identification of the key players within the network.

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[5] It should be understood that this analysis only considers the role of the actors with regards to the IS network, and therefore the analysis of structural equivalence aims at understanding the position different actors play in this network. Hence, two nodes being structurally equivalent in this analysis refers to their ability to perform a similar role in the IS network, connecting similar pairs of nodes. In the case of IS networks, this requires not only to be able to connect the same pair of nodes but also to generate meaningful material and energy flows for those pairs. Therefore, the analysis has to specifically refer to similar transactional contents. In this context, the results of the structural equivalence analysis need to be evaluated cautiously.

5.3.4.3 Cliques

A clique is a subset of nodes, all of which are adjacent to each other. Hence, cliques are cohesive sub-groups of nodes. It should also be noted that it is possible for a node to belong to more than one clique. In the case of the IS network of Kalundborg five cliques were found:

1) Novo Nordisk, Novozymes, Asnaes power station, Statoil refinery
2) Asnaes power station, Statoil refinery Gyproc
3) Asnaes power station, Statoil refinery, component recyclers
4) Novo Nordisk, Novozymes, Asnaes power station, municipality
5) Novo Nordisk, Novozymes farmers

Asnaes power station belongs to 4 of the 5 cliques, while the refinery belongs to 3 of them. The position played by these two actors in the network also explains its relevance in the composition of the cliques. Most of the cliques are composed by core actors. This points to a high degree of cohesion at the core of the network. Looking to the composition of the cliques, it is possible to link the cliques to specific transactional contents. The first clique seems to be directly related to the cascading of energy and exchange of steam, while the second and third are related to material by-product exchanges. The fourth clique is closely linked to water projects and the fifth one to the fertiliser provision to the farmers by Novo industries.

5.3.5 Structural Characteristics of the Network

The main structural characteristics of the network have been analysed for the whole network and individually for the content-specific sub-networks. General results of the analysis are summarised in the Table 5.11.

Table 5.11: Structural characteristics of the network

	Whole network		Materials network		Water network		Energy network		Knowledge network	
Number of ties	22		9		14		6		44	
Density	0.2		0.0818		0.1556		0.0667		0.4889	
Network centralisation	57.78%		18.89%		33.33%		52.78%		33.33%	
Average geodistance	1.585		1.000		1.125		1.143		1.214	
Distance-based cohesion "compactness"	0.279		0.082		0.167		0.072		0.556	
Distance-weighted fragmentation "breath"	0.721		0.918		0.833		0.928		0.444	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Degree centrality	3.273	2.178	1.455	0.782	1.600	1.685	1.200	1.400	4.600	2.615
Betweenness centrality	2.182	3.0778	0.000	0.000	0.200	0.400	0.100	0.300	1.200	2.400
Closeness centrality										
IN	13.407	0.889	9.871	0.713	12.312	2.376	10.788	0.733	23.955	4.737
OUT	29.515	27.922	9.933	1.113	12.606	3.193	11.544	4.273	34.974	16.374

\Source: author generated.

Some key characteristics of the morphology of the network can be derived from the data above. Three different measures of centrality have been used here: degree centrality, betweenness and closeness, as they capture different dimensions of the position of an actor in a network. Degree centrality measures the number of direct links a node has. This measure assumes that the more direct connections a node has, the stronger is its position in the network. Betweenness centrality, on the other hand, measures the ability of a node to pass on information and connect nodes. Therefore, according to this indicator, the identification of key actors will depend on their influence on gaining or cutting access to other nodes in the network. Finally, closeness looks to the distances between nodes in a network. Shorter distances to other nodes result in a higher score in closeness. In general terms, Kalundborg IS network shows a high degree of centralization, which indicates the relevance of central nodes in its operation, as most of the exchanges (or ties) take place among centrally located actors. Also, and partly as a consequence of the level of centralisation and the small size of the network, the average geo-distance, that is the length of the shortest path connecting two nodes, is rather low (1.585), which indicates that the average path between any two nodes in the network is approximately 1,5 nodes. This facilitates exchanges and reduces the transactions costs associated with them. The level of centralisation when comparing the different content network is higher in the case of energy. This seems to point to the relevant role played by the power station in this network, as most of the exchanges are generated by this node. This also increases the risk of fragmentation for this content network. In the case of the material network, however, although the level of centralisation is low, the risk of fragmentation is high, as most of the nodes are just linked to the network by single ties, and therefore, the disconnection of a node, may cause the partition of the network. For example, the disconnection of the refinery would also generate the disconnection of the component recyclers as this is their single tie to the network.

Although the mean and standard deviation values for the network, as included in Table 5.11, offer some guidance on the general characteristics of the network, more relevant insights require the analysis of these measures for each of the network nodes, as shown in Table 5.12, allowing a better understanding of the role played by the different actors in the network.

Table 5.12: Centrality measure scores by actors.

CENTRALITY	Degree	Betweenness	Closeness	
NODES			IN	OUT
Asnaes power station	8.000	8.667	12.346	83.333
Novozymes	5.000	1.667	12.500	47.619
Novo Nordisk	5.000	7.667	12.500	66.667
Statoil refinery	5.000	2.000	12.346	62.500
Municipality	4.000	4.000	14.085	10.000
Component recyclers	2.000	0.000	13.699	9.091
Gyproc	2.000	0.000	13.699	9.091
Farmers	2.000	0.000	13.889	9.091
Fish Farm	1.000	0.000	13.514	9.091
Cement companies	1.000	0.000	13.514	9.091
Soilrem	1.000	0.000	15.385	9.091

\Source: author generated

The results above come to confirm the key role of the power station in the Kalundborg IS. It is not only the actor with the highest number of direct ties but also the one that plays the most important role of brokerage in the network. Also Novo Nordisk proves to be a key actor in the network, especially in its brokerage role, facilitating the connectedness of the network, and therefore its cohesion. In general, as was expected, actors at the core of the network have higher centrality scores. Annex B includes the results from the centrality measures for the different content networks.

5.3.6 Main Findings from the Network Analysis

The network analysis pointed to some distinctive features of the Kalundborg network, which may be shaping the way it operates and develops. Some main findings of the Social Network Analysis are summarised here:

1) The network has a clearly differentiated core and periphery. The core is dense and well articulated, favouring interaction between the members. This morphology favours the rapid dissemination of ideas and information over the network and therefore, offers the basis for the identification of new IS opportunities among member companies. The periphery, however, is not well structured. Linkages among members located at the periphery have not been found and they do not seem to play a role as local bridges, connecting the network to other networks or potential members. When considering the knowledge and information flows into the general matrix, the core is more populated and well articulated, as it can also be appreciated in the matrix that represents the whole network including the transfer of knowledge and information (included in Appendix B). The coordination role of the Symbiosis Institute, has helped to institutionalise the exchange of knowledge and information, however, as most of the projects already developed before the institute was created, informal exchange structures seem to have played a more relevant role in this case.

2) Due to the small size of the network, the path distance is very small, which has contributed to a) reduce the transaction costs associated with the exchanges b) favour the building of trust and commitment among members by strengthening social interaction.

3) In many cases, the linkages are not restricted to a single transactional content but to a combination of them. Companies at the core generally exchange more than one flow within the network. The multiplexity of the linkages contributes to increase the density of the network and favours the building of stronger relationships, which may also contribute to explain the innovation capacity of the network.

4) Analysis of the centrality measures points to three key players of the networks: the power station, the refinery and Novo industries. Asnaes achieves the highest scores in all measures of centrality. These actors, especially the power station, are important not only for the number of direct connections they hold with other members of the network, but also for its capacity to connect other nodes, and therefore, to ensure the cohesion of the network. Hence, the disconnection of any of these nodes will cause an important disturbance to the operation of the network, which could lead to defragmentation. However, analysis of the evolution of the network over the years has shown a strong resilience and capacity of adaptation to the changes operated in the wider economic and regulatory context as well as in the business practices. Both flexibility and capacity of adaptation are connected in this case with the existence of a well developed knowledge network.

5.4 The Construction of the IS Network: Social Mechanisms of Building Cooperation

Analysis of the structure of the network and its morphology has been complemented with a further study of conditions that contributed to the emergence and development of the network, the process and mechanisms for the creation of embeddedness and the discursive dimension of the network. For the analysis of these components, in-depth interviews and informal communications to key players in the network have been used as a main source of data. ATLAS.ti has supported the qualitative analysis of the data.

5.4.1 Exchange Conditions and Social Mechanisms of Control

Following the methodology presented in Chapter 4, the exchange conditions that may have favoured in the first instance the emergence of the network in Kalundborg and social mechanisms that have created the basis for its development are examined.

5.4.1.1 Exchange Conditions

A number of contextual elements have provided a favourable ground for the emergence of the IS network in Kalundborg. These contextual factors refer both to the broader institutional framework where the companies are embedded as well as the physical context and micro dynamics of businesses practices. All these factors interact with each other providing the basis for articulation of the network. Contextual and institutional factors have been identified by interviewees as drivers in the IS development in Kalundborg. A closer look at these elements may help to explain the process of emergence of the IS network.

5.4.1.2 Shortage of Raw Materials

A key factor in the initiation of the network was the shortage of water in the region. The concentration of a number of large industries with high requirement for fresh water for their productive processes increased the pressure on the availability of water and forced the companies to look for alternative ways of sourcing water for industrial purposes. In this scenario the first cooperative, project took form, as explains a former manager and champion of the IS network:

> *"The first project was when the refinery (….) had to use cooling water in big amount and of course the normal water supply was insufficient for that so they try to find another solution and they thought of untreated water, raw surface water, and they found that in the lake Tisso and they decided to run a pipeline. This pipeline would be around 13 km, I think, so it was a big piece of work, and cost a lot of money, the municipality, who had the monopoly of making this water supply could not have afforded that, but the refinery agreed to lend the money to them, so they financed it by lending the money to the municipality, and the municipality paid-back in water, excellent. That was the first one, and you can say that has nothing to do with symbiosis. Now, if you looked at it in isolation that was only an ordinary project you cannot called symbiosis…it is as if you at the piano strike one note, you cannot call it harmony, but if you strike one note and at the same time strike two other notes, then you will find the harmony,…, so therefore in retrospective it could be considered the first project"*

The refinery reached an agreement with the municipality to source its water from lake Tisso. A pipeline, funded by the company, was lined up. The shortage of water as a shared common problem founded the basis for the cooperation among industrial actors. These first projects generated a positive experience of interaction.

5.4.1.3 Ad-hoc Solutions

The solution to a common problem for industries, in this case, the scarcity of water in the area, required the construction of a network of pipelines between different industrial facilities. This solution represented a breakthrough in the normal business practices for two main reasons: a) it proposed the utilisation of an alternative source of water supply, surface water, to be used as a supplement to the ground water provided by the municipality; b) it involved the negotiation between a number of different industrial actors and the municipality; The infrastructural network extended later to include the steam pipelines. This infrastructure bound the companies together not only in physical terms but also created a common ground for interaction and favoured the processes of communication and "*working across the fence*". These solutions, independently of the technical issues, involve an intensive process of social innovation, by coordinating a number of separate industrial actors in a collective project.

5.4.1.4 A stringent Regulatory Framework

The regulatory framework also seems to play a relevant role in the emergence of the network. By regulatory framework is meant the set of norms, laws and regulations that define the parameters of industrial organisations as well as the web of institutions and agents that dictate and enforce these norms. Although the first projects associated with the IS network are not strictly directly derived from the enforcement of new norms or regulations, they do show a connection with water regulation in Denmark, that imposes high standards for the quality of the water supply. Notwithstanding this, it is in the late 1970s and beginning of the 1980s when the limitations to emissions and discharges imposed by law have a direct influence on the exchange projects within the network, as the manager of one of the main companies involved in the IS network explains when reflecting on the drivers of the network formation:

> *"If you look at some of the projects, during the eighties especially they came up as solutions on strengthening of environmental regulations for each company. For example, we had to build or clean our waste water or do it better that we did and we had to build a new waste water plant and instead of building a very big one we looked at the waste water we sent to the waste water treatment and saw that there was some cooling water which was quite clean as we got it from the lake Tisso and we tried to look how can we use it better than send it through our waste water treatment and then the solution came sending it to Asnaes where they could use it for producing steam and such a project came up because we had to do something with the waste water but you have never seen some regulations that told the companies to do so and so, you always have to develop a solution yourselves and when it was a good idea to work with other companies that was done and when we could solve the problem by itself in a best way we did it so…"*

Framing regulation and industrial practices, the priorities set up by the industrial, energy and environmental policy strategies, have had a clear influence on the evolution of the projects developed in the IS network. Whereas in the 1970s there was an emphasis on cogeneration, the priorities in the 1980s and 1990s were set on pollution control and environmental management, as the quotes below from a member company representative seems to point to:

> *"yes, there are a lot of national energy policies, so as the ones you see in Kalundborg, so to speak, like co-generation for example, steam,... several national targets were set up in the late 1970s, at that time the power plant was owned by the government, at the national level or by the municipalities...to promote co-generation. There was a policy goal that each power plant had to respond to it in some ways between politics and industrial symbiosis so to speak...but there were improvements, improvement targets in the company that they are not oblige to do but if implemented they could go beyond regulation..."*

> *"(in the nineties) we got some new regulations companies had to fulfil and we use some ideas in the symbiosis to make better solutions. We were told to clean our waste water and for the authorities it would have been ok to build a bigger waste water treatment plant but from the business perspective this idea (the exchange and recycle of water between different industries) was a better idea.."*

The regulatory context is also characterised by a flexible and collaborative approach for the implementation and enforceability of regulation and policy by social agents, based on a dialogue and negotiation. The application of the regulatory limits and requirements was discussed between the environmental agency and the actors. Due to the size and complexity of the activities located in the area, competency in the approval of permits and control of activities was not held by the municipality, but by the regional government, and its environmental agency. In the interviews, the companies allude to collaboration between authorities and industrial actors and the relative absence of conflicts regarding regulatory issues and compliance. This collaborative environment was favoured by negotiation of regulatory and policy targets and the flexible approach adopted in the implementation by authorities. Unlike other examples of IS networks that face regulatory barriers to, for example, the exchange of hazardous waste streams, in Kalundborg the industrial actors do not seem to recognise important regulatory barriers for the realisation of the exchanges. Only a case of disagreement regarding the taxation of energy exchanges was mentioned in one of the interviews as a relevant conflict with the environmental agency, that prevented further waste energy streams to take place. This distinctive relationship between regulatory bodies and industrial actors is well illustrated in the following quote:

> *"the collaboration with the authorities has been very good and I think still would be.. because they see the interest (of the companies) in doing the right solution"*

5.4.1.5 Other Important Exchange Conditions

Some other factors that have been perceived by the main actors in the IS network to have played a relevant role for the emergence and development of the symbiosis are the following:

1) There was a compatible mix of industries, belonging to different but complementary sectors;
2) There were no direct competitors among the companies located in the area, and therefore there was not a significant reticence to the exchange of information on the company processes or waste streams;
3) High volumes of waste streams and by-products were available;
4) Companies were located near each other, reducing transportation costs;
5) Most company managers already knew each other and interacted in different social networks, not only in the professional area, but also on a more personal level.

Some of these aspects are analysed in more detail in Section 5.4.3, as they play a significant role in the process of creation of embeddedness.

5.4.2 Social Mechanisms of Control

Whereas the exchange conditions examined above may have favoured the emergence of the network, its successful operation relies on the progressive development of certain social mechanisms of control that promote a collaborative attitude among the companies governed by trust and commitment. These mechanisms refer to the way in which tacit rules and norms that define "acceptable" behaviour are adopted by social actors, connecting with the discursive realm of the symbiosis that will be examined in more detail in section 5.5.

5.4.2.1 Macroculture of Cooperation

In parallel with the development of the first IS exchanges, a culture of cooperation has been forged among the companies located in the area, authorities and local community. This refers to the progressive integration of cooperative principles in the modus operandi, practices and decision-making of the different actors. This cultural ethos seems to be grounded on the wider institutional framework, where collaborative rather than conflictive solutions are favoured. Thus, cooperation has entered the range of solutions that are accepted as valid by the industrial actors, permeating the core of the business strategy and connecting with issues of corporate responsibility and social legitimisation. The legitimisation of cooperative approaches is well reflected in the following quote:

> *"so every time you establish new projects you would look at the possibility of IS, to see if a symbiosis solution is the best"*

A number of elements have contributed to the progressive building of the culture of cooperation, such as:

- The existence of a strong sense of community and belonging among companies and company managers, favoured by the fact that most of the company managers do live in the area;
- There are personal relationships reinforcing professional linkages. Managers and staff are connected by several professional and personal bounds, discouraging uncooperative/ conflictive solutions;
- Past experiences of cooperation have returned positive outcomes in business and personal terms;
- There are shared common interests and the companies in the area face common problems, all of which contributes to the strengthening of their shared vision.

5.4.2.2 Collective Sanctions and Reputation

Together with the development of the macroculture of cooperation, collective sanctions and reputation constitute mechanisms of control that discourage defective solutions. Most of the elements mentioned above also contribute to the development of a system of collective sanctions and reputation. Actors are connected to each other by different professional and personal networks, so that behaviour in one network would affect its position in other networks. Managers are acquainted with each other and they live and participate in the local community, therefore uncooperative behaviour would not only affect professional but also personal spheres. Reputation transcends the limits of the business to integrate as well the social sphere of the main actors. Business actors, thus, are held responsible for the local community where they live and work, as the quote that follows seems to suggest:

> *"the managers are acquainted, we knew each other, you know, in a small place like this we know each other not only in one way, we know each other in a number of ways, I had my children in the same class as one of the children of the manager of Statoil, I saw the man from power station in another context, we were in the same lodge club, (....) actually we meet most of us, not all, but most of the managers were members of the club and we met every Monday. I had the chance to meet the other ones, and I knew them personally on first name and I had no problem in saying, by the way I thought the other day...Have you ever thought..could we... and he said, yeah, come over tomorrow we can have a talk about it..."*

Moreover, environmental behaviour is seen as an essential part of the corporate responsibility of the organisation. The fact that the companies located in Kalundborg belong to sectors of activity such as energy, chemicals or construction, traditionally subjected to extensive public scrutiny, has favoured significant efforts by companies to provide information and improve their environmental performance. In fact, most of the companies are required by the regulation to publicise their green accounts. All these elements play an essential role in defining the "licence to operate" of the companies in the area. In this context, IS solutions are not only optimal, eco-efficient solutions but also a key aspect in strengthening the environmental compromise and reputation of the companies on-site.

5.4.3 The Process of Creation of Embeddedness

The concept of Embeddedness in IS networks refers to the automated and integrated tacit rules of operation and communication between network members, based on trust and cooperation. In embedded networks actions are not solely oriented by price and economic gains but by a more heuristic approach, that combines social, cultural, environmental and economic elements. In the case of Kalundborg, the actors involved in the network seem to be conscious of these dimensions when examining the decision-making process to identify "optimal" solutions. A manager of one of the companies located in the area expressed it in the following terms:

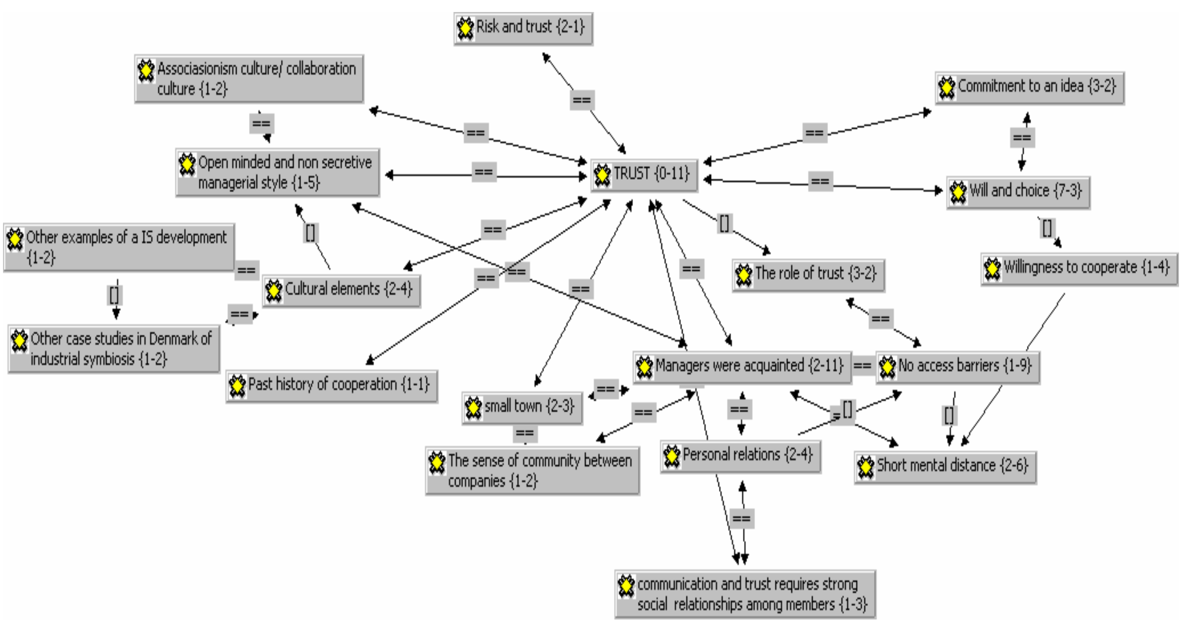
> *"It´s from business point of view and that can be both economical and environmental...each solution in the symbiosis is made as single solution not looking at the big symbiosis network but looking at the single opportunity when you face a problem or see an opportunity... and then the solution you ...normally you have more solutions to choose from but you take that solution that fits best in your business both is ...economy is a big factor in that choice but also environmental...quite a few comes in....so, it depends a little, that is, it is a combination of many factors...but you can say that you try to do the best solution for the business in each case.."*

As argued before, embedded relations are governed by trust, exchange of fine-grained information and joint-problem solving. Other factors considered relevant in the process of embeddedness are global reciprocity and the existence of a shared vision and goal.

5.4.3.1 Trust

Trust has played an essential role in the emergence and development of the IS network in Kalundborg. Main essential factors in the development of trust identified in this case are: the role of experience, past history and common background and the cooperative culture in place. Conceptual map (Figure 5.5), as built from the qualitative analysis, graphically represents the relations between main elements influencing trust building in Kalundborg.

Figure 5.5: Conceptual map: Main factors influencing trust building



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5.4.3.2 The Role of Experience, Past History and Common Background

The process of creating trust requires time and relies heavily on the pre-existence of personal relationships among company managers and staff, as noted in the following quote:

> *"...but again a network is something a bit close to people having big confidence to each other so I don't think you can spread it very wide out because then you would lose the idea with the network..."*

Trust thus seems to be related to past history, shared experience and common background. The existence of a positive past experience of cooperation reduces the resistance to cooperation and strengthens the personal and professional linkages between the companies. This generates trust not only among the participants but also about the same process of cooperation, which turns into an effective a way to solve problems, as the following seems to suggest:

> *"...at each plant at Asnaes, at Novo, at Statoil,...there have been people close to the mindset of working in that way and in some periods there have been management that they might not have thought to go in that direction but then they could be helped by the history and watching prior cases which show that it was possible and it was a good solution."*

The generation of trust seems also to be related in this case to the characteristics of the wider institutional framework and, more concretely, with the culture of cooperation mentioned above. As was pointed out by one of the managers interviewed, the managerial style and business environment in Denmark is fairly open, favouring the process of trust generation and cooperation. Moreover, Denmark, and Nordic countries in general, have experience in by-product exchange and recovery of waste heat and energy, practices widely integrated into the industrial processes.

> *"In our country, in Scandinavian countries, we have a tradition of rather open minded management style, we are not very secretive, actually when we analyse it of course all companies have some kind of know-how which they would not like to get out, but if you really go down and actually analyse that, I have been working in industry for many years, 40 years, and I have been faced with this problem many times, because in all places we always had many cases, and some cases we would hesitate to take it into the plan, but I*

would hesitate that there would be hundred cases we can take in, probably not...a few persons in the world that would just need to look and know, but that's very few normally and most often the know-how you want to protect is not visible it is not easy to see"

5.4.3.3 Role of Trust

Trust influences the operation of the network and favours IS exchanges in multiple and re-enforcing ways.

Trust grants access to other companies and eases the way for negotiation, reducing significantly the costs of transaction associated to the projects, as the following quote notes:

> *"...they are not shy, the managers are acquainted, we knew each other, (...) I had the chance to meet the other ones, and I knew them personally on first name and I had no problem in saying, by the way i thought the other day...Have you ever thought..could we... and he said, yeah, come over tomorrow we can have a talk about it...no access barriers to exchanging our thoughts and I think sometimes those first barriers are the most difficult"*

The role of trust is especially relevant in the adoption of more challenging projects, which require technical and technological development, and a more intensive cooperation. Indeed, trust was a requisite for the undertaking of determinate projects and at the same time cooperation on those projects, contributed to the strength of trust among the parts, in a retro-feeding process.

> *"I always remember the steam project, which started before I came but that I had the pleasure of taking the rope, the four partners, and when you sit down with four partners..., the power station, the refinery, Novo and the municipality and you have to work together and engineer it, and you have to do something not for yourself, because I was involved only in some committee meetings, to follow up how the project was, but we had some engineers that had to sit down and try to find out practical solutions and make suggestions on how the contract had to be and that took long time, it took three years to complete that. But then we found out that we learned a lot about each other, so we knew each others demands, competences, etc...so it was very easy upwards to say if we have been able to successfully develop that project why don't we continue with some other projects, and that is actually what happened, so therefore I think that this project was very good improvement of the communication"*

As important as the question of trust and closely related to it, is the will to cooperate. IS solutions are seen by IS network members as the result of a choice and the will of the companies to go further in their environmental commitment. The creation of trust requires time and effort, and therefore, its emergence is related to the will of the companies to cooperate. In this sense, IS can be interpreted as a business choice that connects to the core principles of an organisation. In the following quote a manager of one of the key companies in Kalundborg comments on the factors driving IS projects:

> *"Economy is one of them but people and mind is much important to…how do you think and how do you act, are they willing to use some time to collaborate with their neighbour and especially if you have a problem try to see how the problem is solved it might not be a big advantage to yourself but it was an advantage for you too…so I think in one of those sheets that describe it as mental distance between people has to be very short and I think that is an important thing...also geographical location of course because much of that here you talk might every meter in fact cost you money and increase you have to pay"*

5.4.3.4 Exchange of Fine-grained Information and Tacit Knowledge

As noted previously, another element that characterises embedded networks is the transfer of tacit knowledge and detailed information, and the way it has been integrated into the praxis of cooperation. This knowledge, which is difficult to codify and is closely linked to the context of the interaction, provides the basis of the cooperation by deepening cooperation opportunities. Tacit knowledge mainly generates through close and frequent communication.

As emphasised in the interviews, communication has played a key role in the development of the industrial symbiosis in Kalundborg. Communication implies the absence of access barriers, the openness and trust in the exchange of information and collective creation of knowledge by interaction. Indeed, the crucial role played by communication is captured in the following quote:

> *"The critical path is the communication. If you have all the good potential project ideas you have if nobody talks, you would have no projects, that is the common denominator, if there is no communication, no projects even if there were good ideas, so good projects, so much money to dig in that's it.."*

A number of factors contributed in Kalundborg to build up communication such as the fact that the managers were acquainted, companies concentrated in a relatively small area and the connection of managers with the local community. Also the fact that there were no direct competitors among the member companies provided, together with the prevalence of a managerial style that is not secretive or closed, the suitable ground for communication to happen and tacit knowledge to emerge. In the following quote a manager of a company member of the IS network explains why the existence of a basic knowledge of neighbouring companies and frequent communication are key in favouring the development of IS projects:

> *"I think as a start is a little bit important to know what is going on in other companies otherwise you would never get the idea that they could help you doing the solution otherwise you would go with the wrong solution and waste their time too many times before you find the right one so next time they won't give you time so you have to know each other but it should be possible when you are located close to each other…but somebody must see the driver in starting making communication"*

5.4.3.5 Institutionalised Mechanisms of Exchange of Information

Awareness of the importance of communication in the operation of the network led to the creation of forums of discussion and periodical meetings of the network members. This had its precedent in the "environmental club", an initiative led by the municipality to favour the discussion among companies in the area about environmental issues. As the symbiosis evolved and Kalundborg became a world-known example of symbiotic cooperation, the companies decided to create the industrial symbiosis institute, as a forum for the exchange of information and communication between companies, and the publicising of Kalundborg experience, through organisation of visits for foreign visitors interested in the network and other related events.

5.4.3.6 Subtle Mechanisms of Exchange of Information

However, at least as important as the formalised mechanisms and channels of exchange of information, are the subtle and not formalised information flows, favoured by the close personal relationship among company members' managers. Moreover, cooperation on some projects forced the companies to implicitly develop dynamics of cooperation and communication protocols that ease the process of negotiation and cooperation, and helped in the identification of new projects and ideas, as stated in the following quote:

> *"...where you have close connection in developing one project and could bring new ideas."*

5.4.3.7 Joint Problem Solving

The other main component of embedded relations is the development of mechanisms of joint problem solving, which are of particular relevance in the case of Kalundborg. As mentioned before, emergence of the network is linked to a common problem, the scarcity of water. The integration of joint problem solving in the business practices of the companies in the area gives an idea of the high degree of embeddedness achieved by the network. The quote that follows shows the internalisation of cooperation and joint problem solving in the dynamics of the network:

> *"if you are facing a problem in your own company and you have this (cooperation) in mind then you can take the phone, make a call…_we are struggling with this kind of things, how have you solved that? because we know you had exactly this same problem_"*

5.4.4 Conclusions: Embeddedness, Institutional Thickness and Untraded Dependencies

Over the last decades Kalundborg has evolved as an embedded industrial symbiosis network. The development of embedded relations has allowed the progressive undertaking of more challenging cooperation projects and the integration of collaboration into the companies' know-how. Joint problem solving, trust and tacit knowledge are all mechanisms in place in Kalundborg that contribute to the achievement of the economic and environmental benefits of industrial symbiosis. The IS network has become a generator of "untraded dependencies" (Storper, 1995), contributing to collective learning and the enhancement of tacit knowledge, adding value to the location and the business processes connected through the network. Although, the network is limited to environmental issues, other infrastructural cooperative projects have arisen from it, expanding the business impact of the IS network.

The degree of embeddedness achieved by the network has also contributed to reinforce cooperation in a context characterised by institutional thickness (Amin and Thrift, 1995). Although the scope of the network is mainly local, a number of formal and informal institutions have been constituted to support the operation of the network. Institutional thickness refers not only to formal bodies, such as research institutes, clubs, trade associations or in this case, the industrial symbiosis centre, but also refers to the sense of common purpose and vision shared by the companies, the informal commitment that links companies together and the practices of communication and interaction between industrial actors, regulators and the community, that implicitly and/or explicitly includes IS and cooperation. In fact, as already mentioned, the network has become a key element in the building of legitimacy of the industrial companies and has favoured their integration into the community.

5.5 Discursive Dimension of IS: Kalundborg IS Network

Elements of a discursive nature and how this dimension interacts with the material and social conditions of the IS network has already been included in the analysis undertaken in previous sections. This section summarises some of the key features of the predominant discursive structure of the IS network in Kalundborg and clarifies the connection between social, material and discursive dimensions. Crucial discursive elements relate with the ontological construction of the network and the internalised values and principles that shape the process of decision-making. The next sections analyse these aspects by looking at the process of construction of the storyline of the network, the elements that shape economic calculus and decision-making and the progressive integration of environmental principles at the core of the business strategy.

5.5.1 Creation of the Story: The "Story of the Story"

The discursive dimension of the industrial symbiosis refers to normative elements that hold together the network, defining the tacit rules, knowledge structures and norms of operation. These elements contribute to shape the perception of the benefits and costs of IS and have an impact on the process of creation of values and decision-making. Indeed, the creation of the network as an entity has been the result of a long and complex social process, which has "constructed" initially separated, individual or bilateral projects to form a coherent unit of meaning, the IS network, which comprises a variety of different projects carried out by different actors.

Understanding the storyline behind the network is essential in examining the discursive structures prevalent in the network, main conceptions and assumed relations. As stressed in the interviews, the construction of the IS network in Kalundborg started as a collection of individual, bilateral or multilateral projects that aimed at overcoming the resource limitations, in this case scarcity of water in the region, and increase the productive capacity of the area. The environmental character of the initiative was only retrospectively constructed, as is remarked in the following quote:

> *"The symbiotic consciousness spread since we started seeing all these things not as separate projects any longer, we saw that there was some kind of common denominator behind that and this common denominator we found it interesting and enjoyed as we could see that we have cooperated well and now we could see to form some kind of entity and the principle that was behind it, which we didn't think of at the beginning"*

The creation of the "storyline", inherent in any process of social cognition, contributes to strengthening of the linkages between companies as it provides: a) a sense of common background, b) a shared vision and purpose and c) a latent commitment to the values and beliefs that support the network.

> *"it started more or less like conventional business among the companies there is water shortage in the region and that enforced a number of the companies to look for ways of saving some water in order to expand production and that enforced facilitated collaboration and that way and gradually other projects, such as recirculation of water, developed"*

It is not by chance, that construction of the environmental ethos of the network took place in the late eighties, linked to the concerns raised by the concept of sustainable development. As is explained in the following quote, the ties that connected different projects and constructed them as a unified project, the IS network, first emerged as part of a school project but, it unexpectedly attracted so much attention that it rapidly took over as reference case study.

> *"We have what I call the story of the story, when you consider how has this became known. This is also quite a fascinating story. The school, the high school here actually ...*

and there was in the period when the Brundtland report was issued and the school here decided they would make a theme out of that, so they devoted a week where pupils of the school were to do some kind of project on the Brundtland report and it ended up with some kind of plenary session and I remember they were split up into 53 groups, that work with different aspects, and one of these groups decided to talk about the cooperation among the industries, and they ended up doing a cardboard model, showing the different industries and with pieces of colour string between them showing the collaborative ties, and finally they had the plenary and they invited some of us from the different industries to tell about this and comment about that and the press was also invited, the local press was also there they took a picture of the cardboard model and that was on the front page the next day and the national papers also looked into that and brought it and then some months later I had the Financial Times here"

The rapid relevance acquired by Kalundborg points to the existence of a latent need to find new models of operation of industrial systems that overcome the traditional conflict between natural and industrial systems, compatible with the strategy of sustainable development. Even though the industrial base of Kalundborg is far from being sustainable, from a strictly environmental point of view, it provides an attainable path of regeneration of industrial systems in moving towards scenarios that minimise requirements of resources and energy of industry. Kalundborg, in this context, provides an excellent example of the opportunities offered by cooperation.

As the story has been elaborated and re-elaborated on multiple occasions and it has also been documented, it has become highly normalised and standardised, with little divergence among actors. This became clear during the interviews that presented a very similar narrative of the process of the formation of the network.

5.5.2 Economic Calculus: Model of Decision-Making

As mentioned before, the construction of the storyline helped to unify the vision of the network among actors. The underlying storyline is also connected to the decision-making process and the way economic and environmental benefits are perceived and accounted for. In fact, the heuristic character of the economic calculus has been recognised by the companies themselves, as the following quote from a manager of a member company illustrates:

"...so we have to talk about a different kind of economics when we talk about industrial symbiosis, the society in general, the rules and behaviours and how is the environmental problem regarded (as good or as bad), how important is acting in an environmental manner, because the pay-back from industrial symbiosis may not come from using the waste product, it might come from savings in reducing the use of some raw materials,..but it may also pull the company in the direction of being an environmentally friendly company, (and that) depending what kind of market you are working in may be important..."

As the previous quote stresses, there are more subtle benefits of IS projects, that go beyond the direct economic savings generated. Indeed, the calculation of the benefits and costs of IS projects are shaped by the institutional framework the companies operate in. Although direct savings and benefits of IS projects can be easily calculated, capturing these other more subtle elements such as the legitimisation of the company in the community or changes in its environmental profile, is a much more complex process, as remarked in the quote that follows:

"But it was difficult to see what was the saving because savings would be in comparison to alternatives and I think we decided (when calculating the benefits), that we would compare it to the most likely alternative if we'd not make the symbiosis...but we had sometimes more than one alternative and that's a difficult calculation, which, when you look back ten years, you might conclude differently to what we concluded at that time, but (calculations were made) at the best of our knowledge"

The economic calculus is, thus, a pragmatic exercise dependent on the circumstances of the moment and factors such as the energetic policy and the prices of energy, regulatory requirements, restricted access to resources or the internal priorities of the company. Therefore, the outcomes of the network are determined not only by a narrow benefit and cost analysis but by a wider framework that considers future changes in legislation, and other aspects such as reputation and social responsibility. In the process of decision-making, optimal solutions are considered the best business alternative and this includes economic, environmental and social elements, as the quote below remarks:

"it is very important to be honest, open, transparent, about what we are doing,...one initiative in our environmental strategy is to use by-products from other companies. Being part of the symbiosis park is just a little part of the environmental management and there

are some economic gains also in there,...but we were talking about the CSR, credibility as well. This is difficult to account"

As mentioned above, the process of calculation of economic and environmental benefits lies either latently or explicitly at the core of the decision-making process. IS projects are also subjected to the values, premises and priorities inherent in the process of decision making. Decisions always imply the prioritisation of alternatives including the status quo. The complexity of this process relates to the fact that different alternatives may have divergent impacts in different areas. For example, it is possible that one project generates fewer economic savings but has a more positive impact on the social or environmental area. In Kalundborg, the degree of internalisation of the dynamics of the networks has led to the automatic integration of the IS alternative in the process of decision making. In this process, projects are not evaluated from a narrow economic perspective, but from a broader approach that considers not only its economic benefits, but also its environmental impact and social repercussion. When faced with a problem, collaboration and cooperation are considered as another option, as the quote that follows clearly illustrates:

"and also important to make projects happen is the fact that people feel comfortable going to discuss things with other companies, you need to show your employees that it is ok to use (time) at there (other company facilities), that as well as you discuss it inside the fence, you can also try to go across the fence"

5.5.3 Integration of IS at the Core of Corporative Principles: Environment and CSR

As already noted, the industrial symbiosis network has also evolved as a legitimising element of the industrial system in Kalundborg. Companies have progressively embraced IS projects as a way to not only solve resource limitations and constraints but also to demonstrate their active commitment to environmental protection. In fact, as was remarked when analysing the profile of the companies engaged in the network, environmental commitment has become a core element in the companies' business strategy, being IS an important part of it.

"I think that all those companies and Novo in special and Statoil in special have promoted their environmental profile. We have to take the environmental principle into our decisions. And it has helped us to think in that way, I think. But still it has to be a

combination between the way you solve the problem in a good environmental way and the economy and the perspective of the solution"

In fact, although the IS network did not start as an environmental initiative, its aims and purpose has been reformulated to encompass environmental protection as the essential and distinctive element of all IS projects, combining it with the pragmatic restriction of economic feasibility. Therefore, IS projects do necessarily need to consider environmental and economic issues and offer better results in both areas than alternative projects, as the quote that follows emphasises:

> *"the principles are "someone waste is another one raw material" is one of the basic idea and we think, that for us to have a project, it is necessary that it is environmental and economic profitable, both. If it was not economical the companies would not invest in it. If it were not environmentally profitable we could make it for other reasons but then it is not symbiosis"*

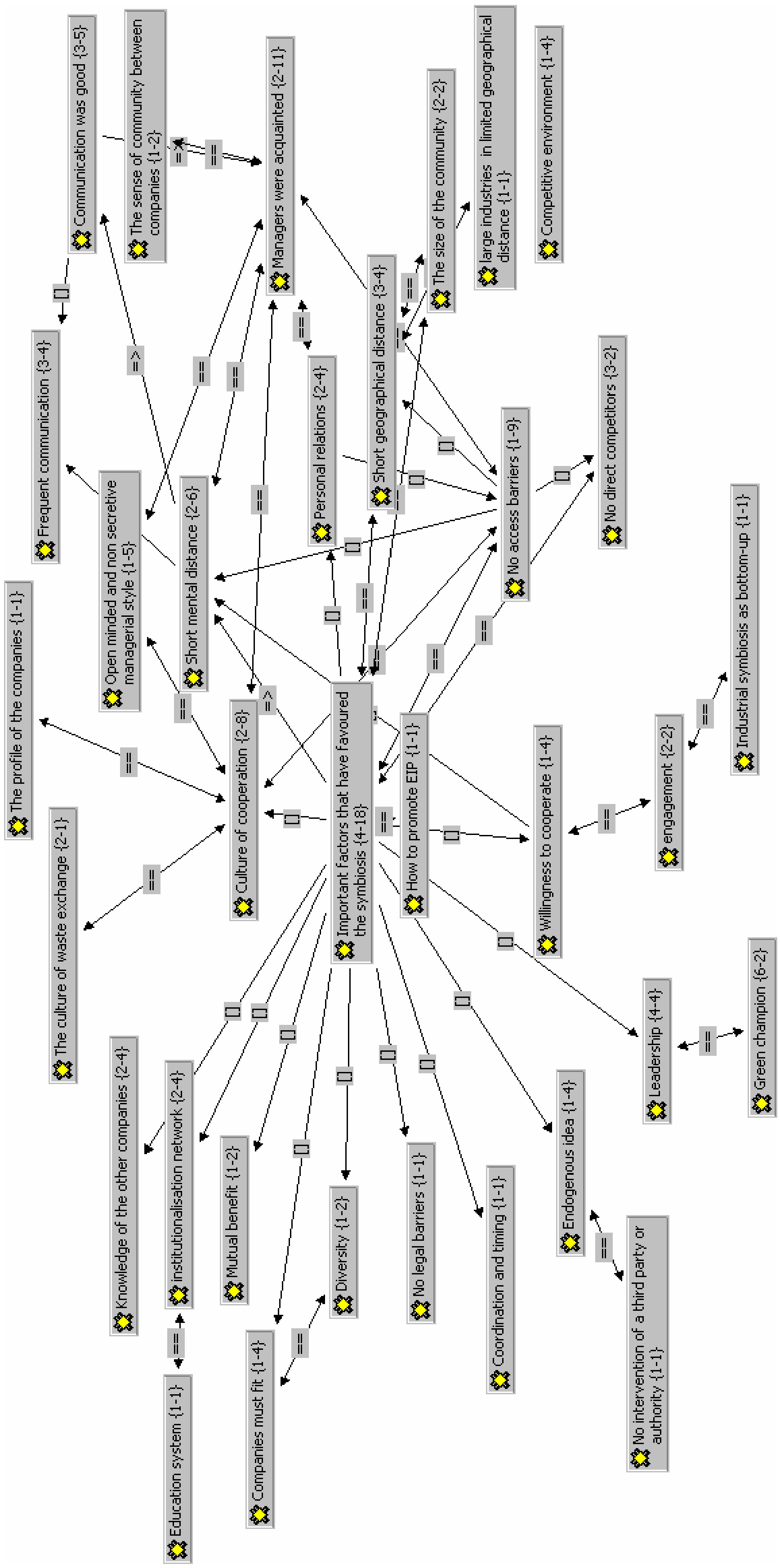
In some cases however, priority has been given to the environmental aspect over the economic when the investment or project were considered essential for the maintenance of the "license to operate". This term encompasses a multiplicity of factors, of an environmental, social and economic nature, that contributes to the social acceptance of the company and its integration in the community, necessary for the successful development of the productive activity. Therefore, the concept of "license to operate" is connected to the corporate social responsibility of the company, which widens the core principles of business in the market economy. As a responsible social actor the company thus assumes the compromises and commitments derived from the accepted values and agreed norms of behaviour. Environmentally responsible behaviour is integrated with other company core principles; the following quote points to how IS projects connect to responsibility in the decision-making process:

> *"the experience is driven by companies and in that sense it needs to be profitable but also it states the will of the managers to do things right"*

5.6 Conclusions: Factors of Success and Challenges

This chapter has examined the main structural, social and discursive elements that characterise the IS network in Kalundborg. The successful cooperation in Kalundborg has been the result of an adaptive process that has developed over four decades. The analysis has tried to identify the distinctive traits that have made Kalundborg possible by looking at the material, social and discursive dimensions of the IS process. These dimensions are difficult to isolate and moreover, rather than its individual components it is the interaction between dimensions that is behind the successful operation of the network in the Kalundborg system. The graph below illustrates some of the complex connections between the different factors that have been identified as contributing to the development of the IS network in Kalundborg:

Figure 5.6: Conceptual map: key drivers



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A number of factors such as the

concentration in a small area of big companies generating a wide variety of products and by-products, the existence of no direct competitors, no significant legal or regulatory barriers and the existence of a short mental distance, favoured by intense personal and professional ties between managers, are all crucial elements in the development of the network. Other factors such an institutional framework where collaboration is praised and promoted, the existence of leadership and community engagement and the coincidence in the time of investment priorities and resources have also played an important role in the IS network.

From the policy making point of view a key question relates to the possibility of replicating these factors in non-spontaneous networks. Some elements such as a favouring of an adequate institutional framework or the removal of regulatory barriers are aspects that can easily be addressed by policy makers. However, other elements such as personal engagement, commitment and leadership are more difficult to replicate or artificially foster. As in this case, these elements require a long-term perspective and active participation, aspects often relegated in the policy agenda.

Notwithstanding the complexity and degree of development achieved by the IS network in Kalundborg, it has not always been a straightforward process. There are also challenges and difficulties that this network also faces. The main challenges have been elaborated in the conceptual map shown below (Figure 5.7):

Figure 5.7: Conceptual map: main challenges

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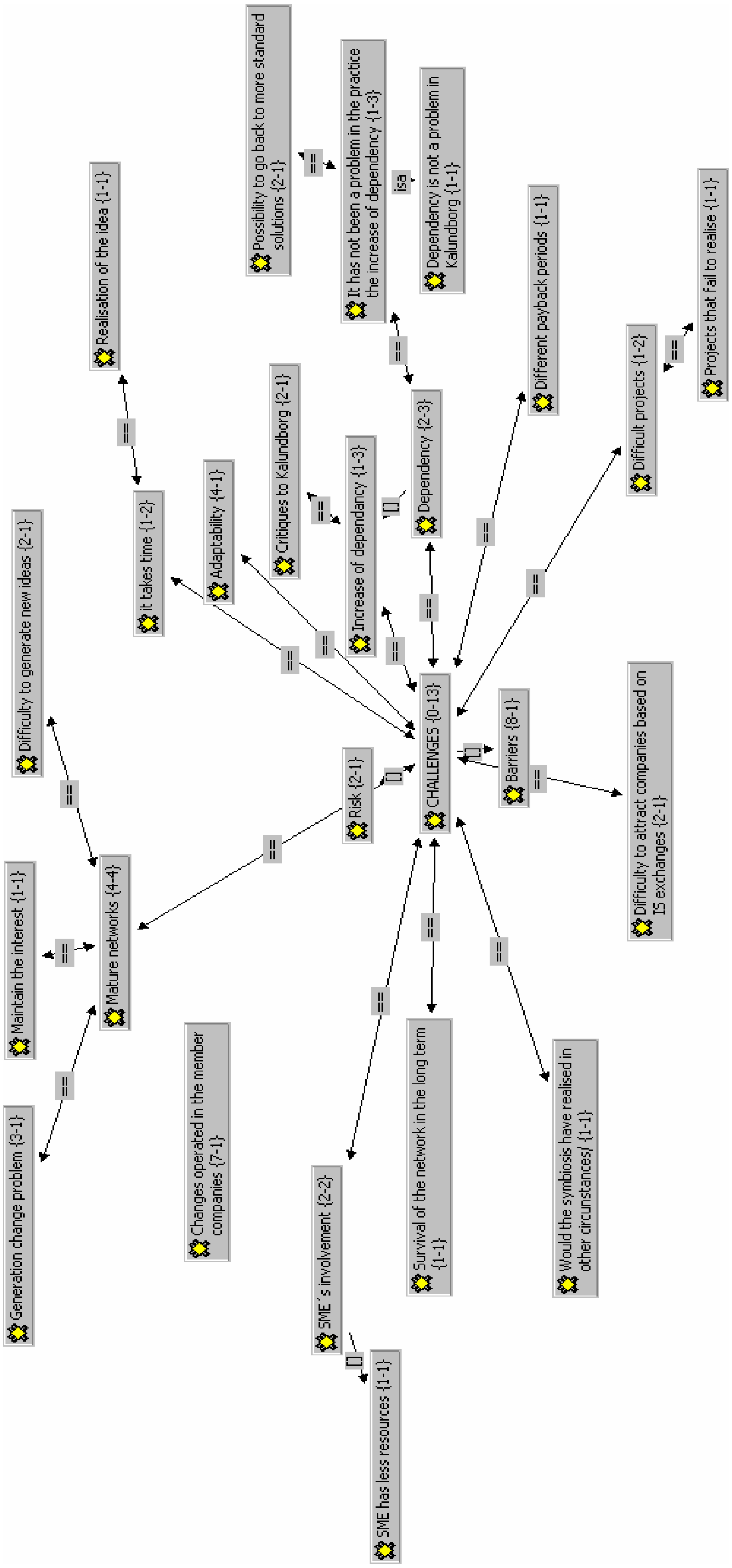
\Source: author generated



As shown in the
conceptual map, the
main challenges
are related to the
difficulties in maintaining
interest and engagement
and in generating
new ideas in mature
networks, the risk of lock-
ins posed by
dependencies and the
impact on personal
relations of generational
change. Although,
dependencies can be
considered a challenge, it
is important to note that
they do not pose an
important risk to the
industrial sector in
Kalundborg as IS
exchanges do not affect
the core productive
activity of any
company; alternatives
in provision of resources
and disposal of by-
products and waste can be
found. The degree of

institutionalisation of the network also reduces the impact of the generational change as routines and dynamics are highly normalised. More challenging is the limitation of mature networks in generating new ideas and maintaining interest over long periods. This requires active engagement and strong leadership to strengthen the connection and generate interest and interaction.

Chapter 6.
The Industrial Area of Sagunto

Sagunto is a coastal town near Valencia (Spain) with an important commercial harbour and a well-established industrial sector, which combines a diversity of activities such as steel and metal transformation, cement production, chemicals and car manufacturing suppliers. Due to the concentration of industries and the complementarities of resources between them, the area has developed along the years a number of IS exchanges, especially among companies in the metal cluster. Notwithstanding this, the full potential of IS is far from being achieved. As a kernel of IS, this case offers invaluable insights into the process of emergence and development of IS ties and the elements that may hinder them. The aim of this chapter is precisely exploring social and discursive elements that may be an obstacle for the development of more complex forms of cooperation, even under favourable material conditions. The analytical framework developed in Chapter 4 is applied to this case in order to shed some light upon the social processes and discourse structures that may prevent further developments of the IS kernel.

6.1 Introduction

6.1.1 Selection of the Case Study

As has been argued in Chapter 3, Sagunto has been selected as a deviant case study as its development and progress clearly deviate from the norm of IS networks and the model set by Kalundborg. Some characteristics of the case study are especially interesting from a research perspective:

1) The case could be considered an example of an "unveiled" IS kernel, where although IS exchanges are taking place among key players, they are not fully aware of their potential in terms of environmental and economic benefits and other opportunities of cooperation are not fully explored;
2) General improvement in the environmental management of the companies has mostly been led by an individual approach that discourages rather than promotes IS exchanges. This has also in some case been enforced by restrictions imposed by the regulatory framework on waste management. All this, together with other elements

that characterise the industrial development of the area, seem to point to a process of "de-learning" collaborative networking;

3) Although from the combination of activities, materials and by-products generated and infrastructural characteristics, the area has potential for the development of a diversity of IS linkages; these are either not taking place or they not fully exploited. Therefore, the case study offers an opportunity for analysing the obstacles preventing IS exchanges from happening.

6.1.2 Scope and Sample

The municipality of Sagunto has traditionally been an area, with an economic structure where the industrial sector predominated, with an important element of steel and metal sectors. Although the relative weight of the industrial sector has declined since the late 1970s, the industry has still a significant direct contribution, both in terms of output and jobs generated, and supports a whole range of industrial services. As shown in the map on Figure 6.1, there are several relevant industrial estates that concentrate along the coast, near to the transportation nodes and the harbour. In this research, the focus is the industrial areas situated along the coast, near the former blast furnace factory and surrounding areas, as they concentrate the most important industrial companies both in terms of economic output and potential environmental impact. These companies also concentrate most of all IS and collaborative linkages in the region. It is important to note that the strategic position of the industrial area, next to the harbour and the rail network, has been a key element in attracting and retaining companies on site. However, its location next to the coast also poses risks for the fragile coastal ecosystems and a protected wet area, included in the ZEPA Directive for the protection of wild birds, called "Marjal dels Moros", situated next to the metal complex.

Figure 6.1: Aerial Map of Sagunto

\Source: Google Maps

Regarding the sampling procedure and the definition of the boundaries of the network, the criteria for the selection of companies to be analysed has been the following: 1) the companies selected are those whose activity, location and processes have or could potentially have IS linkages with other companies; 2) they are relevant in the area in terms of income and employment and 3) the potential environmental impact of the company is significant, and, in most of the cases, subjected to the IPPC (Integrated Pollution Prevention and Control) Directive.

6.1.3 Data Sources and Methodology

The main data sources for the evaluation and analysis of the case study have been the following: 1) site-visits and face-to-face in-depth interviews with the environmental managers or CEO of the most relevant companies in the area (according to the criteria previously mentioned); 2) analysis of the environmental regulatory framework that affects industrial activities in the area and examination of secondary documents from the companies, both internal, collected in the interviews, and external, such as communication documents and publicly available information; 3) Review of the available data on levels of emissions, volume of discharges and waste generation for the different companies located in the area of the companies subjected to the IPPC regulation.

The application of the methodological framework has been adapted to the particular characteristics of the case study. Main phases of the analysis have been structured in the following way: 1) analysis of key actors with potential for IS exchanges; 2) identification of current but also potential dyads between actors, taking into account aspects such as transactional content , intensity, frequency and potential of further development; 3) analysis of the structure of the network (core-periphery, boundaries and local bridges) as well as exchange conditions that inhibit further implementation of IS exchanges and 4) identification of predominant discourses adopted by the key actors and evaluation of the interaction between the discourse dimension and the structural and material conditions of the network.

6.2 Description of the Network

6.2.1 The Municipality of Sagunto

Sagunto is a coastal town, with a population of around 60,577 [6]inhabitants, situated 30km north of Valencia (Spain). Its strategic location as a transport node between the regions of the centre of Spain and the coastal area, and its commercial harbour, contributed at the beginning of the 20th century to its industrialization process, determined by the location in the town of the mining company “Sierra Menera” and shortly after this, the construction of the blast furnace facility of “Compania Siderurgica del Mediterraneo” (later on called “Altos Hornos del Mediterraneo”) for the production of steel. The company, in the peak of its production in the 1970s, created over 6,000 jobs. This generated an important economic activity in the area and attracted other companies, such as suppliers and other service industries, connected with the metal sector. From the blast furnace, some satellite production units developed, specializing in different phases and processes of the metal transformation. The interconnected industrial system gave rise to a dense network of IS exchanges, in which the blast furnace played a crucial role. Metal scrap from the steel

[6] Year 2001, municipal census.

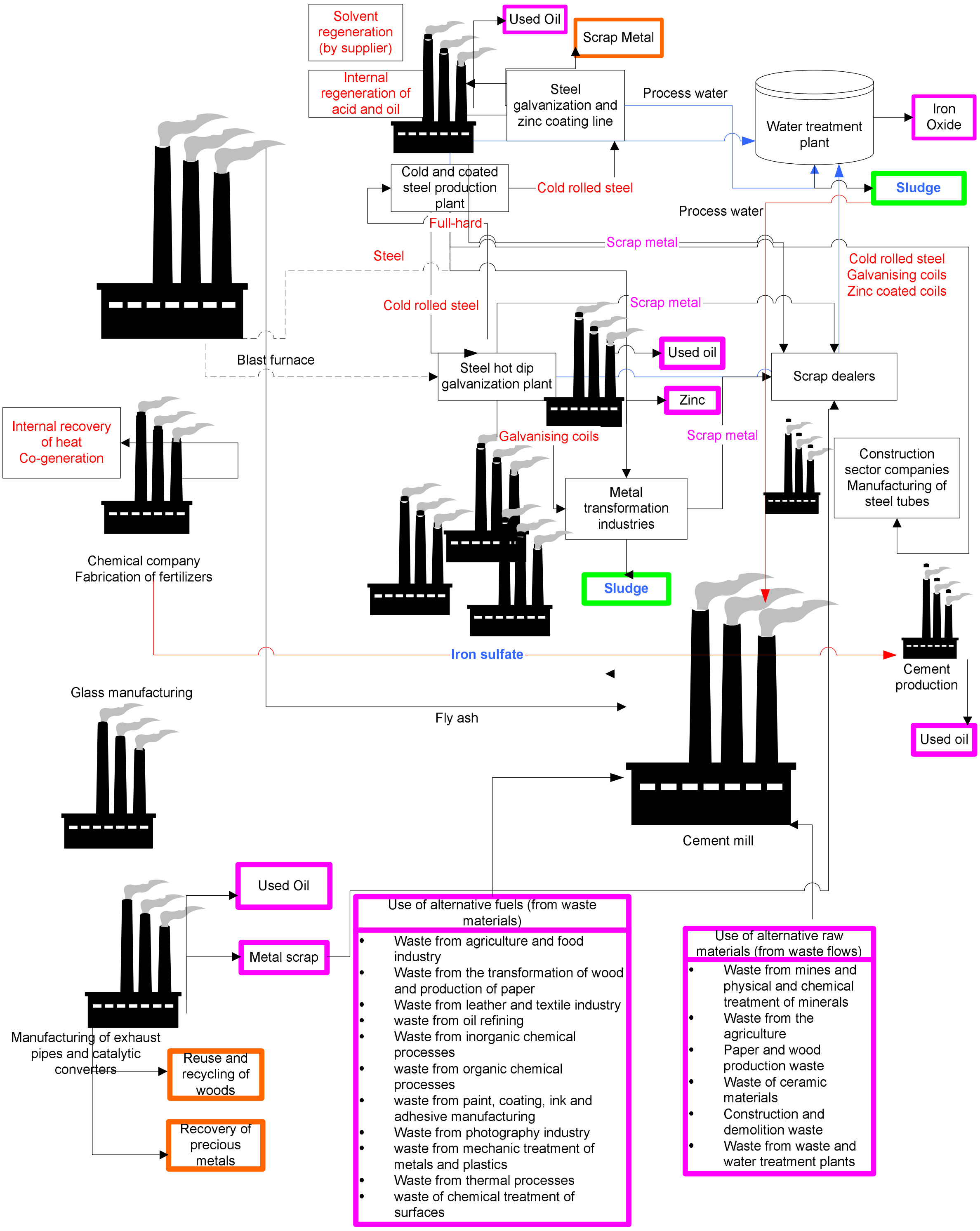
factory was sold and used as input by other companies located in the area. In the 1950s, a cement company located in the near proximity of the steel factory utilized the fly ash generated from the melting process as grinding material for the kiln. Other secondary IS ties developed along the years for the reuse of the metal by-products generated in the industrial complex.

At the beginning of the 1980s, the industrial restructuring process affected the steel industry in Spain and led to the closure of the blast furnace (nationalised since 1978) the core of the industrial activity of the area. To compensate for the reduction of the activity and employment generated by the reconversion process, Sagunto was designated as a "Prioritaire Industrial Location Zone". This status supported the restructuring process by providing economic incentives for the location of companies in the area, such as reduced cost loans, availability of land or facilities, or reduction in taxes. This brought in new investment and contributed to diversification of the industrial system by attracting other sectors of activity such as construction, chemical, glass or food and beverages. Although the blast furnace disappeared, some of its production units dealing with more technologically advanced processes were divided into three different privately owned companies and remained in the area. While all these measures contributed to the economic revitalization of the area, they also introduced changes in the organizational and productive system, which led to profound alterations of the flows that have characterised the by-product exchange network.

Since the mid-1990s, the toughening of the environmental regulation applied to the companies located in the area (some of them affected by the Integrated Pollution Prevention and Control Directive), the environmental requirements set by customers, especially from the car industry, and the demands from local and regional government contributed to a significant improvement of the environmental management of the companies onsite. However, the impact of the regulatory changes in the IS network has also discouraged some waste flow exchange opportunities, due to the constraints imposed regarding the exchange and transport of materials classified as waste. Notwithstanding this, waste and by-product exchange still play an important role in Sagunto. Main IS opportunities come from a) material flows of metal by-products and b) utility sharing (waste treatment plant). In the last years also other material reuse and recycling opportunities have been introduced in some of the companies, although the approach has been mostly individual rather than collective.

This will be examined in more detail in section 6.4.1, when analysing the exchange conditions that characterise the area. The diagram below shows some of the main IS exchanges in the area. Dashed lines refer to IS exchanges that have stopped since the disconnection of the blast furnace.

Figure 6.2: IS kernel of Sagunto



\Source: author generated

6.2.2 Characteristics of the Industrial Sector in Sagunto

As already mentioned, the industrial sector plays an important role in the economy of Sagunto, both in terms of generation of income and employment, contributing to about 24%[7] of the total employment. As shown in Table 6.1, the main industrial activities in order of importance are: metal and metal transformation that together with the sector of manufacturing of mechanical products represents over 50% of the industrial employment; car manufacturing industry and related activities (10%); chemical industry (5%) and food and beverage industries (7 %). Therefore, even though the industrial restructuring process helped to diversify the economic structure of the area, there is still a clear predominance of the metal and metal transforming sectors in the local economy.

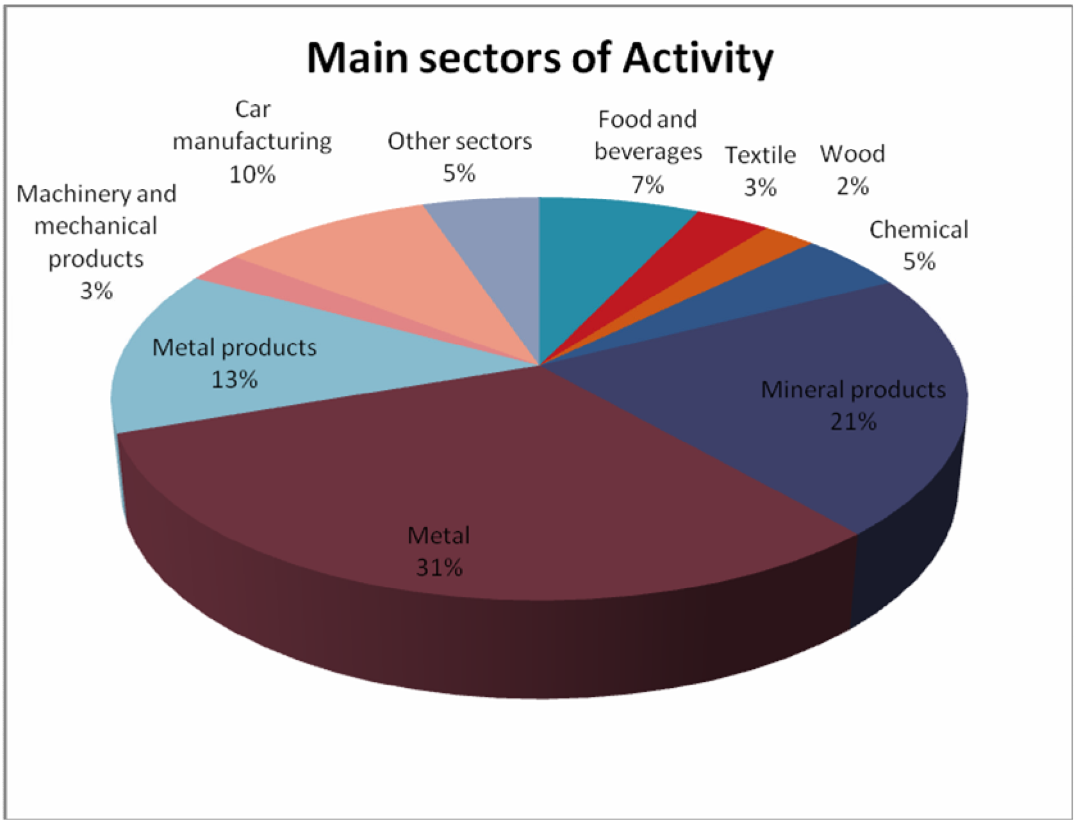
Table 6.1: Number of companies and jobs by sector of activity.

SECTOR OF ACTIVITY	NUMBER OF COMPANIES	NUMBER OF JOBS
Food and beverages	24	287
Textile	6	133
Wood	14	95
Chemical	11	190
Mineral products (cement)	15	847
Metal	4	1254
Metal transformation	32	534
Machinery and mechanical products	7	99
Car manufacturing	2	379
Other sectors	43	209

\Source: author generated based on statistical data (2002).

[7] According to the data of the Spanish National Insurance (Seguridad Social), year 2002. All statistical data included in this section refer to the base year 2002 and come from the same source.

Figure 6.3: Main sectors of activity in terms of job generation.



\Source: author generated based on statistical data (2002).

The companies sampled for the study belong to the most representative sectors of activity and generate most of the employment in the sector[8].

6.2.3 Main Industrial Impacts from the Industrial Area of Sagunto

Taking into account the industrial structure of the area, it is possible to identify the main environmental impacts derived from the industry per sector of activity, as summarised in Table 6.2.

[8] To comply with Data Protection procedures names of sampled companies will be omitted and referred to only by sector of activity and not individually.

Table 6.2: Environmental impacts of main sectors of activity

Sector of activity	Atmospheric emissions	Water effluents	Waste and soil contamination
Cement	NOx, CO2, Cr, Pb, CO and diffuse emissions of dust and particulate	Water mainly used for refrigeration. Potential pollution of cleaning and maintenance waters with oils and heavy metals.	Maintenance oils Polluted containers
Metal industry: Steel and iron	SO_2, NO_x, CO, Pb, As, Cr, Cu, Hg, Ni, Se, An, PCDDs/PCDFs, PCBs, metal dust, particulate matter	Acid and oily waters with organic matter and metals.	Sludge, used oils, Salts, scrap, exhausted acid
Glass	Pb, As, SO_2, CO, Ashes, hydrofluoric acid	Process water polluted with oils and heavy metals	Glass, used oils, silver
Chemical	NO_x, NO, particulate matter, Hydrochloric acid	Nitrates, phosphates	Used oils, organic matter

\Source: Author generated

Due to the characteristics of the area with a dense industrial estates network, its location near to the coastal line and the type of activities undertaken, problems of accumulative pollution and interacting/synergistic effects of polluting substances represent a risk in Sagunto. It is important to stress, however, that in the last decade there has been an increasing awareness of the potential environmental impacts and reduction and control measures have been introduced by the companies with the aim of reducing and/or controlling their main environmental aspects. The IPPC Directive has affected a relevant proportion of the companies in the area, especially in the sector of cement production and metal and metal transformation. The following table lists the companies subjected to IPPC regulation in the study-area.

Table 6.3: Description of main players

Company	Sector of activity	Activity	IPPC authorisation
Aceros Corrugados del Mediterráneo, SL	Metal transformation	Metal transformed products	Pending
ArcelorMittal Sagunto, SL	Steel	Cold rolling and metal coating, including galvanisation	Granted
Ingeniería y Proyectos Medioambientales, SA	Chemical	Regeneration of Clorhidricacid	Pending
Lafarge ASLAND, SA	Cement	Cement and clinker production	Granted
Combined Cycle Power Station/ Regasification Plant	Energy	Electricity production	Granted
Fertiberia Sagunto	Chemical	Production of nitrogenous fertilisers	Granted
Cemenval	Cement	Cement production	Pending
Thyssenkrupp Galmed, SA	Steel	Galvanised cold and hot rolled coils	Granted
Ferrodisa	Metal transformation	Metal transformed products	Pending

\Source: Author's elaboration based on Registry of Emissions and Pollutant Sources, Ministry of Environment, Rural and Sea Ecosystems and BOE.

6.2.4 Key Actors of the Network

As Sagunto does not constitute an institutionalised or formally structured network, a first phase in the research was the identification of the key actors and the definition of the boundaries. Identification of the players was done in two consecutive phases: in the sampling phase, main companies and sectors of activities with potential for the exchange of waste flows and materials were identified and, in a later phase, during the process of data collection, new dyads were identified based on the information collected in the interviews (through snowballing).

As mentioned before, the area is a traditional industrial area, with a history of steel production that goes back to the beginning of the 20th century. The process of industrial restructuring in the 1980s favoured the development of a more diversified and modernised industrial sector, but still retained a significant steel and metal cluster. The steel and metal cluster is composed of three main companies and a number of SMEs connected either as clients or providers of auxiliary services to the three main companies. At the core of the steel and metal cluster there is: 1) a cold rolling mill and electrogalvanising and hot-dip galvanising company, ArcelorMittal, which included the former SIDMED and SOLMED; 2) a steel hot-dip galvanising company, formerly called GALMED, recently acquired by the industrial group Thyssenkrupp, and 3) a metal transformation and cutting company, Ferrodisa, belonging to the industrial group Gonvarri. SIDMED, SOLMED and GALMED were formerly part of Altos Hornos del Mediterraneo, the integral cycle steel factory. The restructuring process led to the closure of the blast furnace, but the three more technologically developed production lines of cold rolling, lamination and surface treatment and coating were divided into three independently-run companies. Although the policy of acquisitions changed the denomination of the companies and merged SIDMED and SOLMED as a single company, the lines of production were maintained and the companies share the same plot of industrial land, of around 2,480,154 m^2. Other important companies in the cluster are: TUMESA, a manufacturer of steel tubes and pipelines; Hierros de Levante, specialising in the supply of laminated iron and steel products such as different flat products and pipes; Forflesa, supplier of a variety of flat steel materials and Thyssen Ros Casares, specialising in the longitudinal and transversal cut of steel rolled coils. The metal cluster provides around 2,500 jobs.

Another main cluster of companies is composed of the manufacturers of automobile components. Bossal and Pilkington are both suppliers to the automobile sector, producing exhaust systems and glass respectively. Together they contribute to the creation of around 400 jobs and occupy a surface of approximately 300,000 m^2.

The cement cluster is made up by three main units of production: Asland, an integral cement factory that produces clinker and cement; Cementval, a cement company that transforms clinker into cement and therefore is only involved in the last phase of cement production and Dragados, a construction company specialising in the provision of large-scale infrastructures. These companies together generate around 450 jobs.

Another important player in the industrial area is the chemical sector. The main company is Fertiberia, a manufacturer of nitrogenous fertilisers, which creates around 100 jobs. Other important companies in the sector are Air Liquide and Oxigeno de Sagunto, producing oxygen, mainly for the health sector.

Recently (2002) a regasification plant has been located in the area, attracted by the strategic position of Sagunto in relation to the LNG-producing countries in North Africa and the Persian Gulf. This plant is partly owned by UNION FENOSA Gas (42.5%), together with Oman Oil Holding Spain (7.5%) and “Infraestructuras de Gas”.

As a result of the industrial restructuring process, the R&D component of the companies, although mostly belonging to mature industrial sectors, experienced a qualitative shift. Since the beginning of the 2000s, the strengthening of environmental regulations together with the changes in the companies’ ownership structure and internal and external pressures, have fostered significant improvements in their environmental management. The table below has been elaborated based on the information gathered in site visits and secondary materials. It summarises some relevant characteristics of the key industrial players in the area, including an assessment of their environmental profile, according to a rating system proposed by the author, explained in Chapter 5.

Table 6.4: Mapping of main actors in Sagunto industrial area

Name	Sector	Environmental profile		R + D	IS streams		Attitude towards IS
		IPPC	ISO 14001		Potential	Realised	
ArcelorMittal	Metal	Yes	Yes	**	Sludge	Metal scrap Used oils	P+/-
Thyssenkrupp Galmed	Metal	yes	Yes	**	Acid recovery	Zinc recovery Oil recovery	P+/-
Ferrodisa	Metal transformation	Yes	Yes	*	Zinc recovery Acid recovery	Used oil	P +/-
Fertiberia	Chemical	Yes	Yes	**	Sludge	--	P +/-
Pilkington	Glass/ Automobile supplier	No	Yes	***	Not Identified	Glass Used Oils	P-
Bossal	Exhaust Fume Extractor/ Automobile supplier	No	Yes	***	Not identified	Used Oils Wood	P+
Cementval	Cement production	Yes	Yes	**	Aggregates	Used oils	
Asland	Integral cement production	Yes	Yes	**	--	Fly ash Paints and solvents Ceramic materials Biomass Sludge	A +

\Source: author's elaboration based on information provided in personal communications (interviews) and secondary materials.

6.2.5 History of Collaborative Projects

As already mentioned, the industrial system of Sagunto has undergone important changes during the last three decades. From an homogeneous metal cluster, the area has evolved into a much more diverse system that combines different sectors of activities and processes. This increase in the diversity of activities has in most not been accompanied with an increase of cooperation or by-product and waste exchanges. Moreover, changes in the composition of the industrial system have led to the disconnection of some of the existing linkages. Figure 6.2 showed in dashed red lines previous IS exchanges that have stopped as a consequence of the restructuring process. Different causes explain the disconnection of some of the IS projects: a) in some cases it has been due to the disconnection of one of the partners, such as the case of the closure of the blast furnace; b) in other cases, it has been the result of changes in the property structure of the company, such as the sale of different metal production units to different transnational companies; c) changes in the regulatory framework, imposing stricter conditions for companies to exchange waste streams with other industrial companies, have also discouraged, in some cases, the continuity of IS exchanges.

Notwithstanding this, new waste stream exchanges have also been adopted in some cases, such as the cement company, that has actively looked for further IS opportunities. Also straightforward IS opportunities have been identified in this study that are not being realised. The next sections explore the reasons behind this situation and the different positioning of companies towards cooperation and exchange of waste streams. The SNA provides a foundation for the understanding of the structural elements that define the kernel of Sagunto and the conditions that are determining the process of emergence and development of cooperative practices. Discursive elements are also considered in the analysis as a way to understand the structure of decision making and individual and collective behaviour of main actors.

6.2.6 Different Types of IS Projects

The IS kernel identified in the industrial area of Sagunto is made up of two main types of IS projects according to Chertow classification (2007): a) sharing of environmental infrastructures and services, and b) exchange of waste material and by-products. Table 6.5 summarises the main realised IS projects, indicating whether it is an internal (IS exchange occurs among co-located firms) or an external project (IS projects where one or more of the partners involved is not located in the area).

Table 6.5: Main IS projects

Exchange tie	Status	External/ Internal	Transaction type
Fly ash from steel blast furnace to Cement factory	Stopped	Internal	Sold
Acid recovery	Operative	Internal	Approximately 50% savings in cost of inputs

Iron oxide	Operative	External	Sold
Zinc recovery	Operative	External	Approximately 80% savings in cost of inputs
Scrap metal to blast furnace	Operative	External	Sold
Scrap metal to scrap dealers	Operative	External/ Internal	Sold
Oil recovery and reuse	Operative	External	Sold
Full hard steel to galvanising unit	Operative	Internal	Sold
Solvent recovery	Operative	External	Saving in cost of inputs
Wood pallets reuse	Operative	External	Free (within company group factories)
Sharing of waste water treatment plant	Operative	Internal	Sold
Sharing of access infrastructures (to reduce atmospheric emissions of particulate)	Operative	Internal	Free
Use of sawdust as fuel for cement production	Operative	External	Sold (cement factory pays)
Use of coal fly ash for cement production	Operative	External	Sold (cement factory pays)
Use of pain residues and solvents in cement production	Operative	External	Sold (external partner pays cement factory)
Animal meal as fuel for cement production	Operative	External	Sold (external partner pays cement factory)
Glass	Operative	External	Sold

\Source: Author generated

6.3 Social Network Analysis

Although according to Chertow (2007) it could be argued that Sagunto complies with the heuristic criteria to differentiate IS networks from other types of waste exchange, the fact that in most of these cases the exchanges have a bilateral rather than multilateral character, and the involvement of external recyclers to transform or recover some of the material streams, point more to a kernel of IS that to a fully developed network. It is also important to note that most of these exchanges occur among metal industries, a sector with a long history of IS ties partly connected to the intrinsic high value of its by-products.

The structural characteristics of the waste exchange relations in the industrial area of Sagunto have been analysed following the protocol proposed in Chapter 4. Analysis of the data has been supported by UCINET (SNA software). This analysis explores the structure of cooperative relationships in the area and the opportunities for development of a fully operative IS networks as well as the potential barriers to increase the complexity and density of the incipient IS network.

6.3.1 Assumptions

The analysis includes main industrial actors in the area as well as other small-sized companies that reuse or recycle some of the by-products generated by the industrial system in Sagunto. However, smaller companies have not been listed as individual actors in the network, but grouped by activity. This can be justified by the fact that their number, volume of production and geographical dispersion, its individual role in the system cannot be compared with that of the main industrial activities. Their inclusion as individual nodes would have introduced distortions in the calculations leading to an overestimation of IS development/potential.

External recycling companies have been grouped as a node and included in the analysis when they are involved in waste exchange ties that imply recovery of waste materials to be reintroduced in the industrial process and/or include the valorisation of waste and by-products for the same or different industrial processes.

The generic node external companies refers to other industrial activities not locate onsite that directly use one or more by-products or waste as an input in their transformation processes or provide waste or by-products to be used as raw materials and/or fuels by any of the industrial companies onsite.

6.3.2 Mapping of Actors

Composition of the industrial system in Sagunto and its main players has already been discussed in section 6.2.4. For the reasons aforementioned, smaller scale actors have been grouped by activity and considered as a single actor for the calculation of the structural measures of the network. The role of external recyclers has also been considered as an IS exchange when they are engaged in the recovery of specific waste flows that can be re-introduced in the system, generally by the companies onsite.

6.3.3 Transactional Content

As already noted it is possible to distinguish between three different types of transactional contents in the IS kernel of Sagunto: i) Exchange of material flows; ii) sharing of environmental infrastructures and environmental cooperation projects and iii) exchange of knowledge. While the two first exchange types refer to material exchanges and/or physical projects, the third type of content if of an immaterial nature, involving the exchange of information and knowledge between activities.

6.3.3.1 Sagunto IS Network Kernel: Matrixes

Three matrices have been elaborated representing the three different IS ties identified in Sagunto. Following the same conventions adopted in the previous chapter, a general IS matrix has also been elaborated. This matrix includes all material and infrastructural ties. Knowledge transfer ties have been analysed individually, in an attempt to identify how the structure of the knowledge transfer network may influence the material network.

Table 6.6: Sagunto IS network kernel matrix

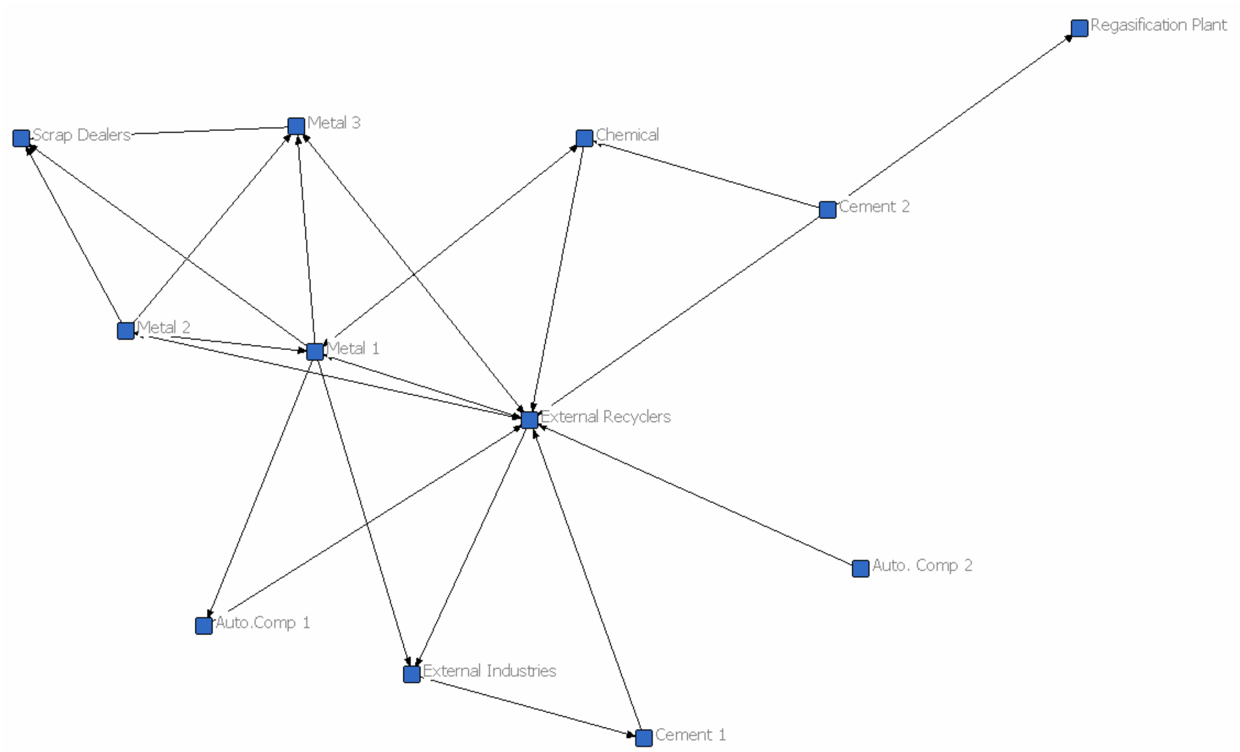
	Cement 1	Cement 2	Metal 1	Metal 2	Metal 3	Chemical	Auto. Comp 1	Auto. Comp 2	Scrap Dealers	Regasification Plant	External Recyclers	External Industries
Cement 1		0	0	0	0	0	0	0	0	0	1	0
Cement 2	0		0	0	0	1	0	0	0	1	1	0
Metal 1	0	0		1	1	1	1	0	1	0	1	1
Metal 2	0	0	1		1	0	0	0	1	0	1	0
Metal 3	0	0	0	0		0	0	0	1	0	1	0
Chemical	0	0	1	0	0		0	0	0	0	1	0
Auto.Comp 1		0	0	0	0	0		0	0	0	1	0
Auto. Comp 2	0	0	0	0	0	0	0		0	0	1	0
Scrap Dealers	0	0	0	0	0	0	0	0		0	0	0
Regasification Plant	0	0	0	0	0	0	0	0	0		0	0
External Recyclers	0	0	1	1	1	0	0	0	0	0		1
External Industries	1	0	0	0	0	0	0	0	0	0	0	

\Source: author generated

6.3.3.2 Sagunto IS Network Kernel: Graph

The graphical representation of Sagunto IS kernel is shown in Figure 6.4 Most of the exchanges take place among the companies in the metal cluster. The node of external recyclers seems also to play an important role, but it is problematic to consider it a key member of the network as: a) it is not a single node but a combination of nodes that have been grouped for the purpose of the analysis; b) it does not strictly belong to the network of industrial actors and c) its main activity is that of recycling and thus, although relevant for IS, ties between industrial and recycling companies are not generally considered as IS, following Chertow (2007) criteria to differentiate IS exchanges from other types of waste exchange.

Figure 6.4: Graphical representation of the Sagunto IS kernel



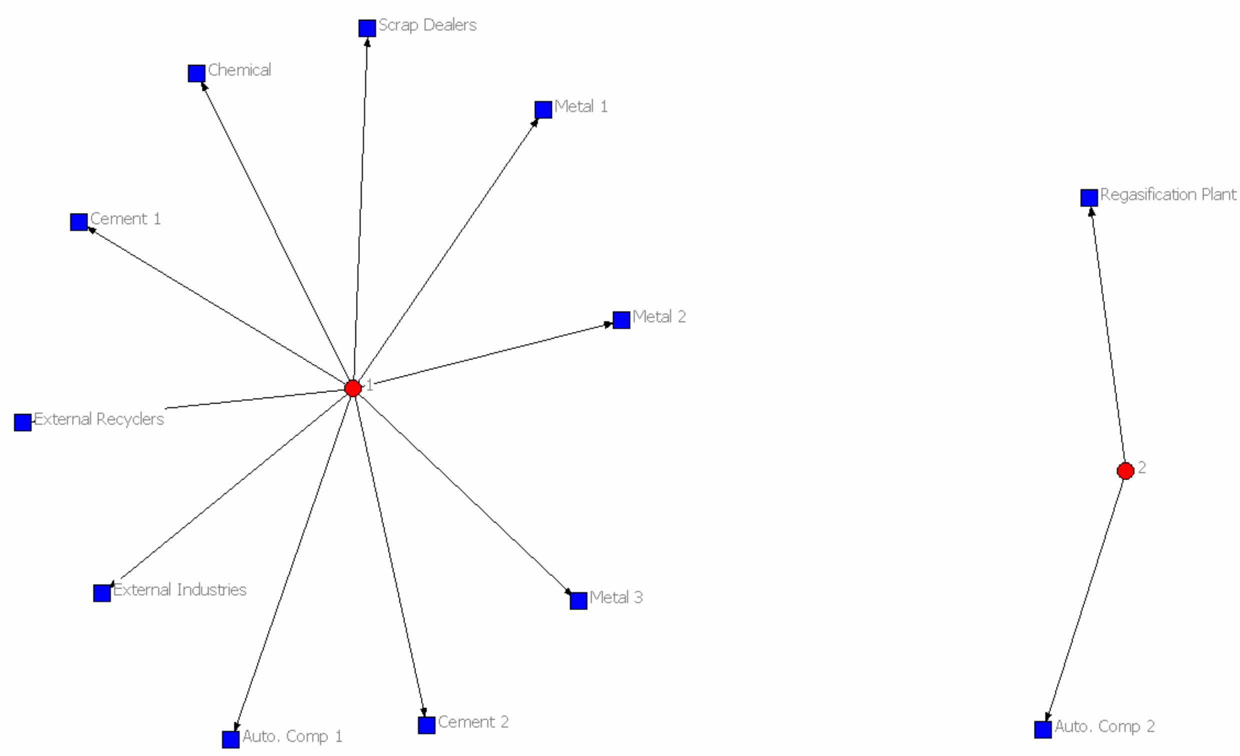
\Source: author generated

6.3.4 Core-periphery and Size of the Network

The industrial area of Sagunto is made up of several small to medium sized industrial estates, concentrated along the coastline. Potential and operative IS exchanges occur mainly in an area that concentrates most of the companies in the metal cluster and some other key industrial players. The IS kernel identified in Sagunto is made up by nine main industrial companies and a diversity of other actors that have been grouped, as previously noted, into three different nodes according to their activity/role in the network. These three external nodes are: the external recyclers, external industries and scrap dealers.

The analysis of the core periphery structure defined two types of membership classes, depending on whether the actor is part of the core of the network (class 1) or its periphery (class 2). The graphical representation below shows that the network is composed of a populated core, while the periphery is only made up by two nodes, the regasification plant and one of the automobile suppliers.

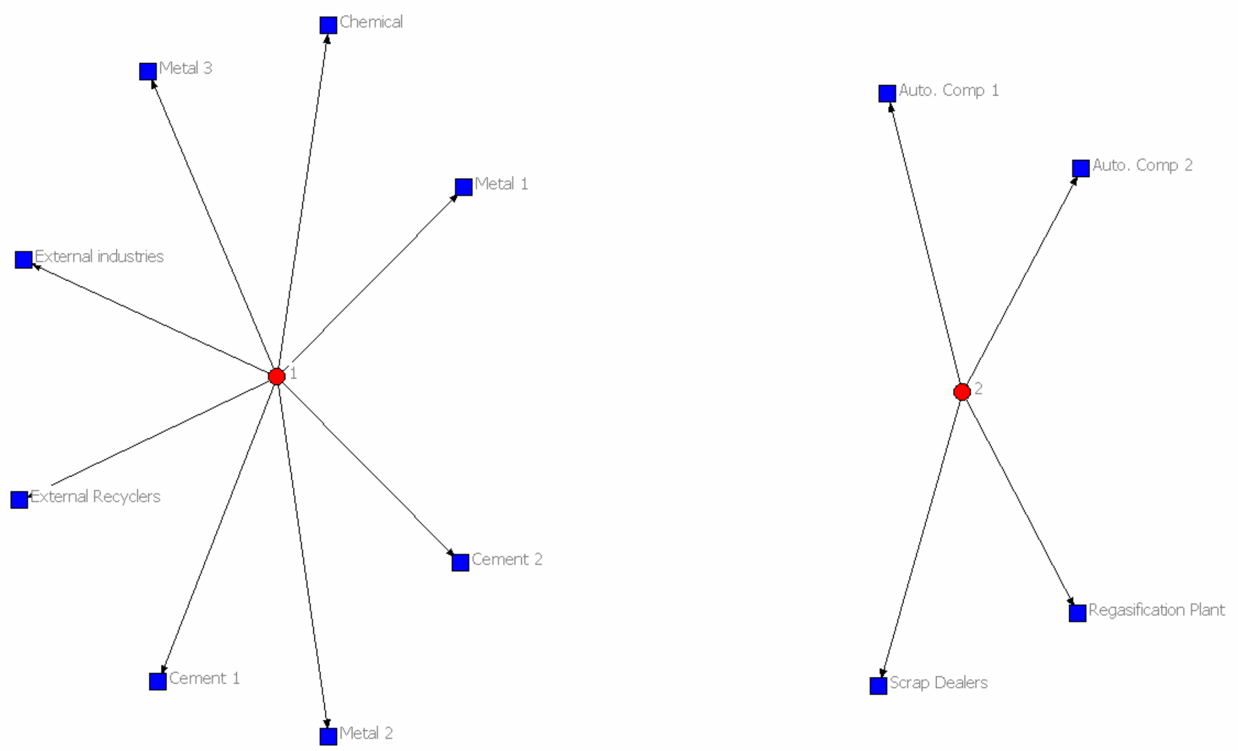
Figure 6.5: Core-periphery analysis of the IS kernel in Sagunto



\Source: author generated

In the case of the knowledge matrix, the core periphery structure shows a less populated core, composed by the companies of the metal and cement clusters, chemical company and external industries and recyclers. The periphery, on the other hand, includes the automobile suppliers, the regasification plant and scrap dealers, as seen in Figure 6.6 below.

Figure 6.6: Core-periphery structure of the Sagunto IS kernel- knowledge transfer.



\Source: author generated

Companies at the core of the IS kernel share some common characteristics that help to explain their position on the network: a) they have been onsite for a longer period and they share a common past. As already noted, in the case of the metal cluster, some of the companies used to be units of production of the metal transformation complex; b) geographically, they are located closer to each other. Distance, in some cases, has been crucial in favouring some common exploitation of environmental infrastructures. On the other hand, companies at the periphery are: a) geographically more dispersed; b) have significantly restricted communication with other actors, due to a strict communications policy and protocols and c) have been onsite for a shorter period. These characteristics will be explored in more detail in sections 6.4 and 6.5, which analyse the exchange conditions and discourse of the network.

6.3.4.1 Local Bridges

External industries and external recyclers act, to certain extent, as local bridges connecting the kernel to other potential networks or actors. Recycling companies have, in some cases, managed to find markets for by-products and waste streams generated onsite. An example of this, is the recovery of zinc, a waste product of the galvanising process, that once recovered has either been reintroduced into the industrial process or has been sold to other industries. External industries have also played a significant role in connecting the IS kernel of Sagunto to other potential IS partners. The recently developed tie between the integral cement factory and the ceramic industries to use broken or discarded tiles as raw material is a good example of this.

6.3.4.2 Structural Equivalence

The results of the analysis reveal that no pair of actors is structurally equivalent in the case of the Sagunto IS kernel. This means that there is no pair of actors that are connected to the same nodes and thus could perform an equivalent role in linking different nodes of the network. Actors that show a lower degree of structural equivalence and whose removal or disconnection could cause a significant disruption of the network are one of the metal companies, identified in the analysis as metal 1, and to a less extent, the external recycling companies. Structural equivalence calculations are included in the Appendix C.

6.3.4.3 Cliques

Cliques are a sub-set of nodes adjacent to each other. In the case of the IS kernel in Sagunto only one clique has been identified. The clique includes companies from the metal cluster and the external recyclers, as shown below:

1: Metal 1 Metal 2 External Recyclers

This is an expected result as it seems clear from the analysis, that most of the significant exchange transactions are taking place within the metal cluster. It is also important to point out, as already mentioned, that these companies share a common past and are located in close proximity, facilitating common use of infrastructures and exchange of resources.

6.3.5 Structural characteristics of the network

The main structural characteristics of the network are summarised in the table below (Table 6.7). The table includes the results for the whole network as well as content specific sub-networks.

Table 6.7: Structural characteristics of the IS kernel in Sagunto

	Whole network		**Material network**		**Infrastructural network**		**Knowledge network**	
Number of ties	26		22		6		7	
Density	0.1985		0.1667		0.0455		0.0530	
Network centralisation	60%		63.64%		14.55%		23.64%	
Ave. Geodistance	1.988		2.014		1.500		1.222	
Distance-based cohesion "compactness"	0.386		0.332		0.059		0.061	
Distance-weighted fragmentation "breath"	0.614		0.668		0.941		0.939	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Degree centrality	3.500	2.255	3.167	2.444	0.667	0.850	0.833	7.576
Betweenness centrality	7.000	12.280	6.167	12.360	0.417	0.954	0.167	0.553
Closeness centrality								
IN	22.466	20.558	20.923	9.215	9.045	1.108	8.967	0.964
OUT	8.443	6.678	16.989	4.077	9.048	1.145	8.939	0.790

\Source: author generated.

From the table above, it can be concluded that the emerging network has in general a high degree of centralisation, density and compactness. The average distance, however, between actors is almost 2, which means, that the average path connecting different actors is two nodes. When cross-comparing the different content networks the material is the most dense and centralised. Indeed, most of the exchange flows have a material content. This contrasts with a rather unstructured knowledge network, which is less dense and shows a low degree of compactness, together with the infrastructural network.

Looking at the mean of the different measures of centrality, that is the degree to which actors are connected to each other in the network, higher scores are obtained for the material network, as could be expected from the morphology of the network. On average each node has 3.5 direct connections to other nodes. Betweeness centrality, which refers to how many nodes stand between two pair of nodes that are not connected to each other, is considerably high (7). Finally, closeness refers to the level of "reachability" of different actors, that is, the ability to reach others or to be reached by other actors. As this is a non symmetric network, closeness, measured as the sum of average geodesic distances to all nodes, is calculated as in-closeness and out-closeness. In this case, out-closeness is higher than in-closeness, which indicates that nodes at the periphery are difficult to reach. A detailed analysis of the measures of centrality by actors would allow identification of centrally positioned nodes.

Table 6.8: Centrality measure scores by actors.

CENTRALITY	Degree	Betweenness	Closeness	
NODES			IN	OUT
Metal 1	7.000	21.167	27.500	24.444
Metal 2	4.000	1.917	26.829	22.449
Metal 3	4.000	1.917	27.500	20.755
Chemical	3.000	1.250	23.913	21.569
Cement 1	2.000	7.000	23.404	20.370
Cement 2	3.000	0.000	8.333	34.375
Auto. Comp1	2.000	0.000	23.404	20.370
Auto. Comp2	1.000	0.000	8.333	24.444
Regas. Plant	1.000	0.000	9.091	8.333
Scrap dealers	3.000	0.000	31.429	8.333
Ext.recyclers	9.000	42.750	32.353	22.917
Ext. Industries	3.000	8.000	27.500	18.333

\Source: authors generates

The results above point to two main central positioned actors: metal 1, one of the metal companies, and the external recyclers. However, as already noted in the assumptions, the latter node is a group of external actors, which have recycling as its main activity, and thus it cannot strictly be accounted as an IS partner, although its role is central in facilitating the reuse and recycle within the system for a number of IS streams. In general, the metal complex nodes have a high degree centrality, referring to the number of direct links they hold. However, in terms of betweeness and closeness, only the node metal 1 can be identified as having a central position. It is also important to note, that the node cement1 has a relatively relevant position if we consider betweenness, or brokerage capacity, and closeness or reachability, and is, indeed, one of the nodes, which has demonstrated a more active role in the identification of new potential IS exchanges.

6.3.6 Main findings from the network analysis

Distinctive features of the morphology of the emerging IS network in Sagunto can be derived from the analysis above:

- The network has a populated core and a rather scanty periphery. The unstructured periphery may also limit the opportunities for IS exchanges, as IS ties among peripheral actors are unlikely. The network is dense and compact although there are significant differences in terms of density and compactness among the different transactional content networks.
- The distance between nodes is almost two for the whole network, indicating that exchanges are generally separated by a two node-chain on average. This measure has to be interpreted with care as IS material exchanges have to be individually analysed as in most cases they refer to different material contents that could not be "transferred" among different actors in the network as material needs are different for each of the nodes that compose the network. Therefore, distance needs to be evaluated for the distinct transactional content matrices.
- The nodes metal1 and external recyclers have a central positioning in terms of direct connections, brokerage and reachability. The position of the node cement1 as broker of material exchanges is also important.
- Regarding the different content networks, material IS exchanges constitute the main exchange type. This contrasts with a rather undeveloped knowledge network, which may constitute a key obstacle in the further development of IS in Sagunto.

6.4 Emerging Networks and the Process of Building Cooperation: Exchange Conditions and Social Mechanisms of Control

The study of the structural and morphological characteristics of the emerging IS kernel in Sagunto has been complemented with an in-depth analysis of the social conditions that define the ground for IS. As an emerging IS kernel the case of Sagunto provides an excellent opportunity for identifying key issues that may foster or limit the adoption of IS at early stages of the collaboration process as well as understand the dynamics and evolution of IS partnerships. The main source of data comes from interviews with key industrial actors in the area and regulatory and policy actors, as well as review of internal company documents and policies.

6.4.1 *Exchange Conditions and Social Mechanisms of Control*

Based on the methodological framework presented in Chapter 4, the exchange conditions and emerging social mechanisms of control are examined for the case of the IS kernel in Sagunto. As a non-fully developed IS network, this case provides interesting insights into the process of emergence of IS networks as well as the potential barriers hindering its development.

6.4.1.1 Exchange Conditions

The main contextual and physical elements defining the industrial system of Sagunto have in some cases favoured and in others hindered the development of environmental collaborative projects and exchange of waste streams among industrial activities. Exchange conditions refer to the factors that define the transactions between actors. In this case, the scope of the research focuses on the analysis of the conditions that define transactions with an environmental component whether this component has a material basis (waste streams and by-products or shared use of infrastructures) or immaterial basis (collaboration and exchange of information on environmental issues).

6.4.1.2 High-Value Waste Streams

As seen in the network analysis, material exchanges are predominant in the IS kernel of Sagunto. A key factor that has favoured by-product and waste exchange is the high intrinsic value of main waste streams such as scrap metal. Metal by-product exchanges have a long history in the area and are an embedded practice of the companies in the metal cluster. As a by-product generating marginal benefits to the companies, metal scrap is not considered a waste of the production process, but as a by-product, which has a well-established market and commercialisation channels. The following quote remarks on the value assigned to metal by-products by companies:

> *"we do not consider the scrap as a waste, for us it is a by-product, and it is recycled within the group 100%"*

The increase in the price of certain metals in the world market in the last decade has also generated opportunities for the recovery and exchange of waste streams as it occurs with zinc, a by-product of the galvanising processes, as pointed out in the quote below by the production manager of one of the metal companies:

> *"We sell the zinc pot, we get paid about 80% of the original price"*

6.4.1.3 Changes in the Regulatory Framework

Other waste exchanges have developed more recently as a consequence of changes in the environmental regulatory framework. Some IS exchanges are the result of the introduction of pollution control technologies such as ih the case of the iron oxide, generated as a by-product of the waste water treatment. The valorisation of used oils and the recovery of acid have also generated some benefits and savings for the industrial companies of the area. Several industries are also trying to find alternative uses for the sludge generated in the waste water treatment process, with high content of iron and potential application to the cement industry or agriculture.

However, changes in the environmental regulatory framework and, more concretely, the waste regulation have also prevented new IS opportunities and discouraged some informal reuse and recycling practices. This together with a scarce communication between industrial actors and regulatory bodies has in some cases discouraged alternative uses or recycling of waste materials. Issues of legal responsibility are generally a major concern when considering the exchange of waste materials, as reflected in the following quote:

> *"If I would change the non-returnable package for a reusable one then I would have to charge the clients for the wood package and then when they return it, I would have to pay them back, this is so complicated that none of the plants are doing it....and we don´t have many alternatives...and the regulation does not help, because If it was not illegal, some clients would return the wood and I could reuse it, but that action is illegal because that is a waste for the client and I am not a waste manager, so I am not entitled to collect it..."*

Material exchanges of streams classified as waste are subjected to the requirements defined by waste regulation and, thus, can only be exchanged between industrial companies if the recipient of the flow has been previously registered as waste manager. Indeed, some of the companies engaged in IS exchanges in Sagunto are registered as waste managers in order to deal with their waste streams or accept waste streams as raw materials. Scrap metal and metal with oil was de-classified as a waste by an especial norm after the pressure of the metal complex to lose the benefits obtained by the sale of scrap metal, as stressed in the quote below:

> *"...when we started with the whole story of the environmental management ...we have always sold the scrap they paid for it and if it was considered a waste then we would have to paid for it...but there was a regional regulation that declassified metal scarp as waste and considered it a by-product"*

The interaction between regulatory bodies and industries is scarce and limited to the exchange of documentation to comply with monitoring and reporting obligations or the administrative process of licensing and granting of permits. Industries recognised that there is very little communication and negotiation regarding the implementation of new regulations. Common concerns raised by industries are the slowness of administrative processes and the lack of technical capacity, especially at the local level, to deal with complex environmental projects, as the following quote emphasises:

> *"the most difficult to solve are always regulatory issues: authorisations, permits and all those procedures that imply local authorities or the administration at the end a year is gone and we have not make any progress...as an example, the IPPC we start the process in 2006, it is now 2008, and I doubt that we will have any resolution in at least two more years"*

This may discourage the undertaking of more complex waste exchanges if they require additional administrative permits or alterations in the controlling or monitoring obligations of industries, as one of the interviewees notes:

> *"we are not allowed to valorise used oils. We could use it as a fuel but we already tried and it was not viable because the controls are very exhaustive and you need to do a lot of analyses and at the end the costs were too high"*

6.4.1.4 Other relevant exchange conditions

Other relevant factors that define the transaction framework for waste flows in Sagunto are the following:

1) Historical practices of waste exchange and sharing of common infrastructures due to the ownership structure and integral integration of activities in the past have

favoured the continuation of some of these practices even after changes in ownership have occurred.

2) Changes in the ownership of metal cluster companies have also transformed previously integrated activities into competitors, changing the power relations and altering trust between them. This may have discouraged further and more ambitious collaboration projects, although it does not seem to have affected already operating linkages. Industries subjected to very competitive environments such as the car manufacturing suppliers are less likely to collaborate as transfer of information and cooperation with third parties is limited by strict and explicit communication policies that restrain any exchange of information with other companies or agents. Although these companies may have developed sophisticated environmental policies they leave little space for cooperation and IS development.

3) There is availability of high volume and wide range of key waste flows. This generates an economic and environmental incentive for companies to look for alternative uses. Moreover, changes induced by climate change regulations have incentivised the search for alternative fuels and raw materials for large energy consumers, such as integral cement factories.

4) Companies are located in a geographical concentrated area, reducing transportation and communication costs. The geographical proximity, however, does not seem to have contributed to the strengthening of the social linkages between companies and companies representatives; remaining trust and embeddedness levels low.

6.4.2 Social Mechanisms of Control

The full development of collaboration within the network relies as much on favourable exchange conditions as on the progressive emergence of social control mechanisms that contribute to the creation of tacit norms and rules, guaranteeing a certain degree of fair play and reciprocity among members. These mechanisms and their level of development are examined for the case of the IS kernel in Sagunto, in an attempt to evaluate the possibilities of the kernel to develop as a fully operational IS.

6.4.2.1 Macroculture of cooperation

Despite the characteristics of the industrial area in Sagunto, with a geographically concentrated industrial system and with some waste exchanges and by-product flows having been taking place in the area for over three decades, there is no trace of the development of a macroculture of cooperation. Indeed, even though some companies have been part of the same business group in the past, no cooperative practices have been established. Waste exchanges and even infrastructure shared use is the result of a common past and a favourable economic incentive linked to the intrinsic values of the waste products. Opportunities for cooperation beside the more standard waste exchanges have not been considered by industrial actors. There is the extended idea that there are no opportunities for cooperation or even, in some cases, actors hold an overtly negative attitude towards collaboration. The following quote captures the prevalent position towards cooperative ties:

> *"we cannot discuss environmental aspects with our neighbours as we have completely different problems and waste streams"*

Moreover, the predominant business culture in the area favours individualist behaviour and a culture of competition rather than collaboration, even among companies that have shared a common past or among companies competing in different markets, as the following quote clearly shows:

> *"we have here in the same industrial plot a hot dip galvanising company. It used to be part of our company but now it belongs to the competitors...although it is true that we are still their main suppliers of raw materials"*

Although most of the companies have been located in the area for over 20 years, personal relationships have only rarely developed and most of the interviewees recognise that they do not know their neighbours. Even in cases when companies have a commercial relation, as happens with companies in the metal cluster and also with companies sharing some infrastructures, the relationship has not evolved towards more complex forms of cooperation. The predominance of a rather individualistic approach to business management and restrictions in the exchange of information and communication seem thus to define the business macroculture of the area. It is interesting to note that even though in the past some companies have belonged to the same group and have necessarily cooperated, practices of cooperation has been de-learned as changes in the ownership structure occurred.

6.4.2.2 Collective sanction and reputation

Collective sanctions and reputation constitute other social mechanisms of control that discourage opportunistic behaviour and increase the chances of establishing reciprocal relationships among network members. In the case of Sagunto, as exchanges are governed by conditions that resemble that of the market, the relevance of these mechanisms clearly decreases, as price and commercial contracts are the main definers of the exchange conditions. However, if more ambitious exchanges, which include some sort of innovation or ad-hoc solutions, are to be developed, these mechanisms would necessarily need to play an important role. Thus, the chances of Sagunto becoming a fully operating IS network rely, to a certain extent, on the possibility for these elements to develop. Some factors in the area of Sagunto potentially could foster and also limit the impact of these mechanisms. An increasingly stringent environmental framework and the progressive incorporation of environmental principles at the core of the strategic policy of companies have both contributed to raise the importance given by companies to environmental issues, becoming an essential part of the overall company's reputation. Most of the companies interviewed have reported that the strengthening of the environmental commitment of the company has been mainly driven by internal factors, as the following quotes clearly remark:

> *"(the main driver) has been mainly internal, linked to development, it has not been because of the market pressure...you either get the certification or you cannot work with us, no, in fact here we have already been certified for 6 or 7 years, and our activity remains the same, we do the same..it has not been a required by the clients... "*

> *"the policy of the group determined that all its plants should hold an environmental certification...the group had the commitment to certify all its plants and they did so...long before the car industry asked for a certification all the plants were already certified"*

Collective sanctions and penalisations in the network have an external rather than internal scope. Companies recognised the importance of being integrated in the community and of improving their environmental image. As the industrial system in Sagunto is composed of industries with a potential significant impact on the environment, public and regulatory scrutiny has been considerable in the area. The companies subsequently have tried to improve their public image by the certification of the EMS and the adoption of pollution prevention and control initiatives that go beyond regulatory obligations in most cases. An example of this is the recent introduction by one of the important players in the metal cluster of open days, where employee's families, community members and neighbouring companies are invited to visit the premises of the company.

However, the inter-organisational dimension of the environmental reputation is considered less relevant. Notwithstanding this, there have been some attempts from local municipalities to establish a system of mutual control of emissions among neighbouring companies, as noted in the following quote:

> *"there is interest by the local authorities to promote collaboration between the different parts so that problems can be detected...the position of the municipality is that it is better that before you complain against each other, that you control and monitor each other and that way you will solve your conflicts"*

The individualistic approach to business and, more concretely, environmental management reduces the opportunities for the development of inter-organisational environmental reputation as a main driver to enhance trust and inter-company collaboration.

6.4.3 Analysis of Embeddedness: IS and the Process of Embeddedness in Sagunto

As argued in Chapter 4, embedded networks are more likely to develop complex IS exchanges by reducing transaction costs and integrating a heuristic approach to collaboration and waste exchanges. According to Uzzi (1997), three main elements define embedded networks: 1) trust; 2) the exchange of fine grained information and 3) joint problem solving. In this section, the level presence and/or potential development of these three dimensions in the case of Sagunto is analysed.

6.4.3.1 Trust

As already noted above, waste and by-product exchanges in Sagunto are mainly governed by conditions that resemble an atomistic market, where price is a key element that regulates exchanges. Although this context can be perfectly adequate for standard by-products and waste materials, it may discourage other types of more ambitious interventions where innovation and collaboration along the different phases of the development of the project is required. Thus, while by-products and waste materials with high intrinsic values, such as scrap metal or zinc, for example, have been easily marketed and produce a revenue, other potential IS exchanges of materials that could be potentially reused or recycled within the system, such as the sludge generated in the metal cluster, have failed. Although the failure of this potential IS project cannot be directly imputed to the absence of trust, it can also be argued that this has contributed to it by limiting the willingness of companies to collaborate and work collectively for solutions.

Although the companies are located in close proximity to each other and even when they are, in many cases, linked by commercial relationships, a social network remains largely undeveloped with many company representatives acknowledging that they do not know their neighbours. This has prevented trust from emerging even in companies that previously belonged to the same corporation, as the following quotes from different environmental managers show:

> *"companies work individually, there is no coordination"*

> *"We belong to the metal sector association of Valencia. And at the beginning I went to some talks, when there was a new regulation, but that's it. With F (one neighbouring company) nothing, with A (another neighbouring company) nothing, we don't have any contacts"*

Another key element which contributes to explaining the absence of trust even among companies that share a common past is the already mentioned prevalence of competition over collaboration in the business macroculture, even among companies that are not direct competitors. In some cases, competition policies have restricted severely communication among industrial actors and have created an atmosphere of distrust and suspicion.

6.4.3.2 Exchange of Fine-grained Information

As trust is not governing network relationships, there is no exchange of fine-grained information among network members. Even among partners involved in IS exchanges, the exchange of information is restricted to the characteristics of the material and/or conditions of the transaction. Collaboration beyond exchange of the material is not considered, decreasing the chances of multiplexity to develop. Negotiation of the conditions of the exchange and negotiations are specified in contractual terms, with little room for informal interaction and emergence of trust among parts. An example of this is illustrated in the following quote, where a metal company that shares the waste water treatment plant with another company recognises that no information is exchanged between the two partners:

> *"In the degreasing process we generate the 80% of our waste water....this waste water goes to the waste treatment plant of AM...I don't know anything (about the treating process)"*

6.4.3.3 Joint problem solving

Given the absence of trust and exchange of fine-grained information, joint problem solving seems an unlikely scenario in the case of Sagunto. While some partial and occasional collaboration has been reported among companies in the metal cluster to deal with some of the regulatory requirements set by the IPPC, this collaboration was restricted to punctual informal exchange of information and transfer of knowledge and advice about the way certain requirements could be met. Potential joint solutions have not been explored in any case and no innovatory solutions proposed. The analysis of the failure of sludge project is a good example of the absence of any embedded procedure of collaboration and joint problem solving. Representatives of a metal cluster company and a cement company explained the failure of the potential IS exchange of sludge in the following terms:

> *"we tried the valorisation (of the sludge) but for the moment we have not found any company that would accept it...the main destination of that type of waste stream is cement factories..we don't know if it is because of the downturn of the construction market but they are not interested at the moment. We offered them to bring it to the door of the factory...but didn't work. We are still going to try because right now the only destination of that waste is landfill. We cannot consider any other legal alternative because the transport cost is very high as it has to be transported by road and due to its weight you cannot transport it over long distances. We have in the proximity two cement factories...and we are trying to try again this year to see if we could manage it that way"*

> *"we are surrounded by companies that have important waste streams, we have been talking to them and we have analysed some waste streams, but for the moment, we have not find anything, ...there are some like AM that have a high volume waste stream but there is a problem because it has a metal, I think zinc, and we don't think we can use it. It is ok, it could be used, but the chemical composition is not adequate..."*

Thus, the project failed because the chemical composition of the sludge did not comply with the requirements set by the cement company; however, there is no exploration of a solution that could be beneficial both in economic and environmental terms for both companies. Dynamics of joint problem solving have not been developed and they are unlikely to do so, given the exchange conditions and level of development of other social mechanisms of control.

6.5 Discursive Dimension of IS: Sagunto IS Kernel

Although discursive elements have been taken into account in the analysis of the exchange conditions and social mechanisms defining IS opportunities in Sagunto, the next sections provide a more detailed exploration of the main traits of the predominant discourse and the interaction between material, social and discursive dimensions, especially focusing on the role of discourse and how it affects the possibilities for IS to develop.

6.5.1 Basic assumptions and main conceptions: IS and collaboration

Although some material exchanges of waste and by-products have been identified in the IS kernel of Sagunto, the concept of IS is not known to any of the companies in place, and in many cases, the environmental benefits are not acknowledged by the companies involved in the exchange. In the case of Sagunto, waste exchange is driven by either economic or regulatory factors, or a combination of both. It is important to note, that in those cases where IS has been triggered by regulatory issues, the environmental benefits are generally recognised and, even, they may be valued over economic benefits. A clear example of this is offered by one of the cement production units in Sagunto. The regulatory pressure for the reduction of greenhouse gases has created a strong incentive for the company to look for alternative sources of fuel and raw materials. Although IS exchanges were thus driven by regulatory pressure, the substitution of fuels and materials, however, has also contributed to the generation of important savings for the company that were not considered before, as explained in the following quote:

> *"The substitution of raw materials and fuels has had an important economic impact in costs savings for the factory...well, it is not that this is a breakthrough, it is not that I use alternative raw materials and fuels and bring my production cost to zero, no, but this is complicated. You have to take into account that for us to reduce production costs by one euro is a lot, I am not going to achieve that even if I increase the amount of waste I use. I*

would need to use at least 50% of waste to reduce one euro the cost of production, but it is a remarkable economic benefit, maybe it is not a euro but if we reduce 60 cents per Tn of product and then you multiply by the total production, then the saving is important"

6.5.2 Environmental Management and CRS: Progressive Introduction of Environmental Principles at the Core of Business Strategy

Important changes have taken place in the environmental position of the companies located in the area in the last decade. Since the late nineties and beginning of the current decade, most of the companies introduced certified ISO 14,001 EMSs and significant environmental improvements, including pollution control and prevention systems. Environmental management has progressively gained in importance within the core of corporative principles of the companies in the area. A combination of different factors may contribute to explain these changes:

- There has been a progressive strengthening of environmental regulations and legal obligations for industrial actors
- There has been a growing internal commitment of companies to environmental performance and willingness to demonstrate an environmentally responsible behaviour.
- There has been a raising awareness of the neighbouring community regarding the potential impacts of industry on health and environment
- A responsible environmental management has become increasingly important for companies operating in highly competitive markets, such as the car manufacturing industry

In most cases, companies interviewed have stressed that the main driver for change has been mainly internal, not directly linked to pressure of clients or community, but to the will of the company to prevent potential complaints and improve its integration in the community. This internal change is linked to a more profound shift and reconsideration of the principles that constitute the core of the business activity and connected to the concept of CSR. The quotes below are a good reflection of this:

"We want to make clear that we are not trying to reduce costs by compromising the environmental performance of the company, and one way to show it is to be up for any new voluntary initiative that comes our way, including the ISO 14,001...we want to make clear that this (the environment) is a sacred area for the company"

"At the end the factory main driver is the profitability and in some cases improvements in environmental management have a null economic profitability...another thing is the social and environmental impact that this may generate...for example the reduction of the noise pollution is something that has no profitability whatsoever for the company in economic terms but socially it has a great value..."

"now we want to reduce by 80% our N_2O emissions...there is still no legislation in Europe or Spain regarding this, but we are so immersed in this (environmental improvement) that we are 7 or 8 years ahead of the normal situation"

It is important to note though that the companies located in Sagunto have a high environmental and competitive profile, characterised by their relatively large size, global or national scale and by belonging to sectors of activity with a relevant potential environmental impact. Therefore they are pioneering most of the changes operated in environmental management in their respective sectors of activity.

The role played by EMSs should not be overlooked. Most of the companies interviewed reported that the introduction of EMS has significantly contributed to the improvement of environmental performance. Different factors have been emphasised regarding the contribution of the EMS to the improvement of the environmental performance of the companies. The table below summarises some of the main advantages identified by the companies.

Table 6.9: Changes induced by EMSs

STRUCTURE	It has created a formal structure to deal with environmental issues
ASSESSMENT	It requires the identification of main sources of consumption and emissions
STRATEGY	It requires the definition of procedures for the designing of an environmental strategy
COMMITMENT	It has contributed to formalisation of the commitment of top management with environmental management
TRAINING	It has raised the levels of awareness and sensibilisation of the staff
CONTINUOUS IMPROVEMENT	It has introduced the concept of continuous improvement of environmental performance

\Source: author generated based on personal communications with key actors of the network.

The process of progressive integration of the environment among business core principles has however in this case not been accompanied by a more integral approach to industrial processes and material and energy cycling. Collaboration among companies is not considered in the design of environmental strategies and programmes. The predominant business paradigm is still based on an individualistic approach that emphasises competition over collaboration. The opportunities to collaborate have not been explored by the companies and they are not considered a feasible option to face environmental problems, as already noted in previous sections.

Some sort of cooperative dynamics have, though, been established within corporate groups. In most cases, there is some sort of coordination of environmental activities at the group level and periodical (normally on a yearly basis) interaction between environmental managers to review their strategies and exchange good practices. The reported impact of these activities varies, in general they are considered relevant although its low frequency and divergence of problems affecting the companies on different sites limit their contribution to practical or specific ideas or improvements. Moreover, as is remarked in the following quote in most cases coordination meetings only focus on the presentation of successful initiatives or case studies while failures or problems in the implementation of environmental strategies are rarely discussed:

"We have coordination between the other Spanish and European plants...we have periodical meetings, like last month that we sent all environmental managers to

Edinburgh for the exchange of ideas, experiences, how have we deal with certain issues ...but what happens is that no one wants to give a bad image and I am not so sure if those meetings are that useful because no one says I did that and it failed"

6.5.3 The Integration of the Environmental Dimension in the Process of Decision-Making

In parallel with the changes operated in the environmental performance of the companies, the environmental principle has been progressively integrated in the process of decision-making. This integration has gone beyond issues directly related to environmental management to pervade strategic policies such as investments, procurement or design. EMSs have contributed to this integration by instituting procedures that favour the integration of the environmental variable transversally across the company's policies, as illustrated by these quotes:

> *"well, ISO 14,001 requires you to have prevention and protection measures, for example, if there is any change in a raw material or process you need to analyse in detail that material or new process and what kind of environmental effects it is going to generate and how you would control and treat it"*

> *"We have a procedure that requires that if you have any new product you need to evaluate its environmental impact and therefore this involves several departments such as procurement, environmental and production"*

> *"every single production investment proposal includes the analysis of potential environmental aspects...that was introduced some years ago"*

Investment decisions are a good indication of the growing relevance that environmental factors are acquiring in the decision-making processes. In all cases, companies have reported that important environmental investments have been approved in the last years. Environmental managers have confirmed that environmental investments have followed special approval procedures and that all investments requested in the environmental area have been approved. This differs from other type of investments, such as production investments, that have had to compete with other projects or plants in order to get approved, as stressed in the following quote:

"The investments are divided into different groups, as a general rule, all investments that the plant requests in the areas of environmental protection and worker security are approved while the other investments requested for production or improving technical ratios, have to compete with the rest of the plants"

The companies generally differentiate between two types of environmental investments:

1) **Operative investments** refer to relatively low costs investments, which are included in the budget of environmental management and are connected to operative decisions and day-to-day improvements, and, thus, they do not require approval from top management.
2) **Environmental investments** required to comply with regulatory obligations or voluntary commitments derived from the company's environmental policy and programme. These investments need to follow an approval procedure which requires the technical and economical assessment of the project. Companies have reported that all environmental investments of this type have been approved in recent years. This reflects the strength of the environmental commitment of top management. The amount of the investments varies from company to company but it has involved in many cases projects of several millions Euros.

The special approval procedure for environmental investments also includes longer payback periods and, in some cases, investments that won't payback but are required to improve the company's performance. The calculation of costs and benefits is close to an heuristic approach, which has taken into account elements that are difficult to quantify such as relation with the community, reduction of complaints, improvement of company's image among other. All these aspects constitute a significant part of the CSR policy of the company and therefore have a value although may not be strictly economic, as emphasised in this quote:

"There are some (environmental) investments that won't payback. They won't payback in economic terms but they have some other type of value...all the investments in noise reduction, control of diffuse emissions, filters,...the filter that we have just installed costs 3 or 4 millions Euros...I am not going to increase production or quality, I am just going to reduce my emissions, then it is 3.5 millions of investment with zero profitability, but it has other type of profitability as now the town does not know if the factory is on or off, as nothing in coming out from the chimney"

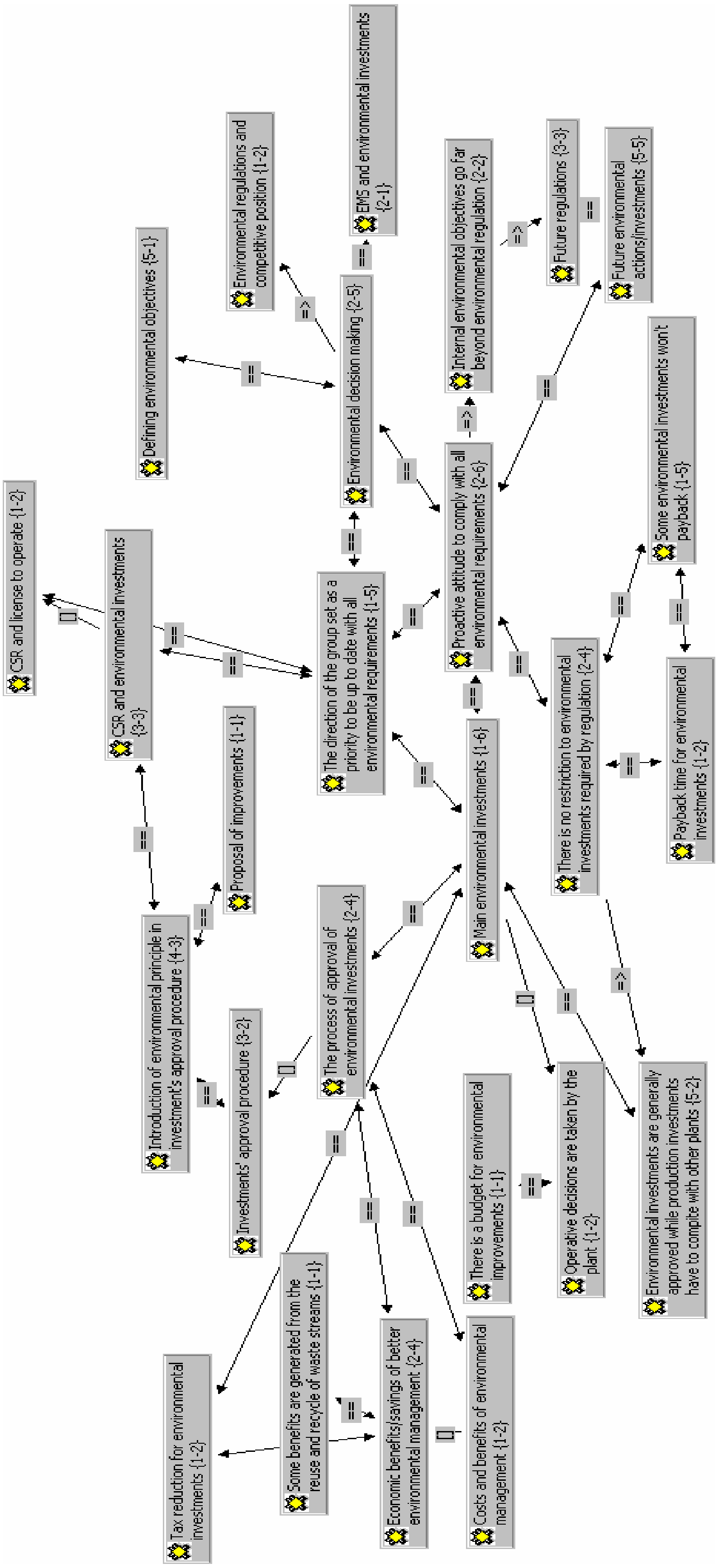
The introduction of the environmental principle at the core of the strategic management and decision-making have led companies to introduce environmental improvements that go far beyond the obligations set up by regulations. Most companies recognise that they are prepared for potential changes in current regulation.

In most cases, the process of decision-making and proposal for improvements follows a bottom-up approach where the technical departments are the ones that propose improvements and further investments to improve environmental management. An exemption to this is strategic decisions such as the implementation of EMS, where a top-down approach predominates, as the following quote relates:

> *"The environmental certification (...) was a voluntary issue that came from the direction in Madrid. The owners said that we had to get the certification, that we should be up to date on all legal issues"*

The conceptual map below captures some of the key elements that companies have reported are influencing their process of decision-making regarding environmental issues.

Figure 6.7: Conceptual map: key factors influencing decision-making processes

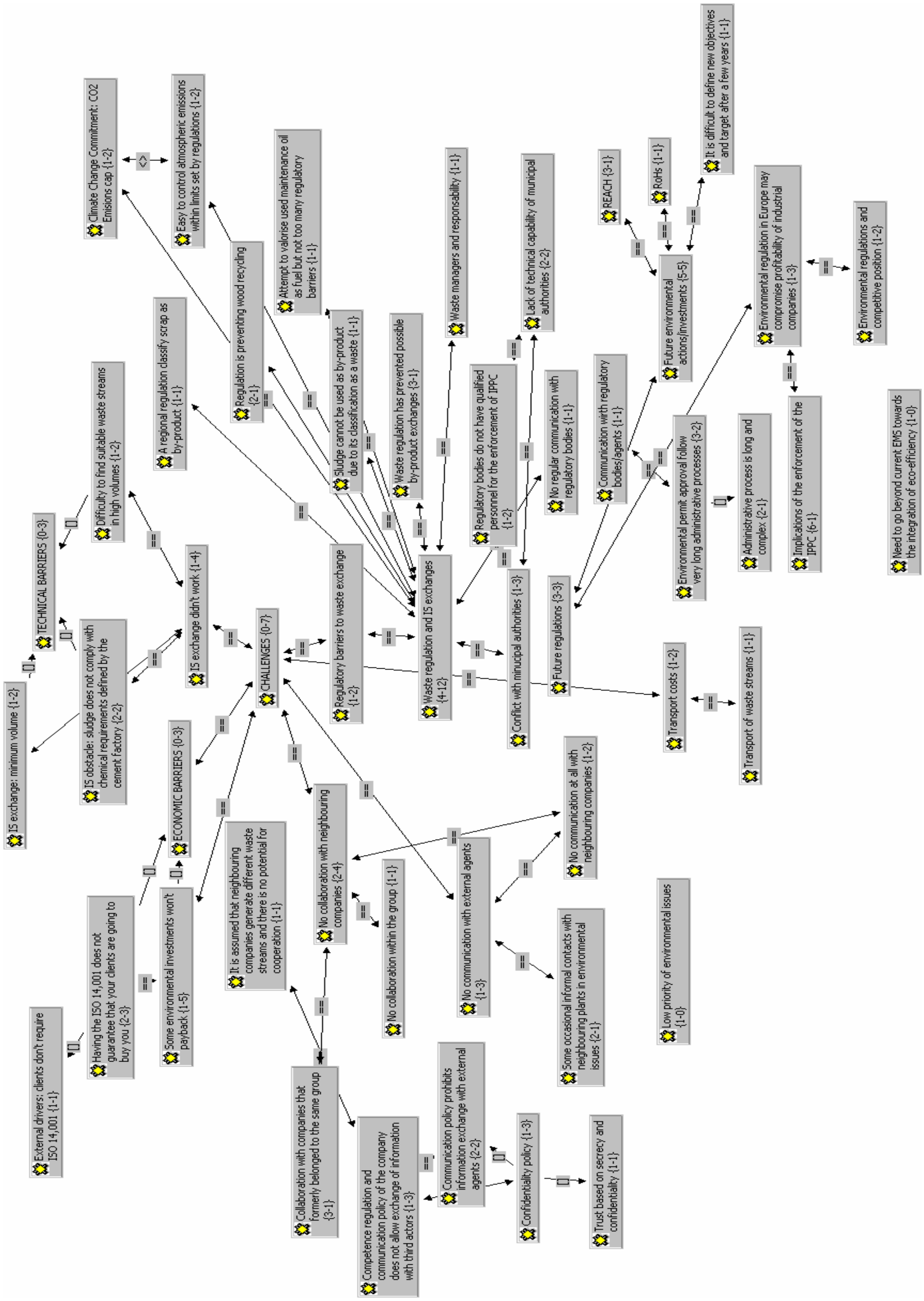


Source: author generated

6.6 Challenges and Opportunities for the Development of an IS Network in Sagunto

Although advances have been achieved in the level of development of the IS kernel in Sagunto, its configuration as a fully develop IS network, which implies increasing the complexity and also profitability of the cycling of materials and energy, largely depends on overcoming a number of barriers identified in the study. These barriers prevent the realisation of IS opportunities and/or increase the transaction costs associated with potential exchanges, thus, reducing their profitability and feasibility. Figure 6.8 shows some of the main challenges identified in the case of Sagunto.

Figure 6.8: Conceptual map: main challenges



Source: author generated

From the conceptual map above, barriers to the development of a fully operating IS network in Sagunto can be classified in the following categories:

Table 6.10: Challenges for the further development of the IS kernel of Sagunto

TYPES OF BARRIERS	IMPLICATIONS
Communicational barriers	Most of the companies interviewed admitted that there is no communication with other neighbouring companies. This absence of communication even happens among companies that are linked by commercial relationships. Companies operating in highly competitive markets, such as car manufacturing, are also subjected to strict communication policies that restrict any exchange of information with third party agents (see codes: "no collaboration with neighbouring companies"; "no communication with external agents" or "communication policy prohibits information exchange with external agents").
Lack of trust	No social networks have developed among companies' representatives and this, together with the lack of communication, generates a context with a very low degree of interaction. Trust is not a component of IS linkages and in most cases, trust is conceptualised as secrecy and confidentiality rather than reciprocity and interaction (see codes: "Trust based on secrecy and confidentiality" or "competence regulation and communication policy does not allow exchange of information with third actors").
Regulatory barriers	Regulatory barriers seem to have played an important role in preventing some IS exchanges. Regulatory barriers include issues regarding: a) the definition of waste. The classification as waste of a material increases the complexity of the requirements and permits the company needs to comply with, increasing costs and complexity of the process, and thus, discouraging the realisation of some exchanges; b) the distribution of responsibility. The producer of waste is legally responsible for the adequate management of its waste streams. Exchange of waste thus requires the companies to register as waste managers. c) Administrative processes are long and complex and therefore any initiative that requires changes in the permits or obligations of the companies are likely to be rejected by the company as transaction costs overcome potential economic and environmental benefits. d) There is no frequent communication with regulatory bodies. Communication with regulatory bodies is rare and is generally based on the exchange of documents and review of regulatory compliance. Issues regarding the interpretation of regulations or the implementation of future requirements are rarely discussed with environmental authorities. Local authorities lack the technical resources to properly deal with complex environmental regulations.
Technical barriers and transport costs	Technical and physical barriers affecting IS exchanges generally refer to: a) minimum volumes that are required to make IS exchanges profitable (see code: "difficulty to find suitable waste streams in high volumes"); b) mismatch between the composition and quality of the waste stream and that required by potential users (see code: "IS obstacle: Sludge does not comply with chemical requirements defined by the cement factory") and c) transport costs associated with the geographical movement of high volumes of materials with marginal value and regulatory requirements (see codes: "transport costs" and "transport of waste streams").
Lack of common vision and discourse barriers	Another key obstacle to the realisation of potential IS exchanges is the predominance of an individualistic approach to management and more concretely, to environmental management. Companies do not know waste streams of neighbouring companies and they assume that they have different and, thus, no complementary needs, concluding that no room for cooperation exists (see code: "No collaboration with neighbouring companies" and "it is assumed that neighbouring companies generate different waste streams and there is no potential for cooperation")

TYPES OF BARRIERS	IMPLICATIONS
Economic barriers	Economic barriers relate to a) the lack of profitability of the exchange in term of cost saving and b) the inability to generate value beyond the actual cost/benefit of the transaction by failing to capitalise on environmental gains. Regulatory requirements and transport costs significantly increase the transaction costs of potential IS exchanges, thus, reducing their likelihood to materialise. On the other hand, some companies do not see a direct link between better environmental performance and sales, compromising the undertaken of strategic decisions, such as IS exchanges (see codes: "ISO 14,001 does not guarantee that clients are going to buy you" or "environmental investments won't pay back")

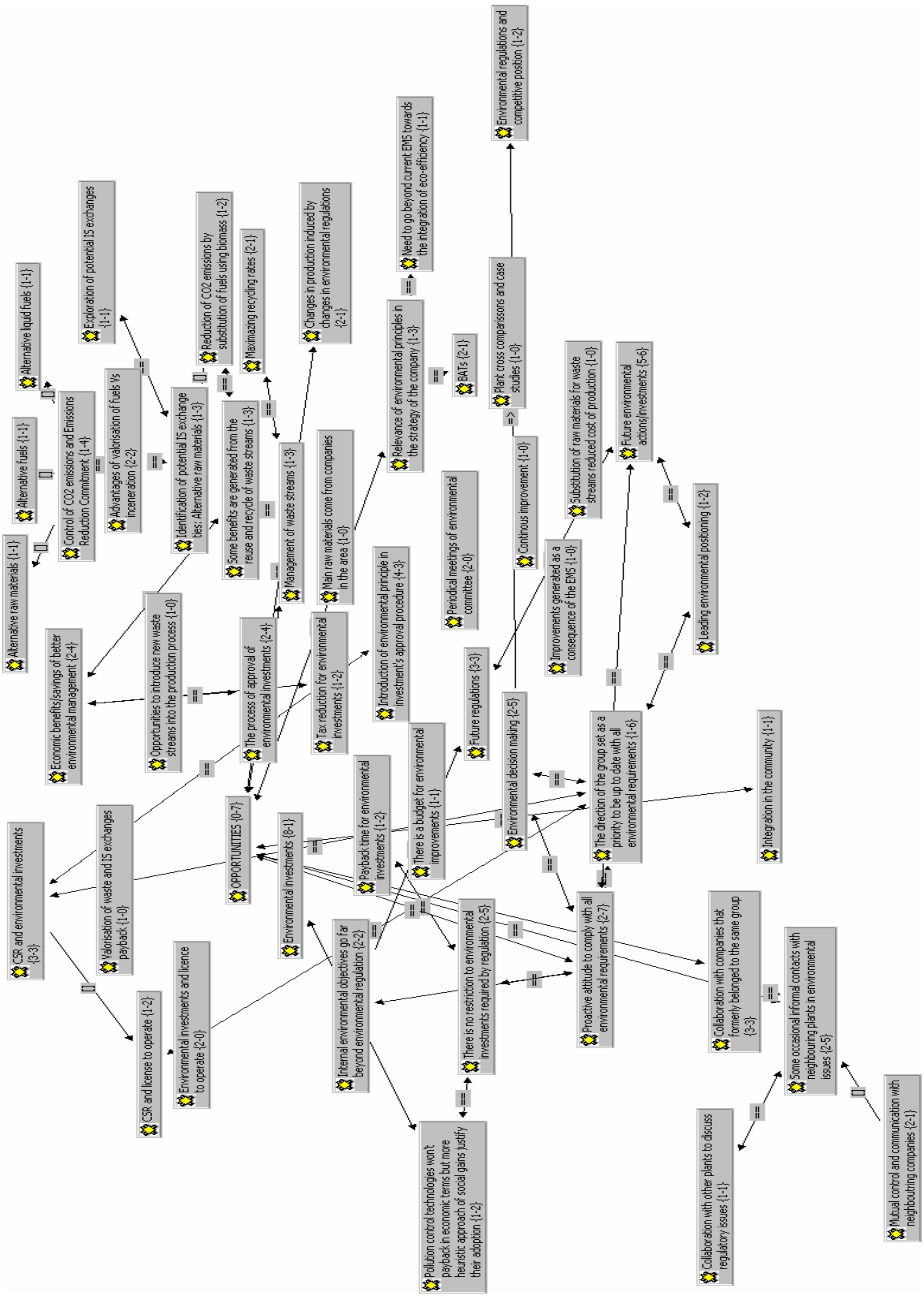
\Source: author generated

Although it is not a general concern, some smaller companies have raised doubts about the future of the industrial sector in Europe. Strict environmental regulations may increase production costs and can damage the competitive position of the company in the global market, especially for those segments of the market competing on price. In most cases, however, environmental management is understood as an integral element of the license to operate companies, as emphasised in this quote:

> *"...recently we had to buy a system to reduce VOC's emissions. It is already installed and working. It has cost 400,000 euro and the only thing that it does is to allow you to work, because the emissions cannot be so high, but it is not going to improve your productivity, neither is it going to make you sell more or improve the product. But it is just going to allow you to work. We understand that this has to be like that because we were generating those VOCs"*

Notwithstanding these barriers, there are also opportunities that may contribute to foster the further development of the IS kernel in Sagunto. These opportunities are related to potential cost savings and reduction of the environmental impact of the system as a whole but also to the possibility of extending cooperation to other areas and creating a better articulated industrial system. Figure 6.9 graphically represents the conceptual inter-connexions between different areas of potential gain.

Figure 6.9: Conceptual map: main opportunities



Source: author generated

Internal changes at the core of corporation, indirectly induced by changes in the institutional framework where companies operate, have brought significant alterations in the role that environmental management plays in the core strategy of the organisations. As already noted, internal drivers seem to be prevalent in inducing changes in environmental performance of the companies as environmental principles have progressively pervaded their strategic core, becoming a key element among the factors that configure the license to operate. For analytical purposes, it is possible to organise opportunities into different categories, as summarised in the table below:

Table 6.11: Opportunities for cooperation in the IS kernel of Sagunto

OPPORTUNITIES	IMPLICATIONS
Economic opportunities	IS exchanges can potentially generate significant cost savings, by reducing the cost of waste management and procurement of raw materials. Companies interviewed that have operative IS exchanges have reported important benefits derived from the sale of by-products or reduction in the cost of raw materials. Also important savings have been generated by the reuse and recycle of waste materials. Other, more difficult to assess economic opportunities are related to the strengthening of the environmental position of the company if IS is presented as an environmental objective (see code: "economic benefits/savings of better environmental management).
Environmental commitment	Companies in the area show a strong environmental commitment and a pro-active attitude towards the introduction of further environmental improvements. In most cases, companies have certified EMS and ambitious environmental programmes. Environmental investments have also grown significantly as a consequence of a conscious policy by top management of complying with all regulatory issues and even going beyond the limits and levels defined by regulation. Indicative of this change is that most of the companies have introduced in the last 10 years BATs in different phases of their production process (see codes: "relevance given to environmental management", "BATs" and ""relevance of environmental principles in the strategy of the company").
Continuous improvement	EMSs have helped to integrate continuous improvement into the managerial procedures of companies. Environmental objectives have oriented company efforts in the reduction of main environmental impacts on a continuous process. Although in some cases companies have reported increasing difficulty in identifying new environmental objectives, this practice has allowed tackling of complex environmental aspects and contributed to strengthening the company commitment, by providing resources on a continuous basis to invest in environmental improvements (see code: "environmental objectives go far beyond the regulation", "proactive attitude to comply with all environmental requirements" and "environmental investments").

OPPORTUNITIES	IMPLICATIONS
Communication	Although as noted in the analysis of the challenges, the absence of frequent communication between network members is one of the main obstacles for the development of a more embedded system of collaboration. Notwithstanding this, although still minimal, some companies have taken positive steps to improve communication with other agents. As already mentioned, cooperation in environmental issues has been favoured at an intra-organisational level, by the progressive implementation of EMSs. EMSs have improved the environmental education of workers and have increased their participation in the environmental policy of the company. Some companies have also celebrated open days and made their environmental policy and objectives available for third parties. The implementation of the IPPC has also created some occasional transfer of information between companies affected (see codes: "periodical meetings of environmental committee", "some informal communication with neighbouring companies", "collaboration with other plants to discuss regulatory issues" and "some occasional informal contacts with neighbouring plants in environmental issues".
Regulatory and tax incentives	Increasing regulatory pressure has also created incentives for the search of alternative uses and recycling of waste streams, by increasing the price of landfilling and waste disposal. Tax incentives given to environmental investments have also contributed to reducing the costs associated with environmental improvements (see codes: "management of waste streams", "advantages of valorisation of fuels vs incineration", "some benefits are generated from the reuse and recycle of waste streams" and "tax reduction for environmental investments").
Decision-making process	The progressive integration of the environmental variable in the process of decision-making of companies and its growing relevance in strategic terms, provides an excellent opportunity for the further development of IS and collaboration projects once the environmental gains of such an strategy are fully recognised (see code: "Environmental decision-making").

\Source: author generated

The analysis of opportunities and barriers also allows the identification of other challenges that could be interpreted as either an opportunity or a barrier, depending on the prevailing strategic vision adopted. One of these paradoxical elements is, as already noted above, regulation. On the one hand, a stricter regulatory framework has contributed to improvement in environmental control and performance of the companies onsite and has created incentives for a more efficient management of waste streams. Some IS exchanges have indeed been generated as a result of the strengthening of waste or emissions regulations. However, waste regulation and the classification of certain material streams as waste has also increased the costs and complexity of potential IS opportunities. Moreover, the lack of a flexible approach of regulatory bodies together with the complexity of administrative processes have discouraged innovative solutions in the management of waste by companies.

On another level, the approach of IS may contribute to overcoming the conflicting dimension of regulation/competitiveness, by emphasising the opportunities of cost savings derived from IS exchanges and a more heuristic approach to value generation, where environmental performance can be capitalised as an asset by industrial companies, both in its technological aspect and in its connection to CSR strategies.

6.7 Conclusions

The IS kernel of Sagunto offers an excellent opportunity to examine the process of development of IS relationships in the early stages of the process. Understanding the barriers and also opportunities that IS faces, and the internal and external dynamics that lead companies to either engage or not in IS exchanges provides a more accurate picture of the potential of IS for the environmental restructuring of industrial systems. As discussed, the IS kernel of Sagunto has potential to develop as a fully operated IS network, due to its mixed composition of companies and the existence of an already established network of material-based exchanges. This, however, will require the overcoming of some of the main barriers identified in the study. Social conditions linked to the absence of communication and interaction, a prevalent individualist approach to business management and the grounded belief that there is no complementarity among neighbouring companies for IS exchanges are limiting the possibilities of a more complex (and thus dense) system of IS exchanges, beyond some standard exchanges of materials with high intrinsic value.

Chapter 7.
National Industrial Symbiosis Programme, UK

Although the National Industrial Symbiosis Programme (NISP) is a relatively new initiative, the excellent results reported have increased the relevance of the case as a new approach to industrial symbiosis. The design of the programme can be traced back to 2000, with the development of IS programme for the Humber region, under the auspices of the Business Council for Sustainable Development (BCSD) UK. This initiative extended to other regions, and led, in 2003, to the creation of National Industrial Programme (NISP), although the programme on a national scale did not start to run until 2005. The main goals of the programme are to promote industrial symbiosis and to foster the exchange of by-products, materials and other assets among companies, so that they can be reused and recycled, serving as inputs for new processes.

The programme puts the emphasis on the promotion of the collaboration between organisations in *"a collective approach to competitive advantage involving physical exchange of materials, energy, water and/or by-products together with the shared use of assets, logistics and expertise"* (NISP website, 2009). To achieve this goal the programme focuses on (a) building up of information channels that favour the exchange of information and data concerning the inputs and outputs required by companies, (b) analysing the potential synergies and exchanges that could lead to economic and environmental benefits and (c) the promotion and undertaking of pilot projects that show new potentialities and possibilities of reuse, recycling or adding value to waste in different sectors or processes. The programme has been the first in the world to implement industrial symbiosis on a national scale and has reported outstanding benefits since it started to operate.

The chapter has been structured as follows: firstly, the scope of the analysis and main data sources are outlined. A brief literature review regarding the role of coordination nodes, and particularly NISP, is then presented. Thirdly, the structure and organisation of the network will be analysed. This will cover aspects like the process of strategy design, recruitment of companies, analysis of phases and conditions for the development of synergies and the role played by NISP in each of them. Then, the technology and knowledge transfer mechanisms in place and the benefits generated by the programme as well as the main barriers and challenges faced by it will be examined. In section 7.4, the exchange conditions that define the context of the IS exchanges and the possibilities for social mechanisms of control to develop in a large and artificially articulated network will be discussed. Finally, the predominant discourse of the network and the process of legitimating will be briefly addressed.

7.1 Introduction

7.1.1 Selection of the Case Study and Scope of the Analysis

NISP has been selected as an example of a non-spontaneous, policy driven initiative to promote IS on a regional and national basis. The study of NISP contributes to the debate within the field regarding the role of policy-driven initiatives in progressing towards closed-loop industrial systems. The analysis of this case study aims to shed some light upon the following areas:

1) Understanding of the roles of coordination nodes in promoting IS
2) To identify key success factors for this initiative to develop and achieve the proposed targets
3) Examination of main challenges faced by coordination bodies as well as the strategies designed to overcome potential barriers and obstacles

The policy-driven nature of the network requires close examination of the exchange conditions in place, which can give an indication of the chances of the initiative succeeding in the medium/long term. It will also be discussed the possibility for social mechanisms of control to develop in the case of non-spontaneous networks, as well as the role played by embeddedness.

7.1.2 Data Sources and Methodology

Main data sources for the analysis of the case study have been the following: 1) site visits and face-to-face in-depth interviews with NISP practitioners and technology managers of the different regional programmes; 2) attendance at quick-win workshops and other NISP events; 3) in-depth face-to-face interviews with companies' representatives, who are members of NISP and have been engaged in synergies; 4) brief telephone and email communication with other companies' representatives members of NISP; and 5) review of the existing literature and secondary materials, such as NISP communication documents and reports.

7.1.3 NISP and the Role of Coordination Nodes

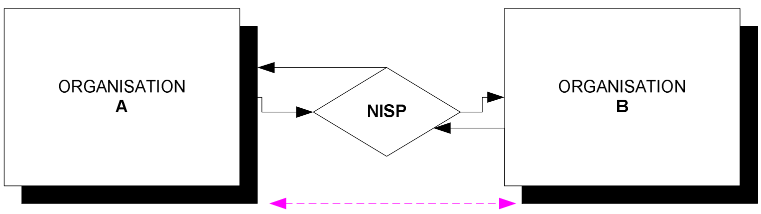
Even though the potential contribution of coordination bodies in promoting IS has been recognised in the literature (Chertow, 2007; Baas, 2008), its role is still scarcely researched. One of the early attempts to address the role of coordination bodies in the case of regional "*type of industrial ecology*" was made by Boons and Baas (1997). The authors emphasise that a crucial aspect for an "initiating" coordination organisation is to have "sufficient" status, which would help to legitimise its action. Although, as mentioned above, NISP is a fairly new initiative, it has already attracted attention within the field of IS. Building on the NISP experience, Mirata and Pearce (2006) focus on analysis of the role of coordination bodies in the development of IS. The authors identify three main areas of influence of coordination agents: a) informational support, b) contribution to the definition of the suitable institutional framework and c) guidance and inspiration for achieving long-term sustainability. This classification lies very close to the one proposed by Paquin (2007). The author identified three sets of facilitation activities fulfilled by NISP: a) conversation, b) connection and c) co-creation. Basically, according to both classifications, it is possible to define three main roles, or areas of action, in which NISP has focused its activity: a) the promotion of the idea of industrial symbiosis and the exchange of information among companies through network meetings, workshops and an ad-hoc web-based informational system, b) the proposal and fostering of synergies and potential opportunities for cooperation between companies in the exchange of waste flows and resources and c) the contribution to the creation of an appropriate institutional framework that encourages or at least does not inhibit the exchange of waste flows between companies. Both Mirata and Pearce (2006) and Paquin (2007) recognise the importance of coordination bodies in contributing to long-term sustainability, by directly and indirectly influencing the priorities of the companies and helping to introduce environmental principles at the core of the entrepreneurial strategy, and therefore, contributing to a change in the perception of the environmental issues in an organisation. These aspects will be examined in the light of the results from the analysis of data from the interviews and field research.

7.2 Structural Characteristics and Organisation of the Network

7.2.1 Structural Characteristics of the Network

In contrast to Kalundborg, one main feature of NISP is the large size of the network. Since the start of the programme, the number of members of NISP has steadily grown, achieving more than 12,500 members in 2009 (Jan). Member companies vary from large, multinational companies to SMEs, belonging to a wide range of sectors of activity. Alongside the companies, NISP has also among its members, universities, research centres, NGOs and other organisations. This variety is seen as an opportunity to establish cooperation across sectors, overcoming the limits of business unit boundaries. In general, although the opportunities for interaction are expected to grow with the size of the network, there are also negative aspects associated with it as: 1) greater transaction costs, 2) slower diffusion of information and 3) risk of interruption of flows, due to longer path distances between two nodes and the existence of weak ties. Therefore, large networks require coordination nodes that help to reduce path distance and promote the establishment of fruitful dyads between its members. In order to deal with the challenges posed by large networks, NISP has developed a star-shaped structure to help in reducing the distance between different nodes, that is, organisations, by centralising the flows through a structure at two interacting levels: national and regional. This structure will allow, for example, the reduction of path distance between two organisations (A, B) located in two different regions to only four nodes (Company A, NISP region A, NISP region B, and organisation B). Shorter pathways are also achieved for regional exchanges within a region, where the path way will be reduced to generally only two nodes, as shown in Figure 7.1:

Figure 7.1: Role of NISP in IS exchanges



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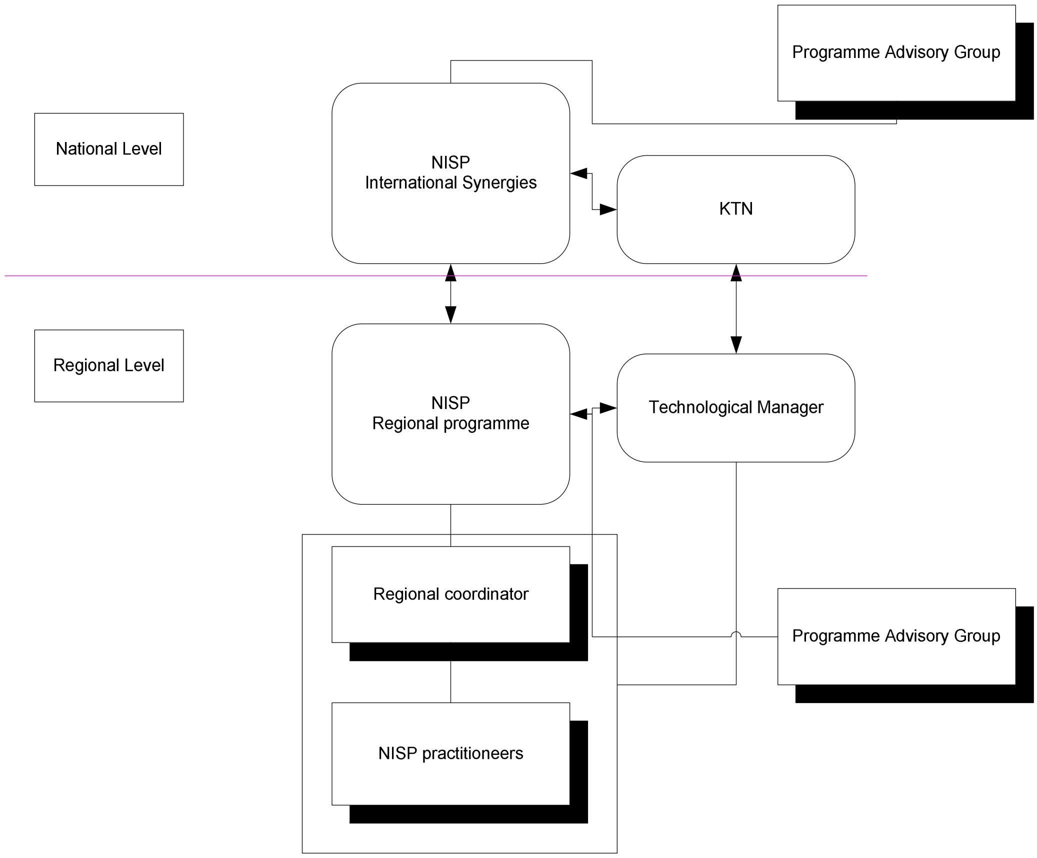
In a star-shaped network, central positioned actors can be easily identified. In this case, NISP, as coordination node, occupies a central position, with shortest path distance to any other member of the network (this applies to either degree centrality, betweeness centrality or closeness centrality). Moreover, all dyads between members are likely to occur through NISP, as it is the node that centralises all information flows. It is possible though that direct dyads between members develop, as will be discussed in more detail later, but this generally occurs in subsequent phases after the identification of a potential synergy. As a consequence of this, dyads in the periphery are scarce and weak. Strong dyads in the periphery can only develop through the intermediation of centrally positioned actors. Notwithstanding these limitations, the large size of the network increases the synergies and opportunities for cooperation. Another issue is the level of commitment and scope of these synergy projects, that may decrease with the size of the network. The role of central nodes, as facilitators, promotes the diffusion of information and knowledge and the identification of potential matches. The initiative reinforces itself as the accumulated process of learning generates new opportunities to cooperate.

7.2.2 Structure and Funding of the Programme

The central position of NISP in the network requires of an internal structure that maximizes the chances to identify potential synergies while reducing the potential caveats of large networks, such as capacity of generation of trust and higher transaction costs. NISP relies on a two level structure (national/regional), organised as shown in the Figure 7.2.

Figure 7.2: NISP Structure



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The national programme defines the overall strategy and methodology of delivery of the programme as well as targets of the programme for the different regions. The regional programmes thus are directly involved with the practical delivering of the programme in the region. There are currently 12 regional programmes covering all UK regions. Regional programmes are delivered by regional NISP delivery partners, appointed consultancy companies selected to deliver the programme regionally. Although, the structure of the regional programmes differs slightly from region to region, regional teams are generally composed of small transdisciplinary groups of practitioners with areas of expertise that range from chemical engineering to more economic and commercial expertise, and a solid knowledge and/or experience in the waste management sector. As seen in the figure above, NISP has set up a partnership with the Knowledge Transfer Network (KTN), another governmental support scheme with a complementary role to NISP, which focuses on the technological dimension of IS. This strategic alliance between NISP and KTN aims to maximize the outreach of the programme by addressing both dimensions of IS exchanges: the informational and the technological dimension. It is also important to note that both at the national and regional levels, NISP strategy is informed by the Programme Advisory Group (PAG). The role of the PAG will be analysed in more detail in the next section.

The programme has been partly funded by DEFRA through the Business Resource Efficiency and Waste Programme (BREW) and selected regional development agencies in England and by the Scottish Executive, in the case of the Scottish Industrial Symbiosis Programme (SISP), The Welsh Assembly, for NISP Wales and Invest Northern Ireland, in the case of Northern Ireland. International Symbiosis is the corporative structure behind NISP and the one in charge to select the different delivery partners for each region[9]. Changes in the availability of public funding since 2008 and the disappearance of BREW have significantly affected the programme raising question regarding its continuity in the future. In the new scenario, WRAP acts as an umbrella programme that manages available funding for Industrial Symbiosis. In the last year (2009), NISP won the tender on IS, but the future availability of public funding for the programme is unclear as yet.

7.2.3 Strategy Design

At the national level targets are defined for the different regions. Targets cover the following areas:

- Landfill diversion
- Water saving
- CO_2 reductions
- Additional revenues
- Cost savings for industry
- Inward investment
- Creation and safeguarding of jobs
- Creation of new companies
- Savings in virgin raw materials

[9] NISP Wales is delivered by a subcontract arrangement.

As noted before, funding bodies may impose additional targets on the programme, as it occurs in regions that are co-funded by EU funds through regional development agencies.

In order to achieve those targets, strategies are defined at the regional level. Strategy design generally comprises: a) identifying key sectors in the region; b) identifying key actors (companies, entrepreneurial associations, business networks...) within the sectors and c) tracing potential IS opportunities between sectors. The strategy is collaboratively designed by the regional team and the PAG. The composition of the PAG in each region comprises key industry representatives, regional leaders and representatives of other relevant bodies such as regional development agencies, EnviroLink, Carbon Trust or the environmental agency, among others. The role of the advisory group is thus to inform the national/regional strategy and more concretely to: a) define new areas of collaboration or potential synergies and b) contribute to the diffusion of the programme through their supply chain and business influence network. Differences in the regional strategies will depend on the industrial structure of the region, requirements defined by funding bodies and the background and areas of expertise of NISP delivery partner operating in the region.

7.2.4 Company Profile and Recruitment Process

NISP membership includes a variety of organisations that ranges from industrial companies to universities and research institutes, waste management companies and public sector. Although the gross of their membership is composed by SME, it is recognised by practitioners that regional teams target companies that generate large volumes of waste, in order to achieve the targets for the region, as expressed in the following quote by a NISP practitioner:

> *"Big companies, they are a priority because they have large waste streams"*

This does not imply that SMEs are not supported by the programme, but as another NISP practitioner commented, there are other support schemes that may be better suited for SMEs:

> *"We target larger companies, of course do not ignore smaller companies, but there are other sources of funding and support that are better suited for smaller companies, but there are no other sources to deal with larger companies"*

Looking at the completed synergies, in most cases they involve medium to large industrial companies, although, there may be SME involved generally, as solution providers.

The recruitment of companies generally occurs through the following mechanisms:

1) Through professional and personal networks of NISP team delivering the programme in the region
2) Referral to the programme by either other company members or other support schemes (Envirolink, Wrap, etc)
3) Through the members of the PAG
4) Through the webpage or industry events or conferences
5) Through "quick-win workshops"
6) Through connection to existing business networks in the area

In some cases, NISP would directly target companies that may either have large volumes of waste or may be interested in particular streams. In these cases, the company is either directly approached by a NISP team member or contacted through the mediation of a third agent, such as local authority, other industrial company or business or entrepreneurial association.

Two main factors influence the process of recruitment of companies in the region: a) size of the company and b) position of the programme in the region. While the level of awareness of NISP among industrial companies is significant in regions where the programme has been running for longer time (West-Midlands and Yorkshire & Humber), in new regions NISP needs to overcome the lack of awareness of the programme, as commented in the following quote by a NISP practitioner in London:

> *"I always find it a barrier to get over the awareness of the programme and also there are so many support organisations that often think, oh it is another organisation....they are nice but they don't really think we are going to really do anything, so it is really important to get a project to work where you can actually demonstrate what you can do and when you do that there is a real change in their attitude"*

In the case of the SMEs, companies generally contact the programme while large companies are sought by NISP, as remarked by one of the practitioners:

> *"Smaller companies tend to come to us through referrals, webpage, associations....but large companies with high volumes of waste we generally target those companies"*

Regarding the environmental profile of the member companies, there are also significant variations among company members. Regulatory and commercial incentives are the main drivers in encouraging companies to engage in synergies; however, in some cases, companies have internal environmental policies that define commitments regarding recycling rates and avoidance of landfill.

> *"we try to suggest to them, ok, some of these things may not be your most important criteria, financially it would not be brilliant but with the landfill cost rising and the disposal charges rising, that is an incentive, but with many of the companies we deal with, they want to improve their wider environmental performance and a lot of businesses they have their own goals things like we tend to avoid all landfill. So, in certain circumstances we push on an open door, it is just that the companies don't have the facilities to link with all these others, so we got some companies that are very well motivated so we don't need to sell the benefits to them"*

7.2.5 The Role of "Quick Win Workshops"

As pointed out above, in most cases, the role of the "*quick-win workshops*" has been emphasised as the main mechanism to attract new members. In these workshops companies are introduced to the programme and to the concept of IS. After a formal presentation of the programme, attendees are organised in tables to conduct a practical demonstration of the concept. The composition of each table is generated by the NISP team, trying to combine industrial activities with solutions providers. In each table there is a NISP practitioner who acts as a facilitator. The table leader starts by giving out small yellow cards so that each participant can write down what resources or "stuff" they are looking for or want to source cheaper. They refer to the term "stuff" to emphasise the idea that synergies may occur not only in the area of material exchanges but also in other fields as energy, facilities, expertise, transport, land, etc. Then small green cards are delivered so that the participants can write down the "stuff" that they want to provide. Green and yellow cards are combined in a synergy matrix, in order to identify matches.

Table 7.1: NISP synergy matrix

		WANT TO SOURCE, WANT TO SOURCE CHEAPER							
		Materials	Facility	Services	Energy	Fuel	Land	Transport	Expertise
WANT TO SUPPLY	Materials								
	Facility								
	Services								
	Energy								
	Fuel								
	Land								
	Transport								
	Expertise								

\Source: author generated; based on NISP

Synergies found are taken apart and noted down on orange cards. Results from different tables are combined and then presented as outcomes from the workshop. The feasibility of these opportunities is later on followed by the NISP regional team and a report is issued including all outcomes generated in the workshop. These workshops play a double role: a) to familiarise the companies with the programme, allowing further engagement and b) to act as a demonstration of potential opportunities derived from cooperation among companies. The relative importance of the workshops among other recruitment strategies varies from region to region. One coordinator from a regional programme stresses the impact of these workshops on the region:

> *"On average we engage 20 to 40 companies within a workshop, but the output from the workshop can be tremendous…All of these outputs that we are talking about are financial opportunities for the companies to make money, and the reason why we don't have that many workshops is because it takes time to get back to all the companies, discuss with them the outputs that came out from the workshop, the further outputs that may well be…."*

However, it has to be noted that only a very small proportion of the identified matches would actually be realised or even overcome the idea phase.

7.2.6 Information Management

As an information driven organisation, the management of information is crucial for the success of the programme. To cope with this challenge a web-based database (CRISP) was created. The system contains general information on company members and also substantial information regarding resources these organisations may have or would want to source. Two levels of membership are defined: 1) member and 2) active member. Active members are those who have resources listed in the database, either as a "want" or "have". The database is accessible online by NISP practitioners and updated on a continuous basis. Automatic matches are generated when the resources wanted match those required. Automatic matches then have to be reviewed by the NISP team to explore their technical and commercial viability before being presented to the member companies. The database contains filtering and searching tools that allow sorting of members by region, sector of activity or resource needs/wants. This allows not only cross-sector analysis but also cross-regional identification of synergies. Resources and waste streams are classified using the classification of waste material defined in the regulation.

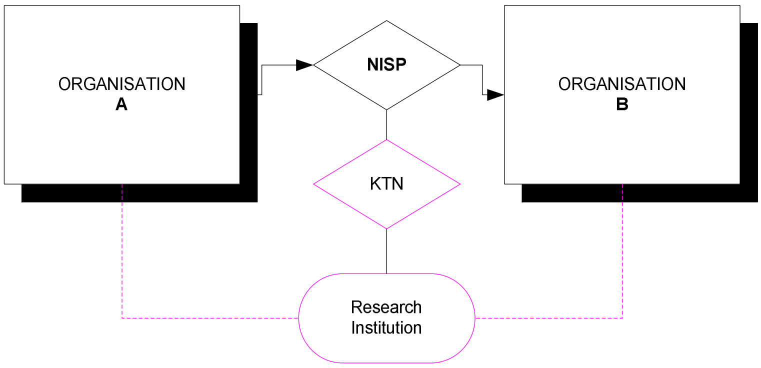
As the number of NISP members grows, the potential for the database to identify matches grows correspondingly. The database is considered to be of great assistance to practitioners, although it does not substitute the work of analysis of feasibility that needs to be undertaken by trained members of the team. Only potentially feasible matches would then be proposed to the company. Completed synergies are summarised as case studies, enriching the knowledge database of NISP regarding management of resource flows and available techniques and technologies in waste management.

7.2.7 Transfer of Knowledge and Technology

As have been noted above, NISP technological partnership with RE-KTN complements the brokerage role played by NISP by providing technological support to overcome potential technological obstacles and barriers. The role of KTN in NISP is thus to provide advice on existing technologies and best practices by making companies aware of existing solutions applied in the sector or other sectors of activity, but also by pointing to future developments in the technology that may generate new IS opportunities. Beyond this, KTN and NISP also contribute directly to foster innovation and research by promoting KTP (knowledge

Transfer Partnerships) between industrial companies and research, institutes and universities, as in the figure below:

Figure 7.3 NISP as facilitator of innovation



\Source: author generated

In most cases technological requirements are related to technologies to clean up waste streams, so that they can be used and/or recycled in other processes or sectors. According to information provided by NISP, over 70% of the completed synergies required some sort of process of technology innovation while over 50% involved the introduction of best practices and knowledge. The interviews conducted with NISP practitioners and technology managers reinforce these findings as they recognise that some sort of assistance in the technological/knowledge dimension was necessary to push forward the process once a potential synergy was identified. Recent cuts in the funding given by DEFRA to NISP has affected the partnership between KT and NISP in many regions, compromising the facilitation role provided by NISP and presumably negatively impacting on the realisation of synergies.

7.2.8 Phases in the development of synergies

NISP identifies different phases in the development of the synergies: 1) identification of opportunities; 2) discussion; 3) negotiation of synergies; 4) implementation and 5) realisation of synergies. The role of NISP in each of these phases varies, as summarised in table below.

Table 7.2: Role played by NISP in the different phases of development of synergies

PHASE	MAIN TASKS (NISP)	NISP ROLE
Identification of opportunities	Identify potential IS exchanges Identify potential IS partners	Facilitation Brokerage
Discussion	Analysis of technical and economic feasibility of potential exchanges	Facilitation Brokerage
Negotiation of synergies	Identification of potential technological and/or regulatory barriers Propose strategies to overcome barriers Identification of technological partner (if needed) or solution providers	Facilitation
Implementation	Technological/ regulatory support	Facilitation
Realisation	Evaluation of the project Production of a case study and dissemination of information	Facilitation

\Source: Author generated.

The first two phases are the phases where the contribution of NISP is more crucial both in terms of brokerage and facilitation. In the first phase, identification of potential matches, the role of NISP includes the identification of potential complementarities between processes and companies. This occurs at a macro and micro level. At the macro level, the identification of potential synergies is closely related to the strategy design for the region and includes the evaluation of potential exchanges among key industrial sectors. At the micro level, the identification of matches focuses on the exchange of specific waste streams generated by NISP members. At this level, the identification of matches generally occurs through: a) quick-win workshops, b) matches generated though the web-database (CRISP) and c) site visits to key companies that generate large volume of waste. It is also possible that the companies themselves approach NISP to propose an IS project when they have already identified an IS opportunity but are looking for a partner to develop it. This can either be a solution provider or another organisation that may be interested in a specific resource or waste stream. The role of NISP is thus to bring companies with complementary needs together. The discussion phase comprises the analysis of the idea in terms of technical and economic feasibility. Issues like the chemical composition or physical characteristics of the waste stream, quantity or continuity of the supply are evaluated at this phase. If the synergy has been considered feasible, the next step would be the negotiation of an agreement. This includes establishing the specifications of the waste streams as well as the conditions of the exchange, including price, quality, quantity, continuity and transport. NISP is not involved in the negotiation of the commercial agreement. As noted by one company representative, once the connection between the companies has been made, NISP needs to step backwards:

> *"To me the role of NISP is the facilitator one, what they need to do is go around everywhere and find matches...see if they can bring them (the organisations) together and find matches but once they have brought them together, NISP role finishes there"*

It is possible, though, for NISP to play an intermediary role in the early stages of the process if negotiation slows down, as noted in the following quote from a company member:

> *"But also the NISP programme, the fact of having someone in the middle seems to help with that. M. (referring to a NISP practitioner) is very good in negotiating things in talking to you and talking to other people and bring this all together"*

Barriers and obstacles to the realisation of the synergy may appear at any of the phases of the process and therefore it is crucial that NISP remains involved in the process to assist in the overcoming of technological and regulatory barriers.

In general, a set of conditions apply for the achievement of successful synergies:

1) The resource/waste stream needs to be available in large volumes and on a continuous/periodical basis. One off exchanges may occur when the benefits generated by the exchange exceeds the transaction and negotiation costs assigned to the exchange.
2) It needs to be commercially viable and thus, the price has to be right. This implies that the exchange should be a cheaper solution than the existing landfill option or that it should provides additional benefits in terms of CO_2 reductions or long-term revenue opportunities.
3) Environmentally the synergy should not contribute adversely to other issues (for example to look at the emissions parameters or creation of dioxins)
4) And it needs to comply with environmental regulatory requirements or should be negotiable with the environmental agency (in companies subjected to IPPC, for

example, this implies the assessment and negotiation for new raw materials or new fuels in the environmental authorisation)

7.3 Strategic Analysis of NISP

7.3.1 Benefits and Barriers

Since the beginning of the programme, NISP has reported excellent results in different metrics, as summarised in the table below.

Table 7.3: NISP reported accumulated benefits since 2005

	Year 1	Year 2	Year 3	Year 4	TOTAL
Landfill diversion (tonnes)	858,477	928,047	1,601,399	1,834,461	**5,222,384**
Carbon savings (tonnes)	328,964	1,688,713	2,408,267	812,115	**5,238,059**
Virgin raw materials (tonnes)	N/A	4,062,333	1,927,991	1,964,387	**7,954,711**
Hazardous waste savings (tonnes)	N/A	296,471	45,717	15,438	**357,626**
Water conservation (tonnes)	264,476	2,241,047	6,709,868	254,347	**9,469,738**
Cost savings to business (£)	36,449,707	34,253,665	33,087,576	27,291,310	**131,082,258**
Increased sales for business (£)	16,510,335	81,433,756	25,440,224	27,713,604	**151,097,919**
Jobs created	182	335	189	134	**840**
Jobs saved	238	431	335	372	**1,376**
People trained	562	1,603	1,099	338	**3,602**
Private investment (£)	22,300,000	44,163,400	43,653,277	5,900,810	**116,017,487**

\Source: NISP

A number of indicators also prove the capacity of the programme to deliver effective solutions that combine environmental and economic gains as shown in the tables below (Table 7.4 and 7.5):

Table 7.4: NISP economic indicators

Indicator	Outcome
CVA	£1,184,295,955
GVA	£471,943,110
TEVA	£1,656,239,065
Cost-Benefit Ratio	0.0638
Corporation tax	£122,705,209
Income tax	£23,875,500
VAT on additional sales	£110,715,009
NISP Tax multiplier	14.5

*Values are based on investments since April 2005.
\Source: NISP

Table 7.5: NISP economic efficiency

Industry Benefit Realised	NSIP required Input
£1 new income generated for industry	2 pence
£1 saved by UK industry	2 pence
1 tonne of virgin raw material saves	41 pence
1 tonne of water saved	34 pence
1 tonne of CO_2 reduced	62 pence
1 tonne of waste diverted from landfill	62 pence
1 tonne of hazardous waste eliminated	9.1 pounds

*Values are based on investments since April 2005.
\Source: NISP

From the perspective of the member organisations, although the commercial driver dominates the identification of synergies, a broader perception of the benefits in terms of improvement of the bottom line is also generally valued. The table below summarises some of the main benefits derived from the collaboration with NISP:

Table 7.6: Benefits generated by NISP for member organisations

BENEFITS	
Low cost of participation	It is a free programme NISP tries to minimise the time and effort asked from member companies, by simplifying information gathering and increasing the value of face to face meeting with companies by through preparation and prior identification of potential needs and requirements
Large network	NISP's large network provides a platform for companies to cooperate with other organisations that wouldn't have been able to contact otherwise

New areas of business	It highlights opportunities that the company was not aware of, both of potential synergies and also technological innovations
Cultural and organisational change	It contributes to changing the mindset of the company regarding waste streams to consider them as potential resources
Cost savings	It contributes to cost savings, by either reducing landfill and handling costs and/or identifying alternative sources of raw materials
Environmental benefits	It can generate additional environmental benefits, such as CO_2 reduction or water saving
Innovation and knowledge transfer	It contributes to the diffusion of knowledge by: 1) working on a cross-sectoral interface; thus allowing the transfer of knowledge between sector borders; 2) providing technical and technological advice on new technologies and best practice and 3) generating new areas of research and collaboration between industrial companies and research institutions.

\Source: author generated

Although the benefits of the programme above mentioned are very significant, only a very small proportion of the potential matches identified is transformed into completed synergies. This gap between potential and realised synergies points to the existence of important barriers that may hinder their realisation. The following table captures some of the common causes of failure of synergies identified both by NISP practitioners and member companies:

Table 7.7: Barriers for the realisation of synergies

BARRIERS	
Technological	Technological barriers may prevent IS to happen due to: a) the unavailability of technologies that allow the transformation or clean-up of the waste stream so that it can be used as a resource; b) insufficient knowledge and/or experience regarding the performance of specific waste streams when used as inputs and c) price of available technology does not guarantee the commercial viability of the exchange.
Economic	Even for technically feasible synergies, economic barriers may prevent their realisation based on: a) cost of the IS project in comparison to other forms of waste disposal or treatment and b) landfill costs. Currently, landfill costs in UK remain comparatively low and landfill is still a convenient and cost-effective solution (landfill cost has been growing in the past years and it is expected to do so in future).
Financial	Technical and economically viable exchanges may also be prevented by adverse financial context with limitations in credit and policies of cost reduction may cut investments in projects with longer pay-back periods.
Geographical/ physical	The geographical and physical scope of IS projects is also limited by: a) technical viability of transporting certain type of resources over long distances (such as steam or heat); b) the cost/value ratio of the transportation, in case of high volume/ low cost resources, such as sludge and c) the environmental rationality of transporting waste materials over long distances.
Regulatory	Although regulation has been a driver for some IS exchanges, the classification waste in regulation and the requirements defined for

	handling with resources classified as waste may also in some cases prevent the realisation of synergies as it imposes extra requirements for the companies involved in the exchange, as the recipient needs to be a registered waste manager, and the transportation has also to be undertaken by a registered waste transport company. This not only increases the cost of the project but also its complexity and thus extends the time required for the exchange to happen. This may discourage organisations in sectors such as construction, where contracts specify time of delivery.
Organisational/cultural	Although not common, some companies may be reluctant to replace virgin raw materials by waste materials. Another important barrier is the lack of a clear understanding of waste costs in a company. Companies may have only a rough idea of their waste costs. Moreover, waste costs are generally identified with landfill and/or disposal costs, failing to capture the totality of cost associated with waste such as cost of waste resources and energy, cost of production and storage, among others.
Negotiation	A common reported cause of failure of technical and economically viable synergies is the inability of organisation to reach a mutually beneficial agreement. This is connected with both organisational and communicational barriers. Companies that have been paying for the disposal of their waste, if they perceive that another company may generate a commercial benefit, they may try to push the negotiation further by elevating their price/benefit expectations.
Communicational	Problems of communication between companies and disparity of business culture may also pose risks to the process of realisation of synergies
Risk and responsibility	Issues of risk and duty of care linked to the use of waste materials are also considered to negatively affect the realisation of IS exchanges, especially those involving hazardous waste.

\Source: author generated

The role of NISP entails work on reducing the impact of these potential barriers by providing assistance and support to overcome them. The table below summarises the role of NISP in overcoming the main barriers identified above.

Table 7.8: Role of NISP in overcoming barriers to IS exchanges

BARRIER	ROLE OF NISP
Technological	Diffusion of available technologies and best practices Foster partnerships between industrial companies and research institutions
Economic	Lobby for increase in the landfill tax Creation of markets for waste materials
Financial	Facilitate access to funding and funding mechanisms
Geographical/ physical	Promote local and regional synergies
Regulatory	Work with the environmental agency to introduce changes in the classification of waste Negotiate exceptions
Organisational/cultural	Introduce changes in the mindset of companies by changing from a uni- to a bi-dimensional concept of waste/resources

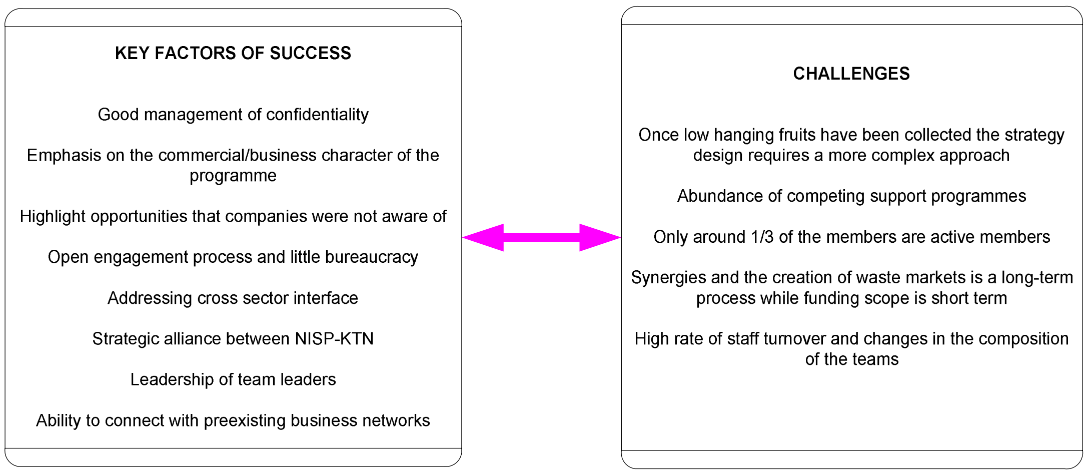
BARRIER	ROLE OF NISP
Negotiation/ Communicational	Facilitate the process of negotiation and communication between companies
Risk and responsibility	Provide case studies and demonstration, trial and pilot projects that help to reduce the risk associated with novel IS projects

\Source: author generated

7.3.2 Key Elements of Success and Challenges

Above the main benefits and barriers associated with the engagement with NISP in IS exchanges have been analysed from the perspective of the business member. An evaluation of the programme from an internal point of view is also crucial for the strategic analysis of the initiative. In this section, key elements that contribute to the explanation of the success of the initiative have been identified together with the challenges that NISP as an organisation faces. This will be complemented in the next section with a SWOT analysis.

Figure 7.4: success factors and challenges of NISP



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Source: author generated

The table above summarises key success factors and challenges for NISP. Among the key success factors, the importance of presenting the programme as a business rather than merely an environmental programme is emphasised by both companies and practitioners, as clearly shown in the following quote:

> *"What bring business together is that companies make money out of it. It is a business programme so M. always says it is a business programme not an environmental programme. So companies get engaged because they wanna make money, improve the bottom line, either by reducing costs or make money, and then you get the environmental dimension"*

The fact that the process of engagement is open and informal also reduces the reluctance of companies to participate. Confidentiality is crucial in the process of trust building with companies, and even though in most cases companies do not show reticence to exchange information, the assurance of confidentiality facilitates the process, as expressed in the quote below:

> *"We have to be very careful with confidentiality. People are entrusting us with quite sensitive information and we have to make sure that we respect that"*

Among the challenges, the high turnover of staff and the continuous changes in the composition of regional teams constitutes a major challenge as it disrupts the process of trust building with members and slows down the process of communication; thus, the potential to achieve synergies. The basis of this problem is the funding structure of the programme, which relies on short-term contracts depending on funding approval from government, as stressed in the quote bellow:

> *"The main challenge is to keep a team together. The funding tends to be on a yearly basis so at the end of every year you don't know if you have got a job the next year and that is very disruptive. The people that come into the programme are people that can see the value of the programme, both the commercial and environmental value, but at the end of the day you need to balance your family and business life and if you don't have a bit of stability there, it is extremely difficult. The NISP programme has a high turnover of staff (..) and some of these projects need a long time, and without the continuity of funding support it is going to be very difficult to bring the programme where it can deliver it fullest potential. I am not saying it is not possible, but it is much more difficult"*

In the case of more mature regions, where the programme has been running longer, one of the challenges is to find new areas of potential synergies once the low hanging fruits have been collected, as expressed by a member of the PAG in the Yorkshire-Humber region:

> *"I am not sure where the programme is going...in the last two years it has been good but most of the easy things have been achieved so now I am chair of the advisory committee and we have a meeting next month and M (NISP practitioner) asked me what shall I put on the agenda...it is difficult to find something new, it is possible to review what we have done but it is difficult to envision a way forward where we can do more and improve what else we can do? The technical advice is a good way forward because it is not about matching company A has that waste company B wants that waste... so it is probably to introduce techniques and technologies that the company is not aware of or that can be transferred from other sectors. I think that is the big area where they can get involved...Technology and knowledge transfer is the next step"*

The abundance of competing business support programmes has also been identified as an element that may create certain confusion among businesses and may reduce their willingness to cooperate in the early stages of the process as there is uncertainty regarding the outcomes of their participation. This also relates with the connection of "free=no value" that some companies attach to these programmes, as commented on the quote bellow:

> *"The culture within UK, when you make contact with someone they assume that there is a catch that you are trying to sell them something and if you say that it is free their perception is of low value if it is free, so it is almost too good to be true"*

However, as it has also been emphasised before, the fact that it is a free programme was crucial in engaging companies in the programme, as it reduced the cost associated with their involvement and the entrance barriers.

7.3.3 SWOT Analysis

A SWOT analysis has been generated to synthesise the main strategic elements of NISP and its opportunities for future development. The SWOT analysis looks at the interaction between internal elements (strength and weaknesses) and external or contextual elements (opportunities and threats).

Table 7.9: SWOT analysis of NISP

Strengths	Weaknesses
Large network Alliance with KTN and research institutions Connections with the waste management industry Accumulation of knowledge and IS experiences, capitalised through the database and case studies Well positioned among business and regulatory actors	Changes in the composition of regional teams Disparity between funding time frame and projects time frames in the case of more ambitious long-term projects Limited engagement with SME, rather than solution providers Dependency on public funding
Opportunities	**Threats**
Changes in Landfill Tax Climate Change Levy Changes in regulation Changes in business mindset and strengthening of environmental voluntary commitments Increase of the world price of certain resources	Delocalisation of industrial companies Competition with other business support programmes Restriction in the availability of public funding Uncertainty about whether the programme can run as a private initiative

\Source: Author generated

As derived from the analysis, main challenges for NISP seem to come from the changing funding scenario that may compromise the viability of the programme in the future. Although the alternative of a private run initiative is being considered, questions regarding its viability in the short to medium-term are raised, as it seems rather unlikely that companies would be willing to pay for the service provided by NISP. As pointed out before in the analysis, the fact that it is a free programme contributed to reducing the barriers to participation of industrial companies in an area where the benefits or outcomes of cooperation are still uncertain and difficult to define a priori.

7.4 Analysis of Embeddedness: Exchange Conditions and Social Mechanisms of Control

Building on the analytical framework developed (and presented in Chapter 4), this section examines the exchange conditions and social mechanisms of control in the case of NISP and its capacity to generate embedded relations.

Regarding the exchange conditions that have favoured in this case the emergence and success of the programme, there are two major challenges in the environmental area that UK- based businesses are currently facing that have an impact on the feasibility of IS exchanges. On the one hand, there is growingly stringent environmental regulation. The current UK position as an "*active pace-setter*" in the context of EU environmental policy (Börzel, 2002), has contributed to strengthen the environmental position of the country and define ambitious policy guidelines and objectives. On the other hand, the scarcity of landfill, has led to the steady increase of landfill taxes, favouring the viability of IS projects. However, as a result of the size of the network and the character of the initiative, social mechanisms of control as collective sanctions and macroculture are less likely to be developed. To compensate for that, NISP has adopted a multi-core structure, setting up a UK-wide network of regional programmes to allow for social interaction to emerge and to contribute to the reduction of the transaction and transportation costs. Regional programmes act as coordination nodes within the region and capitalise on the knowledge and learning generated by novel IS exchanges, which is then diffused through the rest of the network through the web-based information system (CRISP). NISP's role as an intermediary node between organisations also guarantees a certain degree of "fair play" and agreed norms among actors.

While the analysis of exchange condition and social mechanisms of control contribute to the identification of the conditions of emergence and development of the network, the degree of embeddedness of the network is related to its capacity to generate complex cooperation, leading to increased benefits. Following the methodological approach defined in Chapter 4, the degree of embeddedness has been evaluated based on the capacity of the programme to build trust, exchange fine grained information and promote joint problem solving. The table below summarises the level of development of these aspects for the case of the NISP network.

Table 7.10: Analysis of embeddedness

Embeddedness	NISP Mechanisms	Evaluation
Trust	NISP mechanism to generate trust relies on: Performance of the programme and capacity to generate commercial benefits Reputation and status of the programme Inter-mediation of NISP between organisation	As the process of building of trust involves time and interaction, it is unlikely that high levels of trust will develop between network members as a whole, but it can happen in cliques. The role of NISP as a coordinator guarantees a certain degree of "fair play" and appropriate behaviour. Changes in the composition of the regional NISP may create considerable disruption in the process of trust building, as this changes the communication routines and channels and generates uncertainty among member companies.
Exchange of "fine-grained information"/ Tacit knowledge	Methodology for the gathering of substantive information from companies Progressive refinement of IS knowledge as the number of synergies grows Capitalisation of knowledge gained through the generation of case studies NISP database (CRISP)	Fine-grained information is transferred in IS linkages and, although NISP may contribute to the diffusion of more institutionalised knowledge, the particularities of the process and the tacit knowledge generated is unlikely to permeate the network.
Joint problem solving	Capacity to engage a diversity of actors that include industrial companies, solution providers and research institutions	Difficult to develop at the level of the network. It can develop in cliques, and for particular dyads, where companies engage in problem solving as a result of a common problem or potential shared benefit.

\Source: Author generated

In general the creation of embedded ties largely relied on personal, frequent contact, reciprocity or shared vision and goals, aspects which are difficult to replicate in larger networks, where also control mechanisms such as reputation or collective sanctions can have reduced impact. However, from the table above it is possible to conclude that NISP has managed to generate embedded ties in cliques, by building on mechanisms of knowledge and information management and diffusion. Thus, although its capacity to generate embedded ties may be limited at the whole-network level, this does not prevent embedded ties developing in smaller cliques of core members, where cooperation has evolved from simpler initiatives to more ambitious synergy projects that may either involve technological innovation or multiple partners.

7.5 Discursive Dimension of IS: NISP

The predominant discourse of the network relies on the concepts of economic rationality and resource efficiency. Without doubt and as is recognised by the practitioners, the commercial and business approach is emphasised over environmental objectives. Indeed, the environmental dimension is in some cases completely excluded from the discourse as it is perceived as counterproductive for the diffusion and the status of the programme, as expressed in the following quote from a NISP practitioner:

> *"When I introduce the programme I rarely talk about the environment or being green because most of the organisations that are out there working in sustainability do not speak the right language and there is where NISP differs because we talk commercially about cost savings and sustainability is in the back door"*

As noted in the quote above, underlying environmental benefits may permeate organisations wrapped in the predominant discourse of cost-efficiency by changing the conception of waste from something without value to that of a resource. NISP opts for the adoption of a very pragmatic approach, target and action-oriented, that tries to connect to companies by using business tools and language. This reduces the barriers of the companies to cooperation, as they perceive it as a business programme. By emphasising the business opportunities derived from the optimisation of resources and engagement in IS projects, the programme also contributes to the process of cultural and organisational change. This pervasive process helps to move towards the progressive incorporation of environmental principles at the core of the business strategy. This pragmatic approach also makes possible the adaptation of the discourse depending on the level of environmental commitment of the organisation or even of the contact person in the organisation, as is apparent in the following quote:

> *"Depending on the person you are going to talk to, you will approach the potential synergy differently. If you have to approach the procurement department you will focus on the commercial value, while if you speak to the environmental manager you will tend to emphasise environmental benefits"*

7.6 Conclusions

Over the five years that the programme has been running, NISP has achieved impressive outcomes in terms of waste landfill diversion, reduction of CO_2 emissions, creation and safeguarding of employment and generation of revenues and inward investments. The success of the programme can be linked to both internal and external conditions that have favoured the identification and realisation of environmentally and economically viable solutions. From an internal point of view, NISP has developed a strong methodology based on a two-level interface that covers national and regional levels, organised as a multi-node network, where each regional programme constitutes the coordination node at the regional level. At the centre of its methodology are the quick-win workshops, that act both as an element of attraction for members and as a catalyst of IS opportunities and the CRISP database that capitalise on the knowledge gained through IS projects in the different regions and allows its diffusion to the rest of the network. From an external perspective, changes in waste regulation and more importantly the gradual increase in the landfill tax have positively contributed to the economic viability of IS projects. The current climate of economic recession and public funds cuts can compromise the continuity of the programme in the future, and questions are being raised regarding the ability of the programme to evolve as a private initiative. Two main challenges can arguably question the delivery of NISP as private service: the first and foremost is related to the uncertainty of the outcomes of the cooperation and the second, with an ideological component, the legitimacy and, to a certain degree, viability of privatising the knowledge generated in IS exchanges by transforming it into a private commodity.

D. DISCUSSION AND CONCLUSIONS

The conclusions of the research have been summarised in Chapter 8. Based on the cross-comparison of the case studies, the main findings are presented. In light of the research question, lessons from the study are discussed. The chapter ends with a reference to future research needs and policy-making guidelines to foster IS.

Chapter 8.
Discussion and Conclusions

This chapter discusses some of the main findings derived from the cross-comparison of the case studies analysed in previous chapters. The cross-comparison of these IS initiatives covers three main dimensions of analysis: the structural-organisational dimension, the social dimension and the discursive dimension, as proposed in the analytical frameworks outlined in chapter 4. Main conclusions are then presented in connection with the research question and hypotheses that guided the project. Finally, some recommendations for policy and future research are offered.

8.1 Discussion of Key Findings

Following the analytical framework presented in Chapter 4, the cross-comparison of the case studies has been undertaken at three levels: the structural-organisational level, the institutional or contextual level and the discursive level. For the first two levels, SNA provides the main analytical tool for the identification of the key elements of IS networks, while discourse analysis underpins the analysis of the discursive dimension. The next sections discuss the main findings obtained from the analysis regarding the structural characteristics of IS networks, the exchange conditions that may foster or limit the emergence of cooperative relations, the development of social mechanisms of control and their role in the operation of the network and the relevance of embeddedness in achieving the reported potential benefits of IS. Finally, the role of discourse in shaping the operation of IS networks is discussed.

8.1.1 Structural Characteristics of IS Networks

The comparison of the case studies in terms of the structural characteristics of IS networks contributes to the identification of key elements that may favour the emergence of IS synergies and the maximisation of the outcomes of cooperation. Table 8.1 summarises some of the main elements derived from the analysis.

Table 8.1: Cross-comparison of structural characteristics of IS networks

			KALUNDBORG	NISP	SAGUNTO
STRUCTURAL CHARACTE-RISTICS	**External**	**Size**	Small-size network (6 major companies + municipality)	Extended network (12,000 company-members)	Small-size network (8 industrial units and a number of external actors)
	Internal	**Core/ periphery**	High degree of coreness Unstructured periphery	Coordination nodes – High degree of coreness Unstructured periphery	High degree of coreness Unstructured periphery
		Density	High	Low	High
		Openness	Closed network	Open network	Closed network
		Centrality	Centred structure, characterised by a well defined core of central actors	Coordination nodes are central actors	Relatively big core Absence of coordination nodes
		Stability	Stability in the composition of the network, although there have been changes in the linkages among actors.	Fast growing network. Less stable in structural terms.	Although there have been historically big disruptions of the network, since the 1980s the network has had a relatively stable core although new actors in the periphery show more variability.
TRANSACTIO-NAL CONTENT	**Exchange of information and knowledge**		Mostly based on informal contacts	Partly institutionalised through coordination nodes and technological partner	Very underdeveloped network of knowledge and information exchange
	Material and energy exchanges		Formalised in commercial agreements	Formalised in commercial agreements	Formalised in commercial agreements
NATURE OF LINKAGES	**Intensity**		High	Low	Low
	Frequency		Frequent /Very frequent	Varies according to the characteristic of the dyad, level of complexity, duration, etc	Mainly low frequency as in most cases exchanges occur for standardised by-products with a well developed market where transactions mimic that of atomistic market conditions.
	Reciprocity		High and not linked to specific dyads (general reciprocity within network actors)	It is linked to specific dyads and varies according to the characteristic of the dyad, level of complexity, duration, etc	Low reciprocity, as in most cases exchanges occur for standardised by-products with a well developed market where transactions mimic that of atomistic market conditions.
	Multiplexity		High	Low	Low

\Source: author generated

Regarding the structural characteristics of the network, there seems to be a tension between the size of the network and its density, centrality and stability. As expected, small networks show higher degrees of density, centrality and stability. The findings from the case studies suggest that these elements contribute to the explanation of the performance of the network and its ability to generate benefits. Compact and centred networks, with a well defined core, increase the likelihood for IS relations to emerge by reducing path distance and therefore transactions costs. However, it is also important to note that the small size of the network may be negatively correlated with its degree of openness, making it more difficult to attract new members and therefore widening the basis of cooperation. The case of Sagunto, however, shows the importance of the peripheral members in generating new IS opportunities, and their contribution to widening the basis of the IS kernel. Most of the new projects emerging in the network have involved at least one member of the periphery. This also seems to be the case of Kalundborg, where more recent projects have involved network nodes situated on the periphery. Therefore, the importance of nodes in the periphery, generally acting as catalysers of new IS projects (involving in most cases a core and a periphery member), seems to point to the potential of weak ties, and, thus, the validity of Granovetter's (1973) claims on the strength of weak ties. Coordination nodes in large, non-spontaneous networks increase the degree of coreness and centrality of the network, reducing path distance between actors. Moreover, a star-shaped network with the coordination node in the centre, increases the likelihood for peripheral actors to get involved in IS projects.

Looking at the transactional content of the linkages, a crucial aspect derived from the analysis, is the essential role of informational and knowledge transactional flows in the operation of the material network. The existence of a dense information and knowledge network supporting the material exchanges has been identified as a key element for the successful development of the IS networks in the case studies analysed. The success of Kalundborg in developing a complex material IS network can only be explained by the parallel development of a strong knowledge and information network. Information and knowledge transfer has also proved to be a key element in achieving IS synergies in the case of NISP. In both cases, but especially in the case of NISP, that stands for a large and loose network, information and knowledge transfer has been mediated by the coordination node. Also the low degree of development of the knowledge network in the case of Sagunto seems to partly explain the fact that not all IS opportunities among closely located companies are being exploited. Therefore, it can be concluded that the development of a well-established and dense knowledge network seems to be a key element in the success of IS networks. This is also closely related to the nature of the links and the capacity of the network to generate embedded ties that is studied in further detail in section 8.1.3. Issues that have been identified to reinforce the knowledge and information network rely on the development of the social base of the IS network.

As noted, the nature of the links predominant in the network has a relevant impact on the performance of the network. Elements such as intense and frequent communication, a sense of general reciprocity and multiplexity, seem to characterise successful networks. Moreover, the lack of some or all of these components may explain, as the case of Sagunto shows, their role in achieving the potential benefits attached to IS exchanges and the likelihood of new projects to develop. The development of the knowledge network depends to a great extent on the capacity of the network to generate intense, frequent and reciprocal communication procedures and routines. In the case of Kalundborg all these aspects have been favoured by the pre-existence of informal business networks and a structured social fabric. In the case of Sagunto, the absence or low degree of these elements contribute to explain its difficulty in generating new IS projects outside the traditional recycling markets and limitations on evolving from an IS kernel to a fully developed IS network. Achieving intense and frequent communication, multiplexity or general reciprocity is more of a challenge in a network with the structural characteristics of NISP, and more, generally, in any policy-driven IS initiative. All these elements are as well closely related to the social structure of the network and they are more difficult to replicate in non-spontaneous networks, where relations are artificially created to cooperate on specific projects. It is true that, as observed in NISP, more intense ties can be created and frequent communication and a sense of reciprocity can emerge in small sub-groups of actors or cliques, but this is unlikely to be replicated for the whole network.

The analysis of the structural characteristics of the networks and their cross-comparison, can also help to shed some light on the role of anchoring companies in the successful development of IS networks. The literature on IS networks has emphasised the potential role of anchoring companies in the success of IS projects (Chertow, 2000) in favouring the emergence of IS projects. The results from the SNA seem to point in that direction, although they are not conclusive. From the results, it seems that the existence of an anchor company may have favoured the emergence of the network in the first place, but its importance diminishes as the core of the network develops. Once the network has developed, it seems that its performance is more linked to the existence of a well-defined core rather than the anchor company. In this sense the role of the anchoring company would be to initiate the network and then to help in the establishment of a core. This would contribute to the reduction of the risks associated with the potential disruption of the network in the case of disconnection of the anchor node and it would also increase the opportunities of IS exchanges by widening the material basis of the network. Both Kalundborg and Sagunto were initiatives with anchoring nodes (the power station in the case of Kalundborg and the steel complex in the case of Sagunto). However, as noted above, as the networks evolve, the centrality of anchor nodes is reduced and assimilated to other nodes at the core of the network, as can be seen when examining the different centrality scores of the different networks included in Appendixes B and C. This connects with another finding from the research that seems to point to the relation between coreness and performance of the network. The results suggest that a certain degree of coreness is desirable and has a positive impact on the overall performance of the network. In the case of Kalundborg and Sagunto, the networks scored high in coreness. It is also important to note, that significant differences were obtained for different transactional content matrices. In general, more IS exchanges were realised in matrices with a higher degree of coreness, pointing to a positive relation between degree of coreness and network performance. However, more empirical research is needed to ascertain the direction of the causality, as it is also possible that the number of IS synergies was influencing this score. In both cases the role of centrally located nodes was crucial in the operation of the networks. These central nodes, although with slight variation depending on the transactional content observed, were directly involved in most of the IS projects and also played an important role in terms of brokerage. In the case of large networks, such as NISP, coordination nodes were assuming this role of brokerage, by providing connections between different nodes and shortening path distances.

8.1.2 Exchange Conditions and Social Mechanisms of Control

The cross-comparison of exchange conditions and social mechanisms of control rendered interesting results regarding the role played by regulation, the structure of the industrial system and some social conditions in fostering or hindering the development of the IS network.

The regulatory framework can have a direct and an indirect impact on IS exchanges. Direct effects are connected to the introduction of regulatory requirements that set limits for pollution emissions or recycling targets. Indirect effects are changes in the wider institutional framework induced by regulation that have an effect on the structure of priorities of the company and its discourse. Based on the findings of the research, regulation has been proven to play both a fostering and/or hindering role in the realisation of IS opportunities. The research found that a stringent environmental regulatory framework is an essential driver for companies to engage in IS exchanges. Changes in the regulation had a direct impact on company policies regarding waste management and use of alternative fuels. In the cases of Kalundborg, Sagunto and NISP, limitations on emissions of greenhouse gases and other pollutants were the basis of a number of IS projects. Moreover, regulation imposed changes in the structure of relative prices of different waste management options, making the reuse and recycling of materials a more attractive option for the companies in merely economic terms. In the case of NISP, the progressive increase of the Landfill Tax, contributed to the economic viability of some of the IS exchanges realised. Even though in cases where IS exchanges have been part of the history of the industrial area, as is the metal cluster in Sagunto, the environmental regulation has induced new IS opportunities beyond the more standard and traditional exchanges of metal by-products. From a wider perspective, changes in the institutional and regulatory framework have contributed to a progressive introduction of the environmental principle in the industries as an essential part of their corporate responsibility, promoting the adoption of company environmental policies and systems, which, in most cases, set targets and performance objectives that go beyond current regulatory limitations. Indeed, IS projects generally involved sectors of activity subjected to stricter regulatory requirements.

However, regulation could also have a hindering effect. The hindering effect of regulation is related to the legal feasibility of IS exchanges, when materials are classified as waste, and varies according to the degree of flexibility of regulatory bodies in the enforcement of regulation. The requirements imposed on IS synergies that involve materials classified as waste contribute to an increase in transaction costs associated with the exchange, limiting in some cases its viability. The regulatory barriers were especially important in the cases of NISP and Sagunto, whereas in the case of Kalundborg regulation was not identified as a problem for the realisation of IS exchanges. As mentioned above, differences in the flexibility in the enforcement of regulation and the communication with regulatory actors seem to explain the divergences among the cases. Whereas in Kalundborg the relationship with regulatory actors was more flexible, Spain and UK presented a less flexible regulatory framework. This increased the difficulty of obtaining exceptions or permits, and thus magnified the complexity of material exchanges classified as waste, limiting their feasibility.

Together with changes in the regulatory framework, the shortage of essential raw materials and/or the existence of large volumes of high value by-products were also key elements in the emergence of IS projects. Indeed, in the case of spontaneous networks, this condition seems to have played a crucial role in the emergence of the network, as both the case of Kalundborg and Sagunto point to. In these cases, economic gains associated with IS exchanges prompted the development of a by-product market, favouring the emergence of IS exchanges among companies. These exchange structures led in some cases to strengthened cooperation among actors, constituting the key to more embedded IS relations.

The level of competence is another condition which affects the likelihood of emergence of IS relations. The findings of the research point to a link between the level of competition and communication policies. High competitive market conditions when linked to flexible communication policies were found to contribute to fostering the emergence of IS synergies and cooperation projects. However, when linked to strict communication policies, that impose restrictions on the communication with third actors, they constitute an obstacle for building trust and allowing collaboration to emerge. Other exchange conditions that have been proved to play a relevant role in the case studies analysed is the geographical concentration of complementary industries in a relatively small area and the availability of large volume and/or high value waste streams.

The development of social mechanisms of control also determines the cooperation relations. Social mechanisms of control favour the development of the network by promoting the emergence of trust and reciprocity and penalising deviant behaviour by network members. This has a direct effect in reducing the transaction costs associated with IS projects and, therefore, in achieving the potential benefits of IS. Looking at the results from the case studies, social mechanisms of control such as collective sanctions, reputation and macroculture of cooperation seem to have significantly contributed to the successful development of Kalundborg. On the contrary, in Sagunto the low degree of development of some of these mechanisms may explain the fact that IS opportunities are not fully exploited. In this case, the underdevelopment of these mechanisms is closely linked to the business culture in place (that emphasises the individualistic approach based on competition over cooperation) and the lack of development of a common vision and shared goals. Although reputation is important in terms of the integration with communities and clients, it is less relevant at the business-to-business level. Thus, inter-organisational relations are clearly not being addressed by onsite companies. However, it is important to note, as discussed on Chapter 6, that there have been incipient attempts to foster cooperation among companies in environmental issues, generally related to the control of risks. In the case of NISP, the size of the network dilutes the effectiveness of elements such as collective sanctions and reputation, although it could be argued that the presence of the coordination node may help to guarantee a certain degree of fair play between organisations. Notwithstanding this, the fact that in many cases technical and economically viable IS exchanges have failed in the negotiation phase can be connected to the underdevelopment of these mechanisms. Table 8.2 provides a summary of the main emergence conditions identified for each of the case studies.

Table 8.2: Comparison of emergence conditions for the case studies

KALUNDBORG	SAGUNTO	NISP
Shortage of fresh water as input material Stringent environmental regulatory framework Geographical concentration of companies producing high volume of a wide variety of waste flows Extended macroculture of cooperation in business context, past experience of cooperation Multiplexity increases the importance of collective sanctions and reputation	Availability of high volume of relatively high value waste material (metal scrap) Metal transformation industrial complex favours intra-firm exchanges between different production units, belonging to the same business group IS exchanges with neighbouring companies driven by economic gains and low transportation cost Macroculture of cooperation and collective sanctions do not play a significant role Progressive increase in the environmental regulatory requirements and implementation of IPPC	Landfill space scarcity Growing importance of environmental issues in regulatory framework The large size of the network limits the potential development of social mechanisms such as macroculture of cooperation, reputation or collective sanctions The existence of a coordinator might offers some guarantees of "fair play" and contribute to the learning process

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8.1.3 Embeddedness

In the interface between exchange conditions and social mechanisms of control, the degree of embeddedness determines the scope of the cooperation process and the ability of the network to achieve the potential benefits of IS. As explained in Chapter 4, embedded relations have a positive impact on the degree of flexibility, innovation and generation of value associated with IS exchanges. Main components were identified as characterising embedded relations in IS networks: 1) trust; 2) fine-grained information transfer; 3) joint problem solving and 4) multiplexity.

The table below summarises the main findings of the research regarding the mechanisms and outcomes for each of the components of embeddedness in IS networks. The comparison points out distinctive trajectories in the development of some of the mechanisms examined.

Table 8.3: Main features of embedded ties and networks

	Mechanisms/ conditions	**Outcomes**
Trust	• Size of the network • Past-history and shared experience • Common goals and Values • General reciprocity • Emotional contractual ties • Frequent interaction	• Reduces the risks associated with transactions, by preventing opportunistic behaviour • Reduces access barriers and learning costs • Promotes willingness to collaborate
Fine-grained information transfer	• Learning by doing and close interaction facilitates deep understanding of the organizations dynamics • Generation of tacit knowledge	• Flexibility, rapid response and adaptability • Reduces the risks and costs and increases the effectiveness of coordination.
Joint problem solving	• Routines of negotiation and communication • Development of a "common language"	• Rapid identification of problems, due to implicit feedback mechanisms • Cooperative approach
Multiplexity	• Diversity of roles that a pair of nodes can represent • Embedded ties are a combination of business relation, friendship and other social/cultural attachments	• Promotes trust and willingness to cooperate • Minimises opportunistic behaviour • Confers stability and flexibility to the connections

\Source: author generated

In the cross-comparison of the cases studied, the presence of embedded relations was connected to: 1) more ambitious IS projects and 2) the capacity of the network to generate innovations and/or technological development. In these cases, trust, exchange of fine grained information and joint problem solving were essential in the maximisation of the benefits associated with IS exchanges. Outcomes of embeddedness, as previously suggested, relate to increased flexibility, capacity of adaptation to changes and prompt evaluation of problems/challenges and adoption of innovative ways of solving problems. It is also important to emphasise the evolutionary nature of embeddedness as, in most cases, embedded relations develop after participation in other more standard IS exchanges. This highlights the relevance of past experience and learning in the process of building cooperation.

8.1.4 The Discursive Dimension of IS: The Role of Discourse in IS Networks

As discussed in previous chapters, discursive elements are inextricably linked to the social mechanisms and processes governing the operation of IS networks. The findings of the case studies suggested that discursive elements contribute to the explanation of the decision-making process of companies and the priority given to environmental issues. Aspects such as the business macroculture or the conception of the business relations are directly related to the structure of predominant discourses and have a significant influence on the willingness to cooperate and the development of embedded relations. The table below summarises the main features of the predominant discourses for each of the case studies selected.

Table 8.4: Analysis of predominant discourses in IS networks

Discourse features	KALUNDBORG	SAGUNTO	NISP
Storyline	Self-development of the network combining economic and environmental dimensions in mutually beneficial ways	IS exchanges are evaluated from a narrow economic perspective. Environmental advantages of IS solutions are generally not identified/recognised	IS exchanges are connected to resource optimization strategy. The IS network intends to enhance the use of resources in the industrial sector, by connecting resource needs and resources availability
Basic conceptions	Complementary character of economic and environmental performance	Conflicting character of the relation between natural and industrial systems	Inclusive vision built on the concept of resource efficiency maximisation
Main actors	Industry	Industry	Industry Services Public sector Environmental agency
Metaphors and tropes	Symbiosis system of industrial relations Industrial system is seen as integrated into local	The concept of IS is not known to the industries operating in the area. IS flows are regarded as standard by-product	Waste from one company can be another's resource

Discourse features	KALUNDBORG	SAGUNTO	NISP
	natural and social systems	exchanges	
Principles	Connectedness System approach Cooperation Community Gradual change	Optimization of resources Minimization of costs Competition	Optimization of resources Minimization of costs Cooperation
Legitimised way of action	Cooperation is understood in broader terms that include not only waste stream management but also fostering new areas of cooperation Commitment with sustainability is embedded in the organisational strategy Informal information channels/ meetings Absence of coordination entity Self-regulation of the terms and dynamics of the network	IS exchanges are integrated into the by-product strategy of the company and driven by economic benefit Environmental principles are progressively incorporated in the business strategy, although still in rather reactive ways Individualistic approach to environmental management, that stresses competition over cooperation	IS exchanges and cooperation are seen as part of the optimization strategy of the company IS exchanges are evaluated in mainly economic terms More complex

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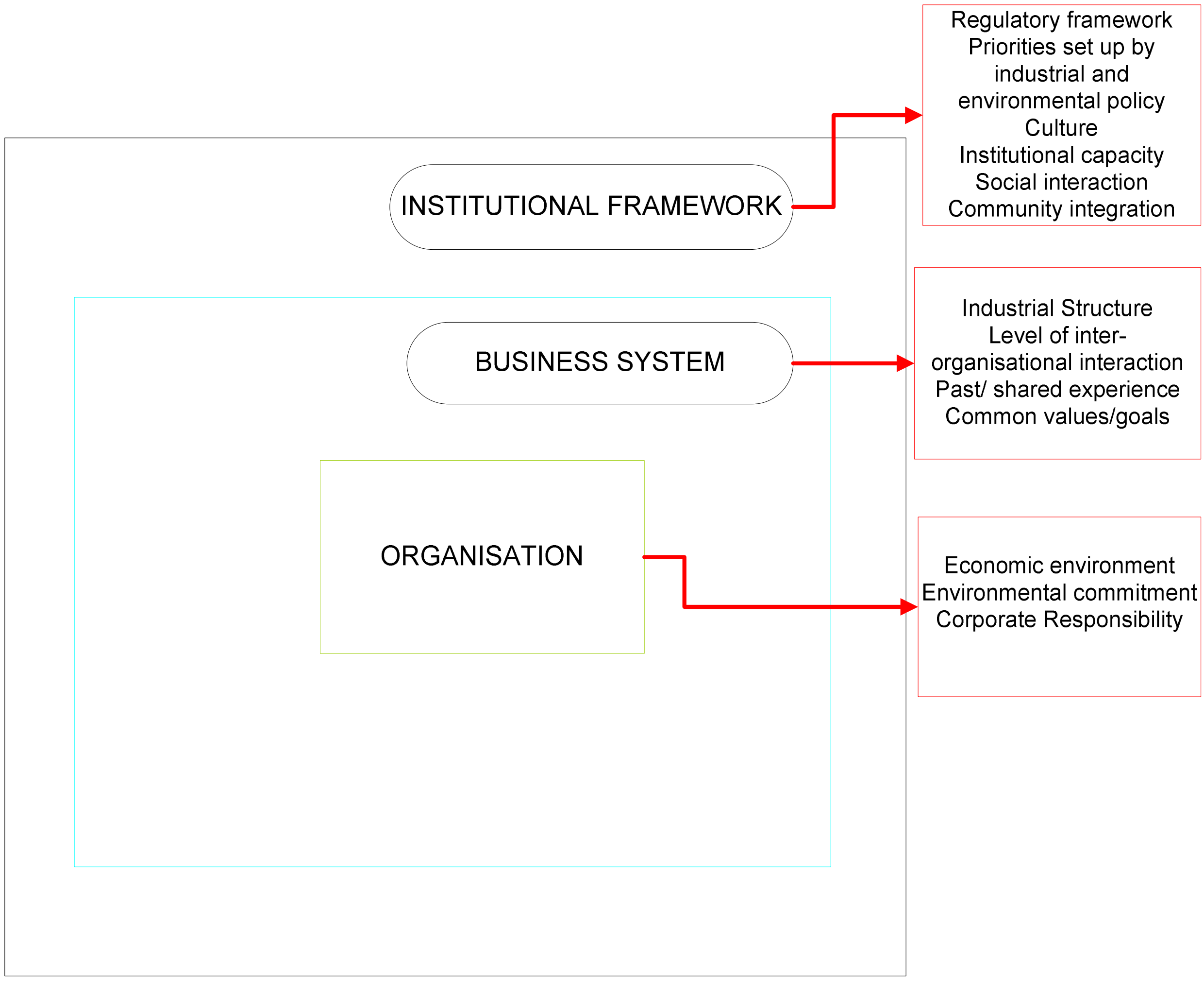
In discursive terms, the network in Kalundborg is the one that shows a more advanced integration of environmental principles at the core of the business strategy. Environmental performance and economic performance are seen not as isolated but as complementary aspects of the corporate policy. IS principles (Korhonen, 2001; Ehrenfeld, 2000) such as connectedness, cooperation, community, gradual change and system approach, have all been to some extent internalised in the IS network of Kalundborg. IS relations have been constructed as a legitimised way of action, giving place to a complex IS system. In the case of Sagunto, although IS exchanges are connected to the history of the industrial development, the predominant discourse is still far from the full integration of environmental principles and the understanding of environmental and economic performance in complementary ways. A conflicting vision between economic and environmental requirements is still widespread among onsite actors. The progressive implementation and enforcement of stricter environmental regulations, such as the IPPC, have contributed to a parallel process of integration of environmental principles into the companies' strategies, although the individualist approach to management is clearly predominant and the conception of competition as opposed to cooperation is prevalent. In the case of NISP, the analysis has focused on the understanding of the discourse adopted by the coordination node and the role it has played in attracting industrial members and fostering cooperation. In this case, the strategy of the coordination node has relied on stressing the business character of the programme, and emphasising the potential economic benefits of IS exchanges. As highlighted in Chapter 7, NISP has consciously intended to adapt to the predominant business discourse and connect IS exchanges with the discourse on optimization of resources. In this rather pragmatic approach, IS exchanges are presented as business opportunities. Notwithstanding this, the rather heterogeneous character of the network also suggests a diversity of environmental discourses, which range from a narrow conflictive conceptualisation of the relationship between natural and industrial systems to more advanced positions that recognise the key role of environmental issues in the strategy of value generation. This diversity has also been recognised by NISP practitioners, as noted in Chapter 7, leading to adaptations of NISP strategy in accordance with the environmental discourse of the company.

In general, thus, the findings seem to suggest that there is a connection between the nature of the predominant discourse, and its level of integration of environmental principles, and the performance of the network. Networks with a more advanced discourse in terms of sustainability and a reliance on principles of cooperation and connectedness, such as Kalundborg, have managed to develop a fairly complex IS network, while networks, whose predominant discourses are based on competition and conflict, such as in Sagunto, have not managed to fully exploit and gain advantage of IS opportunities. However, the direction of the causality is not clear, and further research is needed for the understanding of the interaction between the material and discursive dimensions.

The research also points to three levels of analysis that interact with the creation of the environmental discourse of the network: 1) the organisation; 2) the business environment and 3) the institutional framework. Within each of these levels key factors contributing to the process of discourse construction have been identified, as shown in figure 8.1.

Figure 8.1: Levels of discourse analysis: factors influencing discourse



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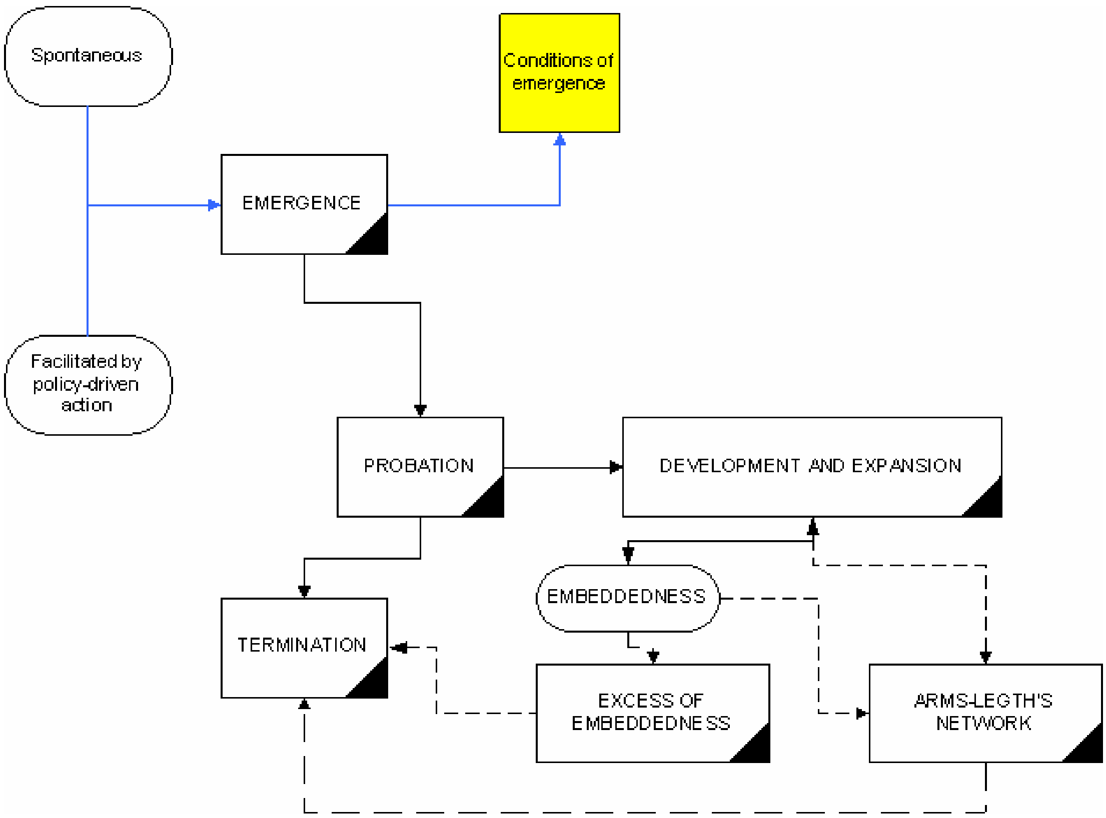
At the institutional level, main factors influencing the discourse are connected to the regulatory framework and the priorities defined by industrial and environmental policies. These factors shape the wider context in which organisations operate and have an impact on the structure of values and principles that guide action, by establishing accepted and deviant behaviours. At the business level, important elements, also contributing to the construction of discourse, are related to the characteristics of the industrial structure, the past or shared experience and other aspects such as inter-organisational relations and common goals and values. At the level of the organisation and in interaction with the business system and institutional dimensions, discourse construction is shaped by the economic environment and market conditions in which the organisation operates, its internal environmental policy, and, closely related to this, its wider corporate responsibility strategy. The findings also suggest that conflict among these three main levels may emerge and that the relative importance of each of these dimensions varies from case to case. Whereas in Kalundborg a rather coherent discourse has been identified along these three levels, in the case of Sagunto, the discourse is more fragmented with elements that build on the traditional industrial discourse on the business system dimension and more advanced positions in terms of sustainability at the institutional and organisational level. In the case of NISP, as already noted, the heterogeneity of the networks is also reflected in the structure of predominant discourses for each of the levels of analysis identified here.

8.2 Phases in the Development of IS Networks

From the analysis, different phases have been identified in the development of IS networks, as shown in Figure 8.2. While the black lines denote the expected evolution of the network, dashed lines show potential deviations that may pose risks to the development of IS. Although the process is continuous and some phases may overlap or merge, the identification of discrete phases serves the analytical purposes of investigation of the dynamics of emergence and operation of IS networks.

Figure 8.2: Phases in the development of IS networks



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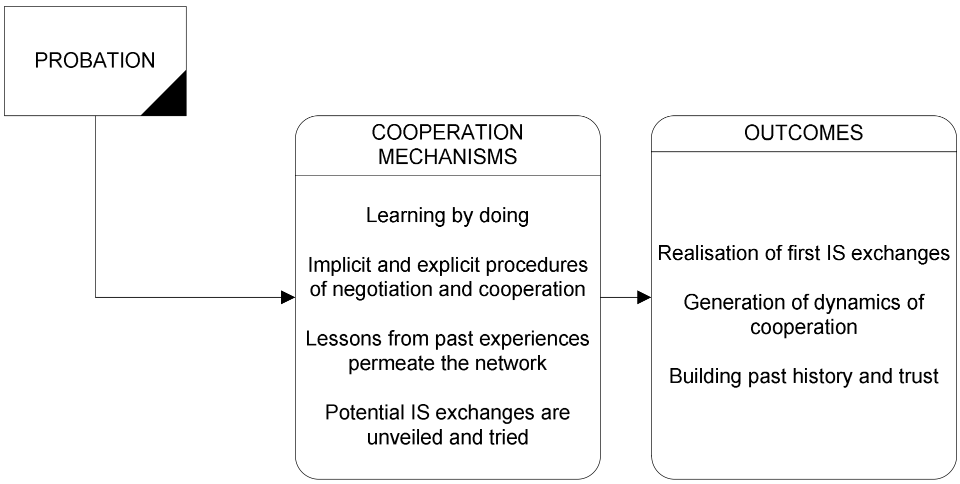
A first phase in the development of IS networks is the **emergence** of the network. As already noted, some main conditions seem to characterise the contexts where IS emerges (Domenech and Davies, 2009). The conditions are: 1) stringent and rapidly evolving regulatory frameworks; 2) shortage of essential raw materials and/or availability of high value byproducts; 3) waste-flow exchanges require customised, non-standard, applications or involve an innovative component or approach, and, therefore, imply uncertainties with regards to the outcomes and process; 4) as a result of the need for customised solutions, high coordination is required, which requires frequent interaction between companies, favouring the transfer of tacit knowledge, "learning by doing", and the creation of a shared culture or "macroculture" (Jones et al, 1997).

In this first phase, initial ties are developed and some straightforward cooperation opportunities explored. Generally, these first ties do not require complex transformation processes, technological upgrades or innovation, but they set the basis of the dynamics of cooperation. The formation of the network may be the result of a spontaneous process, such as the network in Kalundborg and Sagunto, or be initiated by a policy actor, such as the case of NISP. In the case of Kalundborg, the emergence of the network is associated with the scarcity of water, a key productive resource for the companies located in the area. This restriction forced companies to look for alternatives to the shared problem posed by the limited availability of ground water. Cooperation, thus, built up as an adaptive response to the contextual conditions. In the case of Sagunto, the emergence of the IS exchanges can be directly connected to opportunities for the reutilization of valuable by-products generated by the steel blast furnace. This led to a vertically integrated, mono-sector industrial system, linked to the activity of metal transformation since the 1920s, that grew in importance and complexity until the 1970s. Significant changes occurred in the industrial system as a consequence of the process of industrial restructuring in the 1980s, modifying the structure and operation of the IS network. In both cases, Kalundborg and Sagunto, the access to a key productive resource favoured the emergence of structures of cooperation that then evolved into more complex relations. In the case of NISP (but also in Sagunto and Kalundborg) the existence of a stringent environmental regulatory framework is essential in explaining the emergence of the network.

The next phase in the development of IS networks is the **probation** phase. At this stage, network members have a general knowledge of the dynamics of the network and the opportunities of potential exchanges and cooperation. First experiences of exchanges are generated and feedback from them permeates the network, through more or less informal channels that might vary from comments by members in informal meetings to more formalised accounts of the experiences such as publication of case studies. This phase is crucial as failure in the realisation of the opportunities may lead to the early collapse of the initiative. The probation phase constitutes a first step in the development of embeddedness among a selected group of actors among which exchange ties have taken place. The experience of the cooperation generates trust and "learning-by-doing", decreasing the risk associated with further exchanges.

Figure 8.3: Probation phase: cooperation mechanisms and outcomes



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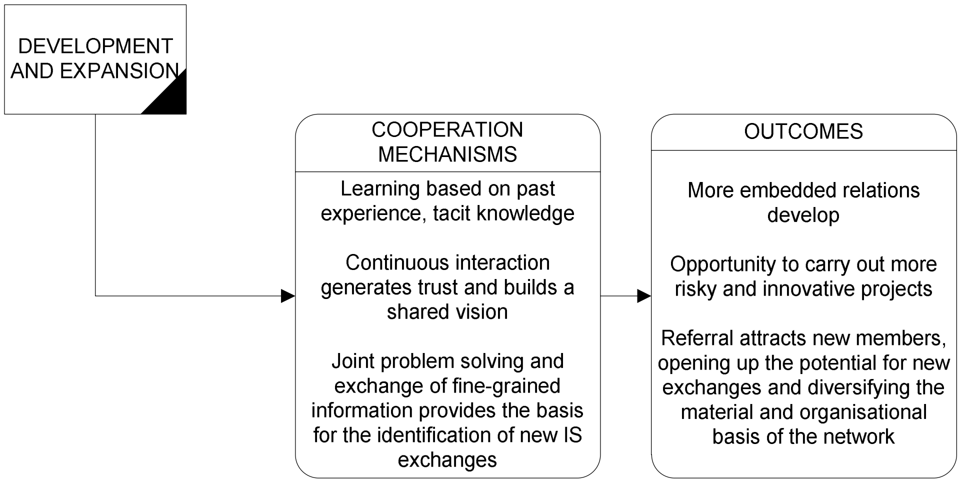
Building on the experiences of the probation period, the network enters into a phase of **development and expansion** by the building of new linkages and/or the deepening of existing relationships. Continuous interaction and accumulation of experiences of cooperation allow the thriving of embedded ties, governed by trust, tacit knowledge and joint problem solving and generate routines of cooperation that significantly reduce transaction costs. More experiences of interaction increase the possibilities of further potential exchanges by a) widening the material and knowledge base of the system and b) through the mechanisms of referral and transitivity (assuming that the referred parties will behave cooperatively), that favour the identification of new potential linkages and actors, deepening the level of embeddedness of the network as a whole.

Figure 8.4: Development and expansion phase: cooperation mechanisms and outcomes



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Expansion of the network, either in size or density, may, however, in some cases, lead to: a) a scenario characterised by an excess of embeddedness or b) an arm's length network.

Embeddedness positively impacts on the economic and environmental performance of network members by providing the mechanisms that decrease transaction costs, increase flexibility and promote learning and innovation. However, an excess of embeddedness may pose some risks for the operation of the network by increasing the dependency among members and, thus, its vulnerability in the face of changes, either in the context or in its composition. It has to be noted, however, as it will be discussed later, in the case of IS networks, this risk and its consequences, even if they may eventually disturb the structure of the network, would be unlikely to have a major impact on the overall economic performance of the company, as: 1) waste and recycling represent a small fraction of the costs structure of the organizations; 2) until other potential exchange ties are found, organisations can look for other alternative sources of input materials and for other routes for the treatment or recycling of their waste streams.

The expansion, in size, of a network may also have a negative effect on the process of building embeddedness, turning it into an 'arm's length' network. This kind of network resembles the atomistic market condition, where price is the main mechanism determining the transactions. In large networks, the process of generation of trust and embeddedness may constitute an important challenge as the social mechanisms that allow cooperation and trust to emerge, are constrained by the size of the network. NISP has addressed this difficulty in coordinating a large-scale network by its organization into regional programmes, which contributes to reduction of the geographical scope of the network, reducing transportation costs and allowing social interaction to develop. Regional programmes act as coordination nodes that facilitate the interaction between organizations that have potential for IS exchanges and gather the knowledge and learning generated by novel IS exchanges. Notwithstanding this, the ability of NISP to generate embedded ties is debatable, as aspects such as personal, frequent contact, reciprocity or shared vision and goals, are difficult to replicate in large networks, and control mechanisms such as reputation or collective sanctions have its impact and relevance reduced. The role of the facilitator may compensate for some of these mechanisms as it guarantees a certain degree of "fair play" and agreed norms among actors. It can occur, though, as tighter ties between companies that have initially been introduced by NISP develop, giving raise to embedded relations.

8.3 Conclusions: How Does the Research Provides a Response to the Research Question Outlined

The main research question that has guided this thesis was concerned with the identification of the key social processes influencing the emergence and development of IS networks. With regard to this, two main contributions of this research can be highlighted. One is the development of a comprehensive methodological and analytical framework for the understanding of the structural, institutional and discursive dimensions of IS networks. This novel framework combines elements from SNA, Network Theory and Discourse Analysis and adapts it to the characteristics of IS networks. As a result of the application of the analytical framework to the case studies, the other main contribution consists of the identification of the main factors influencing the process of emergence and development of IS networks at three interacting levels: internal structure, institutional context and discursive level.

The findings from the research highlight the relevance of the institutional context in which the networks are embedded in shaping their emergence and dynamics of operation. Institutional frameworks characterised by stringent environmental regulatory systems combined with a flexible implementation and enforcement approach provide a good basis for IS relations to develop. The role of the institutional framework is two-fold; it generates economic incentives for IS by altering the relative price structure of pollution/waste generation and it contributes to changing the priorities and principles that guide business actors' decision-making processes.

Structural characteristics of the network such as density or coreness seem to favour the realisation of IS opportunities, although results are not conclusive. However, the existence of a dense and well-established knowledge and information network seems to be crucial for the successful development of the material and energy network. Findings suggest that the existence of knowledge and information flows is essential for the development of the material exchanges, especially those that require some kind of innovation or adaptation, and, thus, any attempt to create or replicate an IS network must necessarily focus on the development of knowledge transfer mechanisms. This seems to apply both for spontaneous as well as policy-driven initiatives. The development of a knowledge network is also closely connected to the possibility of generating embedded relations. Embedded relations maximise the potential of networking by reducing transactions costs and increasing the flexibility but also complexity of the IS exchanges. Therefore, more ambitious IS exchanges and targets require elevated doses of trust and a strong shared vision.

Exchange conditions that may favour the emergence of IS structures have also been identified. The existence of a stringent regulatory framework and the shortage of raw materials or availability of high value by-products favour the emergence of IS networks. Other elements that may play a role are the need for ad-hoc, customised solutions to shared problems or need of high coordination, as when for example waste streams require a pre-treatment or technology innovations in order to be recovered. In the case of spontaneous networks, social mechanisms of control play a relevant role in the building of trust and embedded relations. The study points out that these mechanisms are difficult to replicate in artificially created networks. In this case, the role of coordination nodes is crucial in creating the conditions where embedded relations may develop.

On a discursive level, elements such as the existence of a macroculture of cooperation prevailing over that of competition have an impact on the willingness to cooperate and on the scope of the IS projects. While discourses based on a narrow economic perspective may foster more standard IS exchanges, which generate short-term benefits but have also limited impact; more advanced discourses in terms of sustainability may favour the adoption of a more heuristic process to evaluate costs and benefits and the realisation of more ambitious cooperation projects. Thus, discursive elements may provide the basis for the extension of the temporal horizon and technological scope of IS projects.

Regarding the material conditions of IS exchanges, it was assumed that the existence of complementary activities in an area may favour the emergence of IS exchanges. However, as the case of Sagunto seems to conclude, the existence of complementary activities does not guarantee the exploitation of IS opportunities, unless they are based on well established waste markets for high value by-products. In the absence of other social or institutional conditions, the complementarity of activities proves to be insufficient to generate IS projects. The availability of technologies to clean up or treat waste streams seems also to be a key element in promoting IS exchanges; however, even when technologies are available, the benefit of the exchange has to justify the costs of acquisition and learning. In many cases the risk associated with novel IS exchanges will discourage investments in clean up technology. Aspects such as the quality specifications, volume and timing of the waste exchange are generally specified in commercial agreements. These elements, although important, can generally be accommodated by companies if technologies are available and the IS exchange is viable in economic terms.

Important as these material conditions are, it is the social drivers that influence the decision-making of key actors. The research concludes that aspects such as trust, shared values, leadership and a stronger degree of environmental commitment play a significant role when moving towards more sophisticated forms of cooperation. However, the impact in the emergence of the network and in its early stages of development is limited. This may be explained because these elements constitute the basis for embedded relations, which guarantee the success of the network in the medium or long term, but they do not seem to play a significant role at early stages of the development of the network. All these aspects require time to develop and, therefore, it is unlikely to lead the development of the network in the first place.

The role of the anchor company remains unclear. If it is true that in the case of Kalundborg the power station may have played this role, the evolution of the network and the evaluation of its core/periphery structure indicate that, even when the anchor company either induced the emergence of the network, it does not guarantee its further development. In the case of Sagunto, the blast furnace steel-factory may have in the past played the role of anchor-company. However, its closure, although disruptive, did not lead to the collapse of the IS kernel, and indeed IS projects have been initiated well after that. More importantly, the scope and level of innovation of exchanges developed after the collapse of the blast-furnace is significantly higher. This seems to suggest that although the role of an anchor company may be relevant in the early stages of the network to favour rather simple and straightforward exchanges, the long-term success of the network is conditioned by the development of social processes that favour cooperation and innovation.

Findings also suggest that the level of commitment of main companies to environmental goals certainly has an effect on the scope and ambition of the projects. Again, while more standard exchanges can be motivated solely by economic factors, IS projects that require a long-term horizon and a certain component of technological or technical adaptation can only be developed under business decision-making structures that recognise the relevance of environmental principles and have integrated the environmental dimension at the core of their CSR strategy. Connected to this, leadership and pioneering in environmental issues can act as a catalyser of new projects. Moreover, leadership is important in creating a shared values and an integrated vision of the industrial system, essential in the building of embedded relations. This is also favoured by the existence of a short mental distance between actors, as the case of Kalundborg clearly demonstrates.

8.4 Recommendations

As argued in this thesis, IS has a role to play in moving towards more sustainable industrial systems. Although the sustainability of IS solutions cannot be considered in isolation but as a part of an integral strategy of development, IS can act as a catalyst of the necessary changes that industrial systems need to undergo. Having three case studies in countries with different institutional frameworks has helped to identify factors that may promote or hinder IS. This section summarises the main recommendations for policy making to foster IS and the sustainability of industrial systems and points to future research needs within the fields of IE and IS.

8.4.1 Recommendations for Policy Making

Some main recommendations for policy making can be derived from this piece of research. The findings of the research have pointed to the relevance of the institutional and regulatory framework in the fostering of IS solutions. Hence, policy-making can play an important role in favouring as well as hindering IS development. The main guidelines for policy-making as derived from the findings, should cover the following areas: 1) remove potential legislative barriers to IS exchanges; 2) provide incentives or introduce changes in the structure of relative prices of waste/pollution management solutions, so that environmental costs linked to less sustainable options are internalized and 3) define clear and long-term sustainable strategies in dialogue with industrial actors, that set the framework for more sustainable industrial systems. Therefore, policy making recommendations cover direct and indirect actions aiming at setting the adequate context for IS relations to thrive.

The progressive introduction of the sustainability discourse in the policy-making process has been accompanied by incorporation of the environmental variable at the core of the business strategy, gaining in relevance to become essential in defining the social "licence to operate" of industrial companies. In the case of Kalundborg, overcoming of the opposition towards changes in the regulation has reduced the resistance of industrial actors and has resulted in the widespread adoption of environmental solutions and green technologies. Also in the case of Sagunto, although most of the exchanges are connected to well-developed by-product markets, new projects have emerged in the last years linked to changes in the regulation and the implementation of the IPPC directive. Although, in this case, the adoption of environmental improvements still has a reactive character, in the last decade companies in the area have undergone major changes in the management of their environmental aspects and have gradually incorporated the environmental principle in their processes of decision-making. Also in NISP, changes in the regulatory framework together with a steady rise of the landfill tax and Climate Change Levy have increased the priority given to environmental issues; partly explaining the success of the programme in facilitating IS exchanges.

Having a long-term policy framework that clearly defines priorities and future regulatory requirements could also help the companies to undertake the necessary changes and look for the most eco-efficient solutions, and thus, favour technological change and adaptation. It is also important to promote dialogue between industry and policy makers. Flexible approaches have also proved to foster innovation in IS networks. Indeed, flexibility in the enforceability of the regulation and frequent dialogue with regulators has been crucial in the successful development of the network in Kalundborg. In the case of Sagunto, the absence of communication and dialogue between industries and regulators has discouraged some IS solutions, favouring more standard and less eco-efficient environmental solutions.

Another important area for policy making is the design of information systems that support the development of the resource economy. This would require the mapping out of resources, transfer stations and recycling facilities and the identification of the flow of resources. This could have applications at different levels: 1) at the planning level, it would help in the process of planning regional synergies and the geographical distribution of waste management facilities for the treatment and recycling of waste streams; 2) at the company level, it would assist the process of decision-making regarding most efficient waste solutions and identification of IS opportunities. This is also of special importance for broadening the spectrum of companies involved in IS exchanges, so that the approach could be implemented not only at companies with large volumes of waste streams but also at SMEs.

The creation of the information system of resource flows could also have applications for the industrial spatial policy. This could set the basis for a truly innovative and ambitious sustainable programme, which integrates industrial planning and resource efficiency by encouraging the agglomeration of activities and their distribution on space based on complementary resource needs. Although, it is unlikely that IS exchange will provide enough incentives on its own to have a major impact on business location decisions, spatial planning policy could define priority or incentive structures to favour the agglomeration of activities according to their IS potential. This could include priority in the access/ purchase of land, discounted loans and/or reduced prices of the land. The implementation of this policy, however, would increase the complexity of the planning process and would require expertise and coordination among different levels of government (local-regional-national).

As for direct intervention measures, coordination nodes could be created or funded. Facilitating actors and coordination nodes, may act as a catalyst for the development of IS relations once a favourable institutional framework is in place. As discussed above, facilitating activities can only work if the right incentives shaping industry decision-making (such as environmental regulation or waste generation taxes) have already been developed. If this is the case, coordination bodies can support the development of information systems and can provide assistance in the removing of technical and cultural barriers, as the case of

NISP has proved. However, as argued in Chapter 7, the creation of more complex IS eco-systems, beyond more standard exchanges, requires the parallel development of social mechanisms of control and coordination that are unlikely to emerge by the sole intervention of the coordination body. This points to the need for strengthening social networks and human capital associated with industrial systems; a task far from simple and one that requires an integral approach to environmental policy making. Thus, the creation of spaces for the dialogue among industrial and policy actors should also be considered in the design of a sustainable industrial policy. Table 8.5 summarises main recommendations for policy making.

Table 8.5: Recommendations for policy making

IS POLICY FRAMEWORK
Long-term policy commitments and clear policy strategies allow companies to adapt their processes and explore optimal solutions, contributing to technological change
Stringent regulatory framework needs to be accompanied by more communication with industrial actors and greater flexibility in its enforceability, giving room to the companies to innovate and to find better environmental and economic solutions
Resource flow information systems are crucial in the progress towards a resource economy, where resources are optimally used, reused and recycled
Changes in the relative prices of different waste management solutions that discourage less sustainable options and the internalisation of the environmental costs of less desirable solutions such as the council tax
Creation of incentives for the agglomeration of companies according to IS potential, with policies of priority location, discount on the price of land or discounted loans.
Creation of coordination bodies can speed up the process of maximizing IS relations, once a suitable institutional and social context has been developed
Creation of spaces for the interaction and dialogue among industrial actors and between industrial and policy actors.

\Source: author generated

8.4.2 Recommendations for Future Research

The research has also contributed to the identification of future research needs in the fields of IE and IS. In the light of the findings, further research is necessary to determine key structural characteristics of successful networks. This means not only looking at static elements such as the morphology of the network but also to combine it with a more dynamic evaluation of the exchange conditions and social mechanisms of control. The analytical framework proposed in this research can actually provide a good basis for further investigations integrating static and dynamic components. Application of the research methodology and analytical framework to different contexts and typologies of networks can bring further understanding of the phenomenon and contribute to refinement of theory and methods. Testing and further refining of the analytical framework is another area for future research.

In this thesis, an attempt has been undertaken to codify the evolution of IS networks and identify phases of development. The identification of phases serves the analytical purpose of advancing understanding of the process of formation and development of IS networks and the key influential factors. However, future research needs to test the phases proposed in different case studies and progress towards further understanding of the role played by different mechanisms in each of them.

There is also a clear area that needs to be tackled by future research that connects with the prescriptive dimension of IS. The policy implications of IS networks and, more importantly, the role of policy in fostering the development of knowledge and informational flows as the basis of IS material exchanges, needs to be addressed and further investigated, so that IS networks can be integrated in the wider local/regional sustainability agenda.

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