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# Facilitation of Industrial Symbiosis Development in a Swedish Region

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*To My Lovely Daughter, “MOBINA”*

# Abstract

Today, sustainability of industrial regions and industrial networks is a challenge for business developers, policy makers, regional planners, local and governmental authorities and academic researchers. Because growing cities and industrial regions worldwide are intertwined with social, environmental, and economic advantages/disadvantages and challenges, in recent decades the ambition of industrial development and economic growth without environmental destruction has become a worldwide topic. To address this issue, a number of theories and pathways such as Industrial Ecology (IE) and its subfield Industrial Symbiosis (IS) toward sustainability of industrial regions and networks are being researched, examined and implemented.

The overall aim of this thesis is to explore how local connectedness amongst locally distributed firms in industrial areas can be facilitated using industrial symbiosis theory and tools. To address the overall aim, the facilitation of IS development in this thesis includes three focus areas: 1) using IS theory and tools for categorization, characterization, and definitions of different lines of IS development; 2) matching the supply and demand potential of regional $CO_2$ resources through industrial collaboration; and 3) using geographic information systems (GIS).

Based on the research findings it is concluded that one approach for facilitating IS development is to apply IS theory and tools in an industrial region to find out whether any forms of IS already exist and what definitions of IS fit the area. Furthermore, it is also concluded that another approach for facilitating IS development could be matching the supply and demand potential of resources within industrial collaborations. However, availability and provision of relevant data and information plays an important role. In addition, it is seen that handling and developing existing regional data and information into a GIS-based format could contribute to facilitation of IS development. In general, it is seen that facilitating mechanism and facilitating organization are available, and should be coordinated.

# ACKNOWLEDGEMENTS

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*Linköping, November 2012*

*Saeid Hatefipour*

# LIST OF APPENDED ARTICLES

This thesis is based on the following articles, which are appended at the end of the thesis. Throughout the text, the articles are referenced by Roman numerals.

## ARTICLE (I):

Understanding the industrial network in Händelö/Norrköping, Sweden by applying industrial symbiosis theory and tools (manuscript).

## ARTICLE (II):

Utilization of industrial $CO_2$ emissions by matching the supply and demand potential within industrial collaboration/symbiosis in a Swedish region (manuscript).

## ARTICLE (III):

Using geographic information systems (GIS) for facilitation of industrial symbiosis development in a Swedish region (manuscript).

## Related Publications (not included in this thesis):


- Hatefipour, S., Baas, L., Eklund, M. (2011), The Händelö area in Norrköping/ Sweden. Does it fit for industrial symbiosis development?, World Renewable Energy Congress, May 8-13, 2011, Linköping, Sweden

- Hatefipour, S., Gokaraju, S. V. (2011), Mapping industrial $CO_2$ emissions and utilization potentials in the Östergötland county of Sweden, The R&D management conference, June 28-30, 2011, Norrköping, Sweden

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# THESIS OUTLINE

**Chapter 1** *gives a brief introduction to this thesis. It describes the environmental sustainability challenge for industrial development and the research background, followed by overall aim and research questions, overview of papers and research journey, together with an overview of the studied region.*

**Chapter 2** *provides a literature review of the field of industrial ecology, followed by review of industrial symbiosis research. Facilitation of IS development from a social network point of view is addressed and special focus is given to IS theory and tools for facilitation of IS development.*

**Chapter 3** *consists of the employed research process through the thesis, general methodology used and scientific approach of the whole thesis, and methods and approaches that are employed in each appended article.*

**Chapter 4** *summarizes the significant research findings of the three appended articles.*

**Chapter 5** *discusses and analyses the research findings in relation to relevant literature.*

**Chapter 6** *answers research questions and addresses the overall aim of the thesis.*

**Chapter 7** *presents future research path.*

# 1. Introduction

*This chapter presents an introduction to this thesis by giving a description of the environmental sustainability challenge for industrial development and the research background, followed by overall aim and research questions, overview of papers and research journey, together with an overview of the studied region. A brief literature review given in the research background makes a bridge to identify research needs and the overall aim of this thesis.*

## *1.1. Challenge description*

The majority of environmental problems such as climate change, acidification, eutrophication, resource depletion, and global warming are mainly caused by growing human population and activities, and specifically by industrial development. Since growing cities and industrial regions worldwide are intertwined with social, environmental, and economic advantages/disadvantages and challenges, there is a need to develop and expand industrial areas in a way that contributes to less environmental impact, more economic prosperity, and regional/industrial sustainability. Therefore, one of the big challenges of societies is to meet ambitious goals of industrial development and economic growth without destroying the environment. Today, industrial areas play an important role in sustainable development projects and are a relevant challenge for business developers, policy makers, regional planners, and local governments/authorities. To address this issue, several theories, pathways and approaches such as Industrial Ecology/Industrial Symbiosis (IE/IS) toward sustainability of industrial regions are being researched, investigated, implemented and practiced.

## *1.2. Research background*

In recent decades, a substantial amount of research has been conducted in the emerging field of industrial ecology and its subfield, industrial symbiosis. These research fields address sustainability of industrial regions and industrial networks at different levels using different approaches. The sustainability of localized industrial systems using industrial symbiosis together with the regional scale of industrial symbiosis toward developing sustainable regions are presented by Ristola and Mirata (2007). Supporting this concept, the key elements to industrial symbiosis are defined as *"collaboration"*, *"synergistic possibilities offered by geographic proximity"*, and *"co-located firms"* by Chertow (2000) and Brings Jacobsen (2006).

Existing literature in the field has discussed different pathways of IS and paid attention to different aspects of IS such as social (social network and organization together with human dimension of IS), the evolution, emergence and development of IS, quantitative analysis of IS (environmental and economic benefits of implementing IS), and initiating, fostering, and facilitation of IS.

Concerning social aspects of IS in literature there are discussions about social networks and organization of IS. An approach for understanding the complexity of IS networks is given by Domenech and Davies (2009). They discuss the social aspects of industrial symbiosis by analyzing the potential applications of social network theory to the IS field. The authors concluded that social, cultural and institutional factors that have an impact on development of

IS networks are crucial for understanding the dynamics of IS. Brings Jacobsen (2007) argued the significance of social factors in spontaneous industrial symbiosis development.

By evaluating the incubation and implementation phases, the *"techno-economic"* and social factors of individual industrial symbiosis synergies in the Kalundborg industrial district are compared to each other. He concluded that social factors such as inter-organizational relationships are essential in understanding IS synergies. Baas and Boons (2004) developed a three-stage learning process based on social science theory for analyzing the evolution of regional industrial ecology initiatives in the Rotterdam harbour and industrial complex. Lambert and Boons (2002) also portray the importance of learning processes amongst social actors as a social process toward sustainable development.

Emergence, development and understanding over time in the evolution of industrial systems is studied and discussed by Ehrenfeld and Gertler (1997), Ehrenfeld and Chertow (2002) and Chertow (2000, 2007). Chertow (2007) brought up the concept of *"uncovering"* industrial symbiosis, pointing out that we are surrounded by a number of environmentally and economically profitable symbiotic exchanges of utilized and non-utilized by-products that should be discovered, and then utilized. Some research has paid attention to the quantitative analysis of IS in general and environmental/economical benefits of implementing IS in particular.

Wolf and Karlsson (2008) discussed and demonstrated the environmental benefits of industrial symbiosis in Sweden's forest industry. They concluded that integration of actors and their processes could lead to lower $CO_2$ emissions than the corresponding stand-alone systems, which supports the approach that IS could be environmentally beneficial by changing degree of local connectivity and institutional capacity (Boons et al., 2011).

Quantitative assessment of urban and industrial symbiosis in a case study in the Kawasaki eco-town in Japan was investigated by Van Berkel et al. (2009). The diversity of symbioses and industries as well as the synergistic impact of urban and industrial symbiosis was the core of their research. In a Swedish case study in the Landskrona industrial symbiosis project, the industrial symbiosis networks and their contribution to regional environmental innovation has been investigated by Mirata and Emtairah (2005). They concluded that IS networks could contribute to stimulating environmental innovation at both local and regional levels.

Chertow and Lombardi (2005) have analyzed the quantification of economic and environmental benefits of co-located firms in Guayama, Puerto Rico. The authors concluded that engagement and participation in symbiosis contributed to a few but still considerable economic and environmental benefits for the participants and the community. Brings Jacobsen (2006) has studied the quantitative assessment of economic and environmental performance of industrial symbiosis in Kalundborg, Denmark. Using detailed economic and environmental data, he analyzed industrial symbiotic of exchanges and concluded that, from a firm point of view IS must be realized both as a more collaborative and circular approach as well as individual economic and environmental performances.

Several studies have been done with the aim of initiating and fostering IS. Dissemination and implementation of a series of IS projects in the Rotterdam harbour and industrial complex by Baas and Boons (2007); the Kwinana (Australia) industrial symbiosis initiatives by Van Beers et al. (2007), Bossilkov et al. (2005), CECP (2007), Harris (2007), and Van Beers et al. (2005); industrial symbiosis initiatives in China by Zhu et al. (2007); and fostering industrial symbiosis for regional sustainable development in Kwinana and Gladstone, Australia by Harris et al. (2008) are a few examples of fostering and initiation of IS development.

A few research studies have been made of facilitation of IS by considering the organizational and human dimension of IS, techno-business models for waste management, waste management policies and using ICT tools. Facilitation of IS development by waste management policies in a European context was investigated by Costa et al. (2010).

The authors emphasized the supportive and influential role of policy and legislation in fostering IS development. Paquin and Howard-Grenville (2009) presented the *"third way"* approach which is used for facilitating IS development based on the presence of a brokering organization to bring actors together. They investigated the role of the NISP in the U.K. for facilitation of IS development by providing brokerage services, linking potential actors to potential synergistic possibilities.

Facilitation of IS development using ICT tools together with identification of different tools and their application is investigated by Grant et al. (2010). The authors argued that, since ICT tools have been developed over time from an optimization and data sharing application toward a *"community-building"* tool, it has become more helpful to IS. Furthermore, they identified 16 environmental applications designed for facilitation of IS development.

Chertow (2008) has presented several input/output matching software tools developed by the U.S. EPA as a planning tool, which probably can support IS development and facilitation. FaST (Facility Synergy Tool) was designed as a database for industry input/output of facilities, DIET (Designing Industrial Ecosystem Tool) was built for alternative analysis of variety of facilities used, and REaLiTy (Regulatory, Economic, and Logistic Tool) was made for supporting regulatory barriers, which might come about due to material selection for exchange.

Research efforts have been performed and focused more on development of planned and *"goal-directed"* networks of IS than facilitation of self-organizing, spontaneously developed IS networks. Hence, there is still a research need on facilitation of self-emerging spontaneous IS development which develops over time in the absence of any facilitating plan or agent. Furthermore, the majority of instances of facilitation of IS development have been performed by considering social network, human and organization dimensions of IS, and less effort on facilitation by using IS analytical and planning tools which are mainly dependent on availability, sharing, handling and developing of data and information amongst participating actors and stakeholders in a symbiotic network. Therefore, this has generated the idea of facilitation of an unplanned and spontaneous development of an industrial network, using IS theories and tools.

The present study is related to ongoing research projects at the division of Environmental Technology and Management at Linköping University. On the one hand, it contributes to a research program called *"Sustainable Norrköping"* that focuses on developing links between the industrial and urban parts of the city. The study also contributes to the *"Industrial Ecology Research Program"* (IERP), a research program between Tekniska Verken (the energy corporation in Linköping) and Linköping University. IERP focuses on how industrial ecology approaches can support regional development.

## *1.3. Overall aim*

Literature review demonstrated that there is room for research regarding facilitation of industrial networking in an unplanned industrial eco-system. Since collaboration and connectedness amongst co-located firms is defined as the primary concern of industrial symbiosis, the overall aim of this thesis is to explore how local connectedness amongst locally distributed firms in industrial areas can be facilitated using industrial symbiosis theory and tools. However, facilitation of IS development in this thesis is focused on:

- Using IS theory and tools for categorization, characterization, and definitions of different lines of IS development
- Matching the supply and demand potential of regional $CO_2$ resources through industrial collaboration, and
- Using geographic information systems (GIS)

The thesis will be organized by addressing three research questions that can contribute to the main aim.

- ***Research Question 1***: How can industrial symbiosis (IS) theory contribute to describing and understanding changing degrees of local connectedness in an industrial area?

The reason and motivation for the first research question is that an analysis and understanding of the current situation in the studied region is important. The role of the first research question is to develop a platform for further research by recognizing characteristics of the studied region and what definitions of IS fit the industrial area, using IS theory and tools.

- ***Research Question 2***: How can providing information about supply and demand potential of resources facilitate Industrial Symbiosis development?

The importance of the second research question is to find out the key role of data and information, describing supply and demand of resources that could be useful for facilitation of IS development.

- ***Research Question 3*****:** How can geographic information systems (GIS) be used to facilitate Industrial Symbiosis development?

The role of the third research question is to explore how GIS tools have been used for facilitation of IS development and analyze how GIS tools could play a facilitative role when applied in the studied region.

## 1.4. Overview of papers

*Article (I):*

The first research question aims at understanding, describing and analyzing existing industrial activities and their networks in a Swedish region, using IS theory and tools, which is addressed in the first article.

*Article (II):*

Considering the local connectedness embedded in the region which was identified in Article (I), the second research question explores matching the supply and demand potential of resources through industrial collaboration.

*Article (III):*

Matching the supply and demand potential of resources in Article (II) revealed that providing data and information about amount and geographic location of resources (supply and demand) is a challenge, hence the third research question aims at handling and developing regional data and information in GIS format to facilitate IS development, which is explained in Article (III).

## 1.5. An overview of the Östergötland region and the Händelö/Norrköping industrial area

Östergötland is situated in southeast Sweden and comprises 13 municipalities in an area of around ten thousand square kilometres, sustaining a population of 430,000 inhabitants. Linköping is the largest city in the region following by Norrköping. The twin cities of Linköping-Norrköping are often called the fourth metropolitan region in Sweden. Östergötland occupies about one-fifth of the total area of Sweden. The Baltic Sea is located east of Östergötland, with a regionally important harbour in Norrköping.

Östergötland is an agricultural and industrial region. The major industrial sectors in the region are pulp/paper, food and agriculture, forestry, livestock and fish farming, transportation and logistics, metal and chemical production, machinery, telecommunication, and aviation. The region has a significant production of biofuels and energy service companies that use a large share of renewable resources.

A number of process industries in the region are located at Händelö, a 600-hectare island in the Baltic Sea, just outside the city of Norrköping. Vast areas of a former farm have been developed by industries during the recent years. Due to the nature of Händelö, the area is characterized by *"co-existence"* between nature conservation areas and industrial sites. Furthermore, since renewable energy is an important component of the Händelö area, it can be seen as an attempt to develop an environmentally sustainable industrial area. For around three decades, there have been plans for a major development of industries and infrastructure. Nowadays, the Händelö Island is a centre for logistics companies, and has a renewable energy cluster and Natura 2000 conservation areas. As a result, it attracts interest from business planners/developers, local authorities and academic researchers. Furthermore, the strategic position of the area with access to railway and harbour are other characteristics of the Händelö area.

# 2. Scientific Context

*This chapter gives a brief literature review of the field of industrial ecology, followed by review of industrial symbiosis research. Facilitation of IS development from a social network point of view is addressed and special focus is given to IS theory and tools for facilitation of IS development.*

## *2.1. Industrial Ecology (IE)*

Early footprints of IE concepts can be traced in the journal *Scientific American*, where Frosch and Gallopoulos (1989) introduced the idea of IE in a paper entitled "Strategies for Manufacturing". The authors presented the term *"industrial ecosystem"* and defined it as: "*in such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process… serve as the raw material for another process"*.

The core idea of IE is an analogy between industrial systems and natural ecosystems in which there is no waste generation and renewable energy (solar energy) is the only prime mover in almost all natural processes. Erkman (1997) proposed an analogy between industrial systems and natural ecosystems in which industrial systems and its processes are explained as *"mimicking nature"*. Since it is defined that the IE approach mimics natural ecosystems, all the one-way singular processes and interactions inside the firms and amongst them have to be changed into circular processes and economy to minimize waste generation and maximize usage of renewable energy and profit sharing of each individual firm. Furthermore, industrial ecology has been defined as *"the science of sustainability"* by Ehrenfeld (2004) and *"the study of all interactions between industrial systems and the environment"* by Graedel (1994).

One of the effective pathways for sustainability of urban-industrial regions is the collaborative approach that can be traced in industrial ecology/industrial symbiosis (Mirata and Emtairah, 2005; Kurup et al., 2005). Chertow (2000) suggested that industrial ecology address three levels; *"facility or firm"*, *"inter-firm"*, and *"regional/global"* (Figure 1).

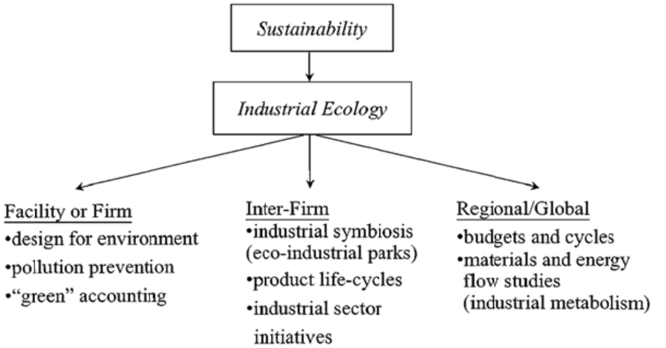


*Figure1. Different Levels of Industrial Ecology (Chertow, 2000)*

Within this approach, industrial symbiosis (IS) can be seen as a part of industrial ecology with the main focus on the *"inter-firm"* level (Brings Jacobsen, 2006). Furthermore, IS and eco-industrial networking (EIN) are presented as IE tools for implementing and applying industrial ecology in industrial regions (Lifset and Graedel, 2002). However, the focus of this thesis is on facilitation of IS development at the inter-firm level involving co-located actors.

## 2.2. Industrial Symbiosis (IS)

### 2.2.1. Industrial Symbiosis definitions, characterization, and categorization

Industrial symbiosis aims at *"engaging traditionally several separate firms and industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products"* (Chertow 2000). Within this concept, the key elements to industrial symbiosis are defined as *"collaboration"*, *"synergistic possibilities offered by geographic proximity"*, and *"co-located firms"* (Chertow, 2000, 2008; Brings Jacobsen, 2006). Accordingly, the concept of symbiotic networks of exchanges within firms and industries is also used by Lifset and Graedel (2002). A rather recent definition of industrial symbiosis was presented by Lombardi et al. (2012). The authors described industrial symbiosis on different subjects and levels such as policy (local, regional, national, and international), and strategic tools for economic development, green growth, innovation, and resource efficiency. Based on this categorization, the authors presented a new definition of IS: *"In spite of the scholarly debates over definition and scope, IS has graduated from academic curiosity to practical tool supported by policy makers, business organizations, and environmental advocates alike — to address a broad policy agenda encompassing innovation, green growth, and economic development, in addition to the traditional focus on resource efficiency."*

Recently, Lombardi and Laybourn (2012) *"unpacked"* a commonly cited definition of IS which was identified by Chertow. The authors presented a new, different definition and perspective of IS emphasizing the principle of IS as an innovative tool for green growth (ibid.). Their definitions sounds more like a *"practitioner-based"* definition of IS that is mainly based on the ideas of practitioners and policy makers, and gives a new position to the IS field as a business opportunity and tool for eco-innovation. Based on the definition by Lombardi and Laybourn (2012), IS is identified as follows: *"IS engages diverse organization in a network to foster eco-innovation and long term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes"*. Some of the key elements of IS that are identified here are: *"diverse organizations, creating and sharing knowledge, and value-added destinations for non-products output"*.

Several instances of IS stated that the network of exchanges, collaborating partners and structure of the cooperative organizations amongst the actors are case-specific (Chertow, 2000, 2007; Van Beers et al., 2007; Van Berkel et al., 2009). Hence, Van Berkel (2009) argued that a frequent theme in IS is the characterization and quantification number of physical exchanges and number of involved actors. Based on this, he presented concepts such as "*connectedness"* and "*symbiotic intensity"*. Another interpretation of IS is presented by Chertow (2007). She stated a *"3-2 heuristic model"* in which at least three different actors are exchanging at least two distinct material/resources, differentiating industrial symbiosis from linear one-way exchanges as a minimum measure. The definition by Chertow is counted on "*symbiotic resource flows"*, while based on Van Berkel (2009), assessment of the symbiotic intensity is stated by counting *"symbiotic projects"*. Moreover, Van Berkel (2009) argued that this methodology (the indicators for symbiotic intensity) seem applicable for monitoring the development, evolution and progress over time of symbioses in any industrial networks and not useful for comparability of IS and for evaluation of economic and environmental benefits of the industrial networks. An analogy between biological ecology and industrial ecosystems made by Hardy and Graedel (2002) contributed to terms such as "*connectedness"* or *"connectance"* for assessing and understanding industrial actors and partners in industrial ecosystems. In a similar approach, Korhonen (2001b,c, 2004b) developed two required features for considering an industrial ecosystem. The author used the terms *"roundput"*, which refers to closed loops and waste utilization between industrial actors, and *"diversity"* to denote the number of different actors involved in an industrial system. Based on Hardy and Graedel (2002) and Korhonen (2001b,c), diversity can create possibilities for increasing connectedness and cooperation. Concerning the industrial networks and industrial actors involved in a symbiotic project, Chertow (2000) made a categorization of an *"integrated bio-system"*, in which the participants and symbioses mainly come from the industrial and agricultural sectors.

Evolutionary approaches to boost eco-industrial development are presented by Chertow (2000). So-called *"green twinning"* refers to projects where some types of energy and material exchanges due to existing synergistic possibilities, are already embedded. Chertow (2000) also refers to the point that already existing organizational relationships and networks can lead to emerging new symbiotic ideas and create a platform for further development. Yet another approach is called as the *"anchor tenant model"* in which, "*Just as shopping malls are built around several large department stores that anchor the commercial development within, one or two large industries can provide the same critical mass for an eco-industrial park*". Power plants and resource recovery plants are typical proposed anchors in many eco-industrial practices (Chertow, 2000; Korhonen, 2001c).

A classification of different exchanges amongst firms and industries in the form of synergies, is made by van Beers et al. (2007) and van Berkel (2006). They categorized the exchanges between industries and actors as supply, by-product, and utility synergies. Since different exchanges have different geographic proximity, which refers directly to the spatial scale (Chertow 2000, 2008), another aspect of industrial symbiosis is devoted to the spatial scale of firms and their exchanges. In this regard, Chertow proposed a methodology based on taxonomy of five different material exchange types, considering both spatial scale and material exchanges amongst firms (Chertow 2000, 2008). The author also suggested that types 3 to 5 *"can readily be identified as industrial symbiosis"* (ibid.).

- *Type 1: through waste exchanges*
- *Type 2: within a facility, firm, or organization*
- *Type 3: among firms co-located in a defined Eco-Industrial Park*
- *Type 4: among local firms that are not co-located*
- *Type 5: among firms organized virtually across a broader region*

Concerning synergistic possibilities and geographic distance, it is implied that by-product synergies can be transported over a longer distance, while utility synergies cannot be economically applied at a longer distance (Chertow, 2000). However, a recent study conducted based on statistical analysis suggests that there is no specific correlation with resource type and geographic proximity (Jensen et al., 2011).

Understanding the evolution, emergence and development of industrial symbiosis is categorized and conceptualized by several scholars in the field. According to Lambert and Boons (2002), development of an eco-industrial network/park can be categorized as a *"greenfield"* or *"brownfield"*. Greenfield refers to a development from scratch, while the latter means restructuring of an existing network/park. The authors also argued that the majority of the current examples of industrial symbiosis are formed within brownfield restructuring.

Concerning management, development, and evolution of industrial symbiosis, Chertow (2000, 2007) presented several terms such as *"planned", "unplanned"*, *"spontaneous"*, *"self-organizing"*, and *"continually evolving"*. A symbiotic network can be developed based on a planned/structured processes in contrast to an unplanned, spontaneous evolution over time. The author also argued that *"in contrast with planned eco-industrial parks, the spontaneous ones are proving to be more robust and resilient to market dynamics"* (Chertow, 2008). This finding is in accord with the observation made by Baas (2011) in comparing planning and uncovering of IS in the Rotterdam and Östergötland regions respectively. He concluded that uncovering the existing symbiotic network in the Östergötland region appears to be in better alignment with small-scale Swedish business concepts than planned eco-industrial parks. In addition, Chertow (2007), who brought up the concept of *"uncovering"* industrial symbiosis, concluded that existing, uncovered symbioses amongst the actors could contribute to more sustainable industrial development in contrast to the cases which tried to build and design new activities from scratch. She also argues that distinctive attributes within the Kalundborg symbiotic network are based on the uncovering of what already exists rather than the introduction of new things.

Some instances of *"self-emerging"*, *"self-organization"*, *"planned"*, *"unplanned"*, and *"uncovering"* industrial symbiosis can be referred to the evolution over time of the Uimaharju forest industry park in eastern Finland by Korhonen and Snäkin (2005), self-organizing spontaneous symbiosis in the industrial district in Kalundborg, Denmark (Chertow 2008), the symbiotic network in Styria, Austria (Schwarz and Steininger, 1997), spontaneous (unplanned) IS developments in the forest industry network in Kisa, Sweden (Wolf, 2007) and biomass/biofuel links in Händelö/Norrköping in Östergötland region of Sweden by Martin (2010) and Nicklasson (2007). Moreover, the likeness and contrasts between planned and unplanned industrial symbiosis activities in the port of Rotterdam in the Netherlands and in the Östergötland region in Sweden are discussed by Baas (2011).

Eco-industrial parks are identified as concrete realizations of IS (Chertow, 2000). Based on this, several definitions of EIPs as a case of IS are presented. According to the U.S. EPA (1995), an eco-industrial park is defined as: "*A community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues including energy, water, and materials. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only*".

The President's Council on Sustainable Development (PSCD, 1997) stated that an eco-industrial park is*: "A community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, water, energy, infrastructure, and natural habitat), leading to economic gains, gains in environmental quality, and equitable enhancement of human resources for the business and local community"*.

Lowe (2001) suggested a broader view and presented a perspective of an eco-industrial park (EIP) and claims that a real EIP should be more than waste and recycling business clusters and environmentally green technology companies.

In a similar approach, in order to get more clarification to the discussed terms, Lowe (2001) also suggested three different categories; introducing eco-industrial projects as:

- *Eco-industrial park or estate (EIP) - 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.*
- *By-product exchange (BPX) - a set of companies seeking to utilize each other's by-products rather than disposing of them as waste.*
- *Eco-industrial network (EIN) - a set of companies that collaborate to improve their environmental, social and economic performance in a region.*

However, the major distinctive item through Lowe's definition of an EIP with others' identifications is that Lowe's focus and core issue is mainly on organization, development and management point of view.

### *2.2.2. **Elements of industrial symbiosis***

In order to assess and analyse IS development, Chertow (2008) has presented elements of industrial symbiosis such as "*embedded energy and materials*", "*cascading*", "*loop closing*", and "*tracking material flows*". Embedded energy and material shows that the sum of the material and energy consumed to generate a new product is equal to the amount embedded in that product. Hence, *"reusing by-products"* in industrial activities maintains the embedded material and energy for a longer time within the industrial systems. When energy or water resources are used several times, this is referred to as cascading, which has environmental advantages. A type of cascading is loop closing, which causes the industrial activities and their links to become more circular. Another key element to IS studies is defined as tracking material flows, which helps to identify and quantify all-important inputs/outputs to each firm individually. It is stated that *"the results are analysed to suggest opportunities for exchange of materials among firms as well as opportunities for more efficient resource use in the industrial ecosystem"* (ibid.*).*

## *2.3. **Facilitation of Industrial Symbiosis***

Considering the literature reviewed and background, it is clear that several determinants such as technical, social-organizational, policy-regulatory and business approaches can be influential for facilitation of IS development. IS facilitation involves both social factors and technological capacity. Harris et al. (2008) stated that *"industry leadership"*, *"process management"*, *"synergy development activities"*, *"funding and promotion"* are the five main determinants and basis for facilitation of industrial symbiosis.

### *2.3.1. **Facilitation of IS from social network and inter-organizational view***

Boons et al. (2011) proposed a theoretical framework for understanding the dynamics of IS in which environmental impact of industrial regions will be reduced by changing their level of connectivity together with an increase in their institutional capacity. Stimulation, development, growth, fostering and facilitation of IS are categorized as key elements in strengthening the institutional capacity for further development of IS. Since understanding of the social factors is necessary for understanding the dynamics of IS and its facilitation, numerous scholars in this field have paid particular attention to facilitation of IS development using social network theory and the role of organization and coordination.

Several researchers in the field referred to coordinating organizations and coordinating mechanisms in their research. Ehrenfeld (2000) argued that industrial symbiosis emphasizes *"connectedness"*, *"community"*, and *"cooperation"* amongst the collaborating firms. He also concluded that the coordination mechanism amongst different actors and stakeholders in a symbiotic network is a primary concern. Furthermore, the need for coordinating organizations and mechanisms is described as essential for building trust, communication and facilitating cooperation amongst diverse actors and stakeholders in a symbiotic network.

There is a great variety of terms in literature for coordinating organizations and their roles. Coordinating organizations such as *"local authorities"* (Von Malmborg, 2004), "*municipalities"* (Wolf et al., 2005; Burström and Korhonen, 2001), *"institutional anchor tenant"* (Korhonen and Snäkin, 2001), and "*professional organizations and associations*" (Baas and Boons, 2004), are found to be possible coordinating agents for IS development. The role of a *"facilitator"*, *"administrative member"*, *"broker"* or *"champion"* to plan, accelerate, and coordinate the activities of IS network are discussed and investigated by Baas (2001), Kincaid and Overcash (2001), Kilduff and Tsai (2003), and Paquin and Howard-Grenville (2009).

Creation of humanistic connections and the coordinator role of regional champions to establish trusting relationships amongst firms in IS networks are investigated by Hewes and Lyons (2008) and Burström and Korhonen (2001). In addition, Heeres et al. (2004) emphasized the role of a coordinating organization for facilitation of IS development by building trust across firms for data and information sharing. In a similar approach, the difficulties of establishing relationships of trust amongst the firms in an IS network was also investigated by Burström and Korhonen (2001). Some other researchers also stated that communication and trust are found to be essential factors in inter-firm cooperation and collaboration, and more importantly that IS requires trust and cooperation amongst its diverse actors (Gibbs, 2003; Chertow, 2000, 2008). Using a social network analysis tool and applying it in the case of an industrial ecosystem in the Barcelona pharmaceutical cluster in Puerto Rico, Ashton (2008) brought support to the idea that trust is a key factor in organizing inter-firm exchanges.

A few instances of worldwide IS emphasize the importance of the presence of a coordinating organization for facilitating IS development. Wolf et al. (2005) investigated the importance of the human dimension of industrial networks through increasing integration and exchanges between local actors. They argued that local authorities such as municipalities could have a coordinator role in local integration projects, managing data and information, and providing decision-making support. The results in the case of a Swedish municipality including local actors within a forest industry cluster showed that a local authority could have a coordinating role in local integration projects. The authors also referred to a few factors affecting the development and formation of a local industrial ecosystem, which could change the level of integration such as *"attitudes to cooperation"*, *"window of opportunity for investments"*, *"profit sharing"*, *"local roots"*, *"power relations in companies"*, and *"environmental regulations"*. Von Malmborg (2004) also highlights the role of local authorities in managing regional industrial ecosystems in Sweden. The potential and unique role of the municipalities as coordinator for industrial ecosystems is emphasized by Burström and Korhonen (2001). Based on their findings they concluded that municipalities could have the role of an institutional anchor tenant and act as an initiating and coordinating institution in industrial ecosystem facilitation, playing the role of managing data and information as well as supporting decision-making. With the purpose of eco-industrial development at the urban level, the Six-County metropolitan area in North Carolina, USA, Kincaid and Overcash (2001) discussed the role of a local organizer and the value of a facilitator to persuade actors and institutions to provide, manage, analyse, visualize, and share data and information in a regional perspective. Facilitation of the development of IS networks by a single brokering organization (NISP) in the West Midlands region in the U.K. was investigated by Paquin and Howard-Grenville (2008). The authors concluded that the IS network in the region had grown considerably over a three-year period, and that the growth came about basically by integrating new actors and firms into the network, which was the role of NISP as the facilitator.

### *2.3.2.* ***Facilitation of IS development by IS analytical and planning tools***

Managing and analysing high volumes of data and information about a number of actors and diversity of symbioses, uncovering and recognition of potential symbioses and synergistic possibilities amongst firms, as well as the spatial scale of firms, organizations and their exchanges, are all issues and challenges that can not be addressed and defined within the stand-alone IS concepts and industrial ecology tools. For this reason and to support eco-industrial development, several ICT tools have been developed and implemented. Isenmann and Chernykh (2009) investigated the role of ICT in industrial symbiosis projects. The authors have provided an overview of environmental ICT applications, applied in eco-industrial development in Europe. Furthermore, the facilitation of IS development using ICT together with identification of different tools and their application was investigated by Isenmann and Chernykh (2009) and Grant et al. (2010). Amongst different ICT tools that are currently used for eco-industrial development, GIS plays an important role in facilitation and support of IS development by spatial planning, decision-making, visualizing, analysing and data management (ibid.).

A geographic information system (GIS) is defined as: *"an organized collection of computer hardware, software, geographic data, and personnel design designed to efficiently capture, store, update, manipulate, analyse, and display all forms of geographically referenced information"* (ESRI, 1995). Within this definition, processing of huge amounts of information and analysing multiple factors in a regional study together with providing powerful visualization are examples of the possibilities of GIS.

Several research studies investigated applications of GIS in IS implementation, facilitation, and development focusing on different paradigms. GIS is used as a tool for decision support, urban and regional planning, synergy finder for detecting and matching supply and demand potential, materials flow accumulation from a spatial and temporal point of view, optimization tool for transportation cost and transportation distance, spatial problem solving such as allocation to meet specific requirements, allocation of sources and sinks of exchanges, and allocation of new infrastructure (Nobel and Allen, 2000; Kincaid and Overcash, 2001; Özyurt and Realff, 2002; Fujita et al., 2004; Massard and Erkman, 2007, 2009).

With the aim of contributing to regional development in the Geneva region in Switzerland, Massard and Erkman (2007, 2009) used GIS as a technical support tool for facilitating and implementing regional IS projects by detecting potential resource synergies and actors. With the purpose of eco-industrial development at the urban level, the Six-County metropolitan area in North Carolina, USA, Kincaid and Overcash (2001) utilized GIS in order to identify and map regional potential actors. Building and synthesizing an agro-industrial ecosystem in the state of Georgia, USA, was the main motivation of Özyurt and Realff (2002) to use GIS. The authors utilized GIS to provide general modelling and decision-making support to combine, coordinate, synthesize and analyse agro-industrial activities, enabling spatial and environmental modelling.

Nobel and Allen (2000) used GIS with the aim of exchanging and integrating industrial water reuse at the inter-firm or regional level for water conservation in Bayport Industrial Complex in Texas, USA. They utilized GIS for identification of regional supply and demand potential of reused water together with geographical distribution of sinks and sources, GIS-based map construction, optimal cost and distance feasibility, as well as decision making and visualization.

Creating an eco-town model for Japanese eco-town projects was the main motivation for Fujita et al. (2004) to utilize GIS in their research. The authors used GIS as a decision-making support tool for extensive industrial symbiosis in Kawasaki eco-town, and for spatial material flows assessment. Furthermore, the evaluation of Kawasaki eco-town's symbiotic network has been performed quantitatively and qualitatively by integration of GIS into the eco-efficiency model of the region.

Chertow (2008) investigated several useful tools for analysing industrial symbiosis development such as industrial inventories, input/output (I/O) matching, stakeholder processes, and material budgeting. It is suggested that as soon as an industrial area is proposed as a possibility for industrial symbiosis, the first step should start with an inventory of local actors and relevant organizations. Because matching I/O aims at linking industries, it can be seen as a *"key to symbioses"* (Chertow, 2008). Three methods such as written surveys, interviews and utilizing simulation software are mentioned for data gathering and analysis (ibid.).

Stakeholder processes deal with involving unconnected participants in industrial symbiosis activities. This community involvement technique brings together many diverse stakeholders to guide them through common goals in the local/national context. In this regard, Chertow (2008) stated that *"Openness among participating companies and continued coordination by a stakeholder group such as an advisory council is important both to establish and to maintain the momentum of a symbiosis"*. Furthermore, she refers to the role of Applied Sustainability in Alberta, Canada and Tampico, Mexico as well as NISP in the U.K. for their coordinating and brokerage activities in gathering experienced stakeholders from companies and national/local governmental bodies.

Another industrial symbiosis tool is material budgeting, with the aim of mapping the energy and material flows through an industrial system. Material budgeting consists of tracking material, including stocks, reservoirs, and flows, and can be used to map and identify both sources and sinks within industrial systems. By material budgeting, the supply (source) and demand (sink) potential of resources can be determined. Moreover, it is stated that *"material budgeting can be a basic building block of an industrial symbiosis analysis"* (Chertow, 2008). Formerly, material budgeting has specified the existence of a symbiotic network in Styria in Austria (Schwarz and Steininger, 1997; Chertow, 2008).

# 3. Methodology

*This chapter consists of the research process employed throughout the thesis, general methodology used and scientific approach of the whole thesis, and methods and approaches that are employed in each appended article.*

## *3.1. Research process throughout this thesis work*

Dynamic research process is the employed research methodology in this thesis, which starts with problem/challenge identification, followed by literature review, research need identification, aim of the research, research questions, research type, research strategy, data management (collection, reduction, validation), data display (results), data analysis (discussion), and conclusion. This process is completely dynamic because during the research process feedback at some stages leads to the need to return to previous stages, making modifications and then continuing.

The part of the research process that deals with challenge identification, literature study, need identification, aim and research questions will be described in this part (3.1), while identification of research type, design of research and data management, which is basically related to methodology used and scientific approach of the whole thesis will be described in part 3.2. Part 3.3 is devoted to methods and approaches used in the appended articles.

Following the above procedures led to the overall aim of the thesis to explore how local industrial networks can be facilitated using IS theory and tools. Facilitation of IS development in this thesis is focused on:

- Using IS theory and tools for categorization, characterization, and definitions of different lines of IS development
- Matching the supply and demand potential of resources through industrial collaboration, and
- Using geographic information systems (GIS)

In this thesis the first research question was derived from the aim, constituting a basis for the second and third research questions. Based on the first research question, the second and third research questions are derived to address the overall aim.

In order to address the research aim, three research questions have been developed. Accordingly, to answer the research questions and to give more operationalization to the research, the associated research questions are then elaborated by three sub-questions (s.q.) through the appended articles as follows:

- ➢ ***Research Question 1***: How can industrial symbiosis (IS) theory contribute to describing and understanding changing degree of local connectedness in an industrial area?
- Sub-question 1: Do any definitions of industrial symbiosis (IS) fit with industrial activities at Händelö/Norrköping in Sweden?

The first sub-question, (Article (I)), provides a description and some understanding concerning the regional characteristics, the existing potential for IS development, the current situation and what definitions of IS fit with the industrial area.

- ***Research Question 2***: How can providing information about supply and demand potential of resources facilitate Industrial Symbiosis development?
- Sub-question 2: Does matching the supply and demand potential of regional $CO_2$ resources through industrial collaboration contribute to facilitation of IS?

The second sub-question, (Article (II)), tries to display how using IS tools such as matching the supply and demand potential of resources through industrial collaboration could lead to facilitation of IS development.

- ***Research Question 3***: How can geographic information systems (GIS) be used to facilitate Industrial Symbiosis development?
- Sub-question 3: How can handling and management of existing regional data and information in GIS format lead to facilitation of industrial symbiosis development?

The third sub-question, (Article (III)), tries to add understanding to how structuring data and information in GIS format can lead to facilitation of IS.

## *3.2. Methodology used and scientific approach*

In general, research studies can be elucidated by identifying research pillars as follows.

- Research type (nature of research)
- Research strategy (design of research)
- Research reasoning
- Data management

### *3.2.1. Research type*

Research result, research purpose and research approach are the items identified as research type. According to Hedrick et al. (1993), research result can be categorized into applied, development and basic research. In this thesis and its appended articles, since the aim is to study how using industrial symbiosis theory and tools can facilitate local connectedness in an industrial area, and the core is applying IS theory, therefore applied research is more favourable as the research result.

Yin (2009) has categorized the research purpose into descriptive, explanatory, and exploratory research. Descriptive research mainly deals with answering the questions of “how” and “what”. In explanatory research, the researchers attempt to address the testing of causal relationships between variables (ibid.). According to Saunders et al. (2007), exploratory research is used when researchers want to explore the hypothesis of a subsequent study. In this research, concerning the general aim, the research purpose seems more explanatory. However, when considering the research questions and appended articles, this will be slightly different. For instance, in Article (I), which attempts to understand and describe an existing case matching IS tools and definitions, the research purpose sounds descriptive. However, articles (II) and (III), which try to explain how relational tools such as using GIS or matching the supply and demand potential of recourses, facilitate industrial symbiosis, have a more explanatory nature.

According to Ghauri and Gronhaug (2005), depending on the approach, a research study can be done using a qualitative or quantitative method. The aim of qualitative research is to obtain a deeper realization and description of a problem, while in the quantitative approach, the researcher tests relationships between different variables, which conclude in the ability to prove or disprove the relationship. The current research, whose core aim is describing facilitation of IS in an industrial region by different ways and approaches applied to an already formed local connectedness, takes a qualitative research approach.

According to the above description, the research type of this thesis can be seen as applied-explanatory-qualitative.

### 3.2.2. Research strategy (design of research)

The design of a research project is basically a plan or sequence of actions to be followed ensuring that aims and objectives of the research are fulfilled. It is affected largely by the type (nature) of the research. Research strategy should properly align with the chosen research questions. According to Yin (2009), research can be performed through five different strategies: experiments, surveys, archival analysis, history, and case studies. It is stated that when designing research, it is also essential to identify what type of evidence (source of data) is required to answer the research questions. Sources of evidence will be later described in data collection. Furthermore, Yin (2009) stated that research design is not related to any specific method of data collection or any particular type of data. In this thesis, because the type of research is applied-explanatory-qualitative, “how” types of research questions are asked, and the research has very little control over events, hence case study has been employed as research strategy.

This thesis was initiated from the idea of sustainability of industrial regions and how industrial symbiosis can contribute to sustainability of Östergötland as an industrial region. Looking at the aim and research questions identified, it is evident that in order to fulfil the aim and answer the three research questions, symbiotic activities in Östergötland region in general, and eco-industrial activities at Händelö/Norrköping (Article (I)), industrial $CO_2$ emitters/users in Östergötland (Article (II)), and existing data and information in GIS format in Östergötland (Article (III)) in particular, are selected as case study objects.

### 3.2.3. Research reasoning

The basic philosophy behind research reasoning is to find out the relationship between theoretical and empirical studies, in other words, how to combine theoretical and empirical findings. To describe the relationship between empirical data and theory, Patel and Davidsson (2003) have suggested two approaches, theory building (inductive) and theory testing (deductive) (Yin, 2009).

In the current research, both empirical and theoretical findings are used to address and answer the overall aim and the research questions. This thesis started with industrial ecology/industrial symbiosis as the theoretical background, and uses collaboration and local connectivity aspects of IS. This led to facilitation of local connectedness of co-located firms in an industrial region, and finally to empirical findings in the region. A basis in IS theory in Article (I) contributed to describing and understanding the local connectedness of an industrial area in the region, Article

(II) involved collaboration aspects of IS amongst industrial partners to address supply and demand potential of resources in a region and Article (III) used spatial scale of IS to address ways to develop existing regional data/information in GIS format to facilitate industrial symbiosis development in a region. Therefore, a deductive or theory-testing approach is applied for research reasoning.

### *3.2.4.* ***Data type, method of data collection, and data analysis***

In general, common issues related to data are type of data, method of data collection, source of data (evidence), originality of data, and data analysis. Method of data collection and type of data are affected by the research approach (Ghauri and Gronhaug, 2005). Three common qualitative methods of data collection are participants' observations, in-depth interviews, and focus groups.

Since case study is selected as the research design, according to Yin (2009) there are six different sources of data (evidence), including documentation, archival records, interviews, direct observation, participant observation, and physical artifacts. Moreover, it is stated that case study should rely on multiple sources of evidence (ibid.). Interviews are one of the most important sources of case studies. Interviews can be structured, semi-structured, or unstructured. Ghauri and Gronhaug (2005) argued that interviews could be conducted via e-mail, phone or in face-to-face meetings. Concerning the originality of data, data can be either primary or secondary. Primary data is original and will be collected for the particular research purpose, while secondary data is already collected for different purposes (Ghauri and Gronhaug, 2005).

The purpose of data analysis is to provide explanations and make sense of collected data. Data analysis is largely dependent on what type of data is collected, qualitative or quantitative. According to Yin (2009), the most complicated part of case study research is qualitative data analysis. However, a framework including three different activities in the process of data analysis has been suggested by Miles and Huberman (1994). The activities involved in the process of data analysis are data reduction, data display, and conclusion drawing/verification.

As stated earlier, both empirical data and theoretical findings are used to answer the research questions. In this thesis, because the research approach is qualitative, type of data and method of data collection are qualitative as well.

The empirical data are collected from different sources such as interviews, field visits, and internal documents, while literature review contributed to the theoretical framework of the study. Since case study is the research strategy for this thesis and a case study should rely on multiple sources of evidence, both primary and secondary data are used.

The primary data are mainly collected from interviews and field visits, while secondary data are gathered from literature review and internal company documents. Most of the interviews included in this study are phone interviews and e-mail interviews. The interviewees were mainly drawn from local industrial actors and regional/governmental institutions. Several field visits were made to industrial plants in the region, ranging from process industries, CHP plants, biofuel production plants, and waste collection and recycling companies. Secondary data collection was mainly from company environmental reports, regional reports by governmental institutions, company websites, and literature review for theoretical framework. In this thesis, the collected, reduced and simplified empirical data were then used to compare and be matched with theoretical findings, for analysis and discussion.

### 3.2.5. Validity and reliability

When conducting scientific research, judgment and evaluation about the quality of research is important to take into account during the research process. According to Flick (2009), reliability and validity are two important dimensions of research quality. Yin (2009) explains reliability as the ability to repeat the research and get the same results. In this research three factors such as collecting and analysing data based on interviews, documentation and recording the interviews as well as the skilfulness of interviewees, increase the level of reliability.

According to Ghauri and Gronhaug (2005), validity is a measure of how good the results of research are and whether they can be justified and considered to be a true and accurate reflection of reality. In this research, all the data, information, notes, and facts resulting from interviews and field visits (observations) were then documented and sent to interviewees and experts at local/regional organizations and industrial plants to be validated, ensuring the validity of collected data and results. Concerning any modifications or data correction, feedback from interviewees was received.

## 3.3. Methods and approaches of the appended articles

The first article aims at understanding, describing and analyzing the existing industrial activities and their development in a Swedish region, using IS theory and tools. It describes industrial activities at Händelö/Norrköping to address the first research question. This was done by an extensive literature review on industrial symbiosis and eco-industrial development together with several definitions and concepts. Article (I) prepared a general platform for Article (II) and (III) concerning theoretical framework and applying facilitation of industrial symbiosis.

Considering the local connectedness embedded in the region which is identified in Article (I), Article (II) was written for the purpose of utilization of industrial $CO_2$ emissions in an industrial region by matching the supply and demand potential of resources through industrial collaboration. This paper utilized the core IS theory described in Article (I) and also the symbiotic activities amongst the industrial actors in the region. In this regard, the contribution of Article (II) is mainly to answer the second research question and to some extent the first research question as well.

Article (III) was written with the intention of analysing how GIS can be used for facilitating IS development. Since matching the supply and demand potential of resources in Article (II) revealed to this point that providing data and information about amount and location of resources is a challenge, this paper utilized the core IS theory described in Article (I), some basic concepts developed in Article (II) in the form of detecting and matching the potential resources and potential actors, as well as developing a literature review on how GIS has been applied in IS development by categorization and characterization of different lines of GIS and IS. In this regard the contribution of Article (III) was mainly to answer the third research question, aimed at handling and developing data and information in GIS format to facilitate IS development, and to some extent the second research question as well. The governing approaches and methodology used of the three appended articles are summarized in Table 1.

*Table 1. Methods and approaches used in the appended papers*

| Article | Approach | Method |
|---|---|---|
| **(I)** | Categorization, and characterization of different lines of eco-industrial development using IS models, concepts and definitions. | • Case study<br>• Inventory<br>• Literature review of industrial symbiosis and eco-industrial development<br>• Data collection by interview and field visits<br>• Theory testing |
| **(II)** | Utilization of resources by matching the supply and demand potentials through industrial collaboration using IS theory. | • Case study<br>• Inventory<br>• Literature review of industrial symbiosis and utilization of resources by industrial collaboration<br>• Data collection by interview and field visits<br>• Theory testing |
| **(III)** | Analyzing how GIS can be used for facilitating IS development by categorization and characterization of different lines of GIS used in IS development. | • Case study<br>• Literature review of industrial symbiosis and utilization and development of GIS in IS<br>• Data collection by interview<br>• Theory testing |

# 4. Results

*This chapter summarizes the significant research findings of the three appended articles.*

## 4.1. Describing and understanding the industrial activities at Händelö/Norrköping using IS theory and tools

This part, which is based on Article (I), summarizes the results of analyzing the Händelö/Norrköping industrial area and its development by different definitions, categorizations, and characterization of IS theory.

Describing and understanding the industrial activities at Händelö/Norrköping is performed by recognizing what definitions of IS are applicable to that industrial area. Händelö/Norrköping industrial area involves *"co-existence"* of nature conservation areas and industrial plants, a centre for logistic companies, a renewable energy cluster, access to railway, and proximity to the harbour (Article (I) and Martin, 2010).

Inventory of the investigated actors showed that there are 14 industrial partners that exchange material, energy, by-products, and waste. Their detailed activities and industrial interactions is presented in Article (I), and in the illustration below (Figure 2.)

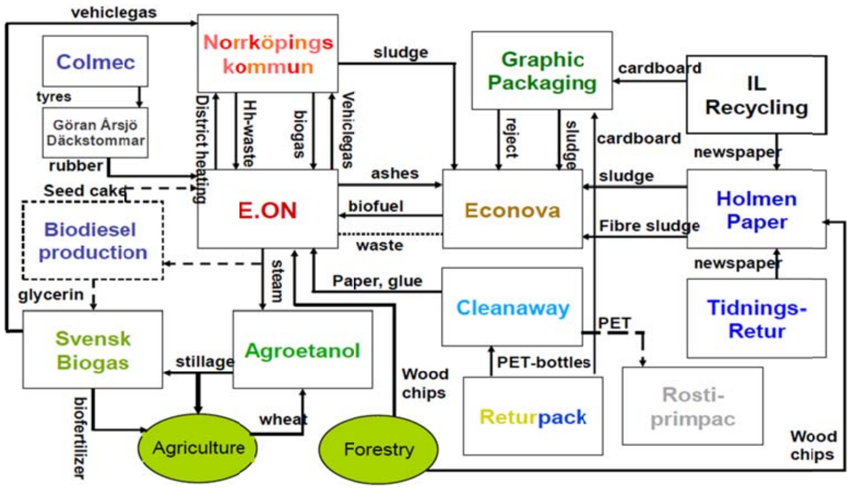


*Figure 2. Industrial activities in city of Norrköping (Nicklasson, 2007)*

Due to the types and level of activities currently run by E.ON, Econova, Lantmännen Agroetanol, and Norrköping municipality, they are considered key actors. Furthermore, all investigated actors have links to one of the four industrial clusters. The clusters are PET bottles, energy/biofuel, pulp and paper/forestry, and rubber. The involved actors, key actors, and their respective industrial clusters are summarized in Table 2.

*Table 2. An inventory of actors and their respective clusters in Händelö/Norrköping*

| *Key Actors* | | | |
|---|---|---|---|
| E.ON. | Norrköping Municipality | Econova | Lantmännen Agroetanol |
| *Industrial Clusters* | | | |
| PET-bottles | Energy/Biofuels | Pulp & Paper/Forestry | Rubber |
| • Returpack<br>• Cleanaway<br>• Rostiprimpack | • Lantmännan Agroetanol<br>• Svensk Biogas<br>• E.ON. | • Graphic Packaging<br>• Holmen Paper<br>• Tidningsretur<br>• IL Recycling | • Colmec<br>• Göran Årsjö Däckstommar |

Applying tools such as industrial inventory, input/output matching, stakeholder processes, and material budgeting contributed to understanding and describing industrial activities in the region. Considering industrial activities at Händelö/Norrköping, several elements of industrial symbiosis such as *"reusing by-products"* exist amongst the industrial actors in the region. Retreading of rubbers from scrapped tires and reuse for new treads; converting waste cardboards into new product with the same quality; thin stillage from ethanol production and sewage treatment to generate biogas; sewage sludge used for landfill cover; bottom ash from waste incineration plant reused as construction materials, are all examples of loop closing, cascading, and reusing by-products that are embedded within the industrial activities in the region.

Regarding the types of material exchange and synergistic possibilities within the spatial scale and geographic proximity of the Händelö/Norrköping area, a few samples of co-located exchanges (type 3) are evident. However, there are also some cases in which exchanges occurred within a local geographic proximity (type 4) that are not immediately co-located. One example is fibre sludge and rejects, by-products of Graphic Packaging and Holmen Paper, which are used by Econova in another part of Norrköping. Another example of type-4 exchange is supplying recycled PET material by Cleanaway to Rostiprimpack, which is not co-located with Cleanaway at Händelö. Exchanges amongst firms that are located further away in the region (type 5), also exist in the industrial activities in Händelö/Norrköping. Thin stillage from ethanol production at Händelö is sometimes fed to the biogas plant in the city of Linköping, about 45 km from Norrköping. Therefore, existing exchanges in Händelö/Norrköping represents types 3-to-5 of exchanges that are identified as industrial symbiosis. Furthermore, resources are of course exchanged on a much larger scale, including long-distance supply of wood waste and PET bottles.

At Händelö/Norrköping, cases of both by-product and utility synergies are evident. Exchange of sewage sludge, fibre sludge, and ash are all examples of by-product synergies, while there are also some exchanges such as process steam and electricity from E.ON to ethanol production, utilization of an active landfill owned by E.ON and managed by Econova that can be seen as utility synergies. Furthermore, amongst different by-product and utility synergies, there are special cases of exchange that can count both as utility and by-product synergy. For instance, thin stillage is a by-product synergy of ethanol plant, but also a utility synergy due to its high temperature and energy content which drives the process at the biogas plant. E.ON's and Agroetanol's activities are mainly focused on energy exchanges, while Econova's activities can be labelled the hub of material and waste exchanges. More than 95% of exchanges of energy, material, and by-products are based on non-fossil sources, meaning Händelö/Norrköping is a hub of renewable energy exchanges. In addition, most by-product/utility synergies in the area can be categorized as utilized. One exception from this practice is $CO_2$, which is a by-product from the fermentation process in ethanol production. Hence, according to different types of exchanges of by-products, non-utilized by-products give a new attribute to this categorization and characterization, which can be clearly traced in industrial activities at Händelö/Norrköping.

Since most of the material and by-products exchanges within the industrial network in the region originate from forestry and agriculture and are handled by companies such as E.ON, Econova, Svensk Biogas, Agroetanol, and Holmen Paper, it resembles the idea of the integrated bio-system, as described by Chertow (2000, 2008). Regarding the industrial history of the area, its development and growth over time as well as existing and embedded potential, it can be stated that the industrial network at Händelö/Norrköping displays components from both brownfield restructuring as well as greenfield characteristics.

The industrial network in Händelö/Norrköping accords with several definitions and characterization of IS such as displaying local connectedness, eco-industrial network, symbiotic intensity, local integration, and type 3-5 of exchanges. Moreover, regarding the diversity of the exchanges of energy, material, and by-products together with variety and number of actors, it can be inferred that a certain degree of local connectedness is already formed within the industrial network in the area. In addition, according to several industrial and commercial links between Agroetanol with its counterparts such as E.ON, Svensk Biogas, oil companies, farmers, and animal feed factories, Lantmännen Agroetanol together with the E.ON CHP plant are identified as important anchor tenants for the energy/biofuel cluster.

### 4.2. *Utilization of industrial $CO_2$ emission by matching the supply and demand potential within industrial collaboration*

It was observed that several industrial actors and stakeholders including the municipality and 13 industrial partners are exchanging energy, material, and by-products in the eco-industrial area in Händelö/Norrköping, Sweden. Exchanges of by-products existed between the actors. Some by-products are reused and utilized in several steps while others are not utilized. One significant resource that is not used is $CO_2$ from the fermentation process of Lantmännen Agroetanol, the bioethanol production company (Article (I)). An inventory of the major industrial $CO_2$ emitters in the region and their processes that contributes to $CO_2$ emission is presented in Article (II).

The main sources of biogenic $CO_2$ emissions are the pulp and paper industry, biofuel production (bioethanol, biogas) industry, and biomass CHP plant where large amounts of biomass is used and processed. Processes such as fermentation, gas cleaning/upgrading of biogas and black liquor gasification are processes that generate fairly pure streams of biogenic $CO_2$ (concentration of $CO_2$ around 95%), making them the most interesting processes for $CO_2$ recovery. The geographical location of $CO_2$ emissions in the region is mainly close to the two bigger cities, especially Norrköping, implying that it could be an appropriate place for a company that wants to utilize $CO_2$. This idea is also supported by the strategic location of Norrköping.

Greenhouses, beverage and food industries (sparkling water), algae farms for biodiesel production, oil fields for enhanced oil recovery (EOR), production of artificial fertilizer, transport refrigeration, pulp/paper production and fire extinguisher manufacturing are identified as examples of activities on the demand side of extracted and utilized $CO_2$. The main users of $CO_2$ in Sweden are the food/beverage and pulp/paper industries.

The present demand for $CO_2$ in Scandinavia, by the industry that provides $CO_2$, has been estimated at around 200,000 tonnes per year. Considering indicators such as population, area, share of manufacturing and process industries, and GDP, a rough estimate of the Swedish share of $CO_2$ is about 40% of the Scandinavian demand. This means a demand of about 80,000 tonnes per year. Comparing the supply and demand potentials displays a big mismatch between the size of regional supply and the national demand. The national demand is about 3.5% of the total supply available in Östergötland. This demand can be easily fulfilled with half the supply of the ethanol company or combination of several biogas plants. Furthermore, the Scandinavian demand is around 9% of the total Östergötland $CO_2$ supply, which can almost be covered by the $CO_2$ from the bioethanol plant. The bioethanol production in Östergötland generates 170,000 tonnes of highly concentrated $CO_2$ per year which is a promising potential for a utilization plant. Recently, AGA Gas AB and Lantmännen Agroetanol AB have signed a letter of intent concerning construction of a $CO_2$ utilization and purification system at the ethanol facility.

## *4.3. Facilitating industrial symbiosis development in a Swedish region using geographic information systems (GIS)*

According to section 4.2, availability and provision of data and information concerning potential actors and resources as well as geographical distribution of supply and demand of resources (resource allocation) is an interesting challenge, (Article (II)). However, this part will address how using and developing geographic information systems as a tool can lead to facilitation of IS development (Article (III)). Results are based on the comparison made between the theoretical findings on how GIS has been applied in facilitation of IS development, and empirical information about Östergötland region's existing system and organizations involved in developing GIS.

Findings in IS literature suggest that GIS can play an important role in facilitation and support of IS development by spatial planning, decision-making, visualization, analysis, and data management. GIS has been used as a tool for decision support, for urban and regional planning, as a synergy finder for detecting and matching supply and demand potentials, for materials flow accumulation from a spatial and temporal point of view, as an optimization tool for transportation cost and transportation distance, for spatial allocation problem solving, for allocation of sources and sinks of exchanges, and for allocation of new infrastructure. Table 3. characterizes different lines of using and applying GIS for facilitation of IS development.

*Table 3. Characterization of GIS in IS*

| ***Literature Reviewed*** | ***Aim & Motivation*** | ***Why use GIS? (Role and usage)*** | ***How has GIS been applied?*** | ***How did they organize it?*** |
|---|---|---|---|---|
| Massard G., Erkman S. (2007)<br>Massard G., Erkman S. (2009) | Regional policy context for the local Agenda 21, Geneva, Switzerland. | • Decision making support tool.<br>• Technical support tool; facilitating and implementing regional IS project, detecting more potential resource synergies and industrial actors.<br>• Visualization<br>• Optimal location identification | • Providing regional database by industrial input/output and EMFA analysis.<br>• Building database management tool for the treatment of input/output data.<br>• Using and linking GIS tool to regional industrial database. | Established an advisory board for IE/IS implementation with collaboration of relevant government agencies, University of Lausanne, the Territorial Information System Office, and consulting company (SYSTEMES DURABLES). |
| Kincaid J., Overcash M. (2001) | Eco-industrial development at the urban level; six-county metropolitan area in North Carolina, U.S.A. | • In order to identify regional potential actors and industrial partners.<br>• To facilitate selecting any facility's location with their input-output.<br>• Mapping the location of actors and industrial partners with their input/output. | • Preparing an inventory of actors and industrial partners in the region.<br>• Building regional database.<br>• Linking the database gathered from industries and institutions in the region to regional GIS maps. | The project was initiated by a governmental planning organization including 30 local governments. The project was undertaken with partnership of several other organizations such as universities, local economic development, the state pollution prevention agency, and a group of representatives from local industries. |
| Özyurt B. D., Realff J. M., (2002) | Building and Synthesizing an agro-industrial ecosystem in the state of Georgia, U.S.A. | • To provide general modeling and decision-making support to combine, coordinate, synthesis and analyze the agro-industrial activities.<br>• This is done with use of GIS; enabling spatial and environmental modeling. | • Identification/screening, selection and implementation of energy and material exchanges between existing facilities combined with the addition of a small number of new facilities.<br>• Using the Manufacturing Directory of the state of Georgia together with Georgia GIS data and applying analysis tools ArcView GIS with additional information from the American Peanut Sheller Association (APSA).<br>• Making a database of sources and sinks of materials, energy exchanges and facilities and linking to GIS database. | Based on the previous work by U.S. EPA for designing industrial ecosystems tool and another U.S. EPA sponsored project for eco-industrial development in North Carolina, U.S.A.<br><br>Combining different tools based on industrial ecology concepts, environmental science and engineering, processes system engineering and GIS. |
| Nobel E. C., Allen T. D. (2000) | Exchanging and integrating industrial water reuse at inter-firms or regional level for water conservation in Bayport Industrial Complex in Texas, U.S.A. | • In order to identify regional supply and demand potentials of reused water together with geographical distribution of sinks and sources.<br>• Based-map construction<br>• Optimal cost and distance feasibility<br>• Decision-making<br>• Visualization | • A GIS-based water reuse model was used to incorporate spatial information into water ruse analysis.<br>• The model utilized a linear programming method embedded in GIS model. | |
| Fujita et al., 2004 | Creating an eco-town model for Japanese Eco-town projects. (The case of Kawasaki Eco-town project) | • Decision-making support tool for extensive industrial symbiosis in Kawasaki eco-town.<br>• For spatial material flows assessment.<br>• The evaluation of Kawasaki eco-town symbiotic network has been performed quantitatively and qualitatively by integration of GIS and eco-efficiency of the region. | • Data from national and local statistical database.<br>• Environmental reports of industries.<br>• Using GIS software and integrating with regional database. | Establishment of eco-town program by Japanese government.<br><br>Preparations of an eco-town plan and model by local government and approved by the Ministry of Economy, Trade and Industry, and the Ministry of the Environment. |

According to the regional inventory of existing organizations, there are a number of organizations relevant to GIS for IS development. At the local level, municipalities organize information in the form of ArcGIS shape formats for building types, road lines, water bodies, and water lines. However, maps do not contain information about industries to build an IS-relevant GIS model. On the regional level, Östsam is a regional development agency including 13 municipalities as members that coordinates Östergötland development affairs. At the moment there is no GIS data available for industries at Östsam. Recently such a project started up in collaboration with Motala municipality on a local development basis.

Östergötland County Administrative Board, a governmental organization on the regional level, holds a range of data and GIS-related information on industries such as their locations and road maps and environmental reports of companies. In addition, they work closely with another national governmental agency called *"The Swedish mapping cadastral and land registration authority"* (Lantmäteriet) which has a GIS database. The Swedish mapping authority (Lantmäteriet) has official GIS-based maps. However, there are restrictions on use by third parties. Statistics Sweden (SCB), another national governmental agency, uses digital borders for use in GIS for municipalities and counties in ArcView shape and MapInfo formats. They also own a national/regional material flow database, which could be suitable for building regional-industrial GIS systems.

Cleantech Östergötland is a regional economic development organization with the aim of regional industrial symbiosis development having around 100 members, including Linköping and Norrköping municipalities, Linköping University as well as more than 85 industrial actors. Several IS activities and initiatives are already developed in the region, such as the eco-industrial network in Händelö/Norrköping. Cleantech Östergötland collects information about their member industries and their activities including information about their input/output, energy and material cycling, and waste/water handling. However, this type of data is more suitable for building a regional-industrial database.

Industries themselves keep track of their input/output flows and streams of material, energy and by-products. However, this information is normally not kept in a GIS format. In some cases GIS data are available, for instance GIS maps of district heating networks of energy services companies. These are not shared, however, due to security reasons.

It can be stated that lack of enough information, unavailability of relevant data, restriction of using and sharing data and information are the most important barriers and challenges toward making regional-industrial GIS maps. Furthermore, there is no general practice in Sweden for industrial actors to build and manage appropriate data and fit it within GIS models. In addition, developing GIS on a regional level is not a stand-alone organizational activity; it needs cooperation among several organizations.

In conclusion about the feasibility of GIS to support IS development, it is obvious that there are already existing organizations and data sources in the studied region. With improved coordination a GIS-based system could be developed that could contribute to further IS-related activities in the region.

*Table 4. Existing organization and available data/structure*

<table>
<tr><th>Organization</th><th>Level</th><th>Available data</th><th>Required data</th></tr>
<tr><td>Municipalities</td><td>Regional /Local</td><td>Some based-map data/information in ArcGIS shape format is available, however none of theses maps contain detail information and map attributes to build a GIS model.</td><td rowspan="7">• Digital maps and elevation of the area and industries/facilities inside<br>• Location of industries and facilities<br>• Road networks<br>• Industries pick up/delivery points<br>• Industrial potentials<br>• Industrial categories and based maps<br>• Regional-industrial database (energy-material, waste handling, water and by-products flows and exchanges amongst industrial actors)</td></tr>
<tr><td>Ostsam Regional Development Council</td><td>Regional</td><td>No available data with GIS and industries. Recently a project started up in collaboration with Motala municipality on a local development basis.</td></tr>
<tr><td>Ostergötland County Administrative Board (Länsstyrelsen)</td><td>Regional</td><td>Industrial locations and road maps, industries' data and environmental reports of companies. They work closely with data from Lantmäteriet and have access to their database, however they cannot share those data with the third party such as University for instance.</td></tr>
<tr><td>CleanTech Östergötland</td><td>Regional</td><td>Information and data about industrial companies, their capacity, products, input/output, symbiotic networks, symbioses initiatives in the region</td></tr>
<tr><td>Industrial actors</td><td>Regional</td><td>Input/output flows and streams of material, energy and byproducts. In some cases GIS data are available, but due the security of information they will not share those data (GIS map of district heating network, for instance).</td></tr>
<tr><td>The Swedish mapping cadastral and land registration authority (Lantmäteriet)</td><td>National</td><td>Access to official GIS-based maps; restriction to use.</td></tr>
<tr><td>Statistics Sweden (SCB)</td><td>National</td><td>Digital borders for use in GIS for municipalities and counties in ArcView shape, MapInfo formats</td></tr>
</table>

# 5. Discussion

*In this chapter the research findings are discussed and analysed in relation to relevant literature.*

Understanding and describing "what" will be facilitated, using IS theory and definitions, is the main prerequisite of this research which is primarily constructed based on the results from Article (I).

The starting point of this research was to understand and describe the industrial activities in Händelö/Norrköping by having enough knowledge about the area and relating it to IS theory and tools. IS tools such as inventory of actors and stakeholders, mapping exchanges of energy, material, and by-products were applied to find out whether any form of IS exists, and what definition of IS fit with the industrial activities of the area. This approach has been suggested by Hardy and Graedel (2002), Korhonen (2001a,b, 2004b), Chertow (2008), and Van Berkel (2009), who emphasized that the characterization, quantification and understanding of the number of industrial actors, partners and physical exchanges in industrial systems is a frequent theme in IS.

The industrial activities in Händelö/Norrköping, in the form of exchanges of energy, material, and by-products (Article (I)), show several instances of reuse of by-products, loop closing, and cascading which are identified as the elements of industrial symbiosis for assessing and analyzing IS development (Chertow, 2008). The diversity of actors and types of exchanged symbioses in Händelö/Norrköping reveals consistency with definitions such as *"connectedness* and *connectance"*, *"roundput* and *diversity"*, *"integrated bio-system"*, and *"symbiotic intensity"* by Hardy and Graedel (2002), Korhonen (2001a,b, 2004b), Chertow (2000, 2007), and Van Berkel (2009) respectively. Furthermore, when assessing and understanding the structure of the actors and their flows, the concept of "*symbiotic resource flow"* (Chertow, 2007) is a better match than the concept of *"symbiotic project"* (Van Berkel, 2009). In addition, different exchanges between industries, such as by-products, material and energy, are consistent with the two definitions given by Van Beers et al. (2007), Van Berkel (2006) and Chertow (2007) as by-product synergy and utility synergy. However, it is worth noting that synergies can be both a utility synergy and by-product synergy (Article (I)).

Considering the collaboration, synergistic possibilities and geographical location of the industrial exchanges and activities in Händelö/Norrköping, they extend within a range of door-to-door proximity, general vicinity, and across the region (Article (I)). Therefore, the synergistic possibilities within spatial scales are matched with the *"type 3-5 of exchanges"* definition and categorization given by Chertow (2000, 2008) as industrial symbiosis. Furthermore, the research findings concerning industrial collaboration and synergistic possibilities amongst firms within a geographic proximity in Händelö/Norrköping are matched with the primary concerns of IS as *"collaboration"*, *"synergistic possibilities offered by geographic proximity"*, and *"co-located firms"*, given by Lifset and Graedel (2002), Brings Jacobsen (2006), and Chertow (2000, 2008).

Since thin stillage from ethanol production in Händelö/Norrköping has sometimes been fed to the biogas plant in the city of Linköping about 45 km away, *"geographic proximity"* in IS is a relative term and needs further research attention (Jensen et al., 2011).

The *"connectance"* between Agroetanol and E.ON CHP plant as the main hubs of exchanges of energy, material and waste relates to the definition of the anchor tenant model given by Chertow (2000, 2008) and practices in the biofuel industry by Martin (2010).

The already formed industrial network in Händelö/Norrköping accords with several definitions and characterizations of IS as presented by IS scholars, including definitions such as local connectedness, connectivity, eco-industrial network, symbiotic intensity, local integration, connectance, and type 3-5 of exchanges. Moreover, the existing industrial activities and network at Händelö/Norrköping also show some consistency with the definitions of EIPs given by the U.S. EPA and PCSD. Considering the definitions and characterizations of an EIP presented by Lowe (2001), the industrial activities in the region sound more like an eco-industrial network (EIN) than an eco-industrial park, since there is no structured and planned development program or a management organization to control the development. The existence of such an organization is in contrast with spontaneously developed industrial symbiosis.

Applying tools such as industrial inventory, input/output matching, and material budgeting in the case of Händelö/Norrköping (Article (I)), also led to the idea of the existence of a number of non-utilized by-products embedded within the industrial network in the region that could be utilized (Article (II) and Chertow, 2007). Using and applying IS tools depends on the availability of relevant data and information, which was a challenge addressed in Article (II) and throughout this thesis.

Mapping flows (Article (I)) led to the uncovering of non-utilized by-products such as $CO_2$, as a by-product of the bioethanol production company (Article (II)). Moreover, matching the supply and demand potential of industrial $CO_2$ emissions contributed to suggesting new actors for the network, and linking potential sources to sinks, respectively. These findings accord with the observation made by Paquin and Howard-Grenville (2009) for linking potential actors to the potential synergistic possibilities by the NISP.

Possible utilization of industrial $CO_2$ emissions in the region (Article (II)) by matching the supply potential and demand market would influence environmental performance as studied by Chertow and Lombardi (2005). Boons et al. (2011) also suggest that environmental impact of industrial regions will be reduced by changing their level of connectivity. Wolf and Karlsson (2008) concluded that integration of forest industry actors and their processes lead to lower $CO_2$ emissions. Their findings are also consistent with the observations that diversity can create possibilities for increasing connectedness and cooperation (Korhonen and Snäkin, 2005). Availability, providing, and sharing relevant data and information about the supply and demand potential actors and potential resources as well as their geographical distribution was a challenge in Article (II) that led to the idea of using geographic information systems as a tool for facilitation of IS development in Article (III).

The findings from studying use of GIS for IS facilitation shed light on the existence of organizations that already promote and develop GIS in the Östergötland region such as municipalities and regional governmental organizations. Similar findings were reported by Kincaid and Overcash (2001) and Heeres et al. (2004). Using GIS for identifying the geographical distribution of regional supply and demand and detecting potential actors was suggested by Nobel and Allen (2000). This research also addresses how GIS has been used. The purpose of making a regional-industrial database and regional GIS model is similar to that of Kincaid and Overcash (2001), Özyurt and Realff (2002), and Massard and Erkman (2007, 2009). However, availability and sharing of relevant data and information for developing GIS was a challenge, and it may require a coordinating organization for developing GIS to be useful for IS development.

# 6. Conclusions

*In this chapter, the overall aim of the thesis is addressed and the three research questions are answered accordingly.*

Following the aim of the research, it is evident that the overall aim is two-fold; on the one hand, addressing whether any footprints of IS exist and what definitions of IS fit an industrial area, and on the other hand how that can be facilitated. R.Q. 1 and Article (I) cover the first part, while the second part is fulfilled by R.Q. 2, R.Q. 3 and Articles (II) & (III). Hence, the conclusions and lessons learned are summarized in the proposed research questions followed by a general description.

## *6.1. <u>Using IS theory and tools for describing and understanding industrial regions</u>*

When fostering, facilitating and promoting further IS development, an analysis and understanding of the current situation is an essential background. Therefore, the role of Article (I) and R.Q. 1 was to create a platform and starting point for facilitating IS in an industrial area. This is done by describing the area, what potential exists, whether any forms of IS exist and if any definitions of IS fit the area. More generally expressed, this refers to:

***How can IS theory contribute to describing and understanding changing degree of local connectedness?***

Based on the research findings in Article (I), it can be concluded that using and applying IS theory and tools in an industrial region can contribute to facilitation of IS development. Facilitating IS development requires knowledge, information and recognition about the area in the form of what potentials and links already exist. IS tools such as inventory of actors and stakeholders, mapping exchanges of input/output of energy, materials and by-products are useful components in the early phase of facilitation. Thereafter, categorization and characterization of IS types also play a role in further facilitation. It can be concluded that applying the aforementioned tools in the case of Händelö/Norrköping led to the idea of the existence of a number of non-utilized by-products and suggestions of new actors for the network and linking potential actors to potential synergistic possibilities. Furthermore, due to the strategic position of Händelö/Norrköping, the diversity of the actors and symbioses, and exchange of resources at a much greater distance from this area, Händelö has the capability of bringing more potential actors to be included in the existing symbiotic network. Hence, the industrial network in Händelö/Norrköping stated elements from both brownfield restructuring as well as greenfield characteristics.

## *6.2. <u>Facilitating IS development by matching supply and demand potential of resources</u>*

From Article (I), it is accepted that a certain degree of local connectedness in the form of physical resource exchanges (by-products, energy and material) is already embedded amongst the actors in the region. Exchange of data and information about potential resources amongst actors refers to both their provision and handling. Hence, R.Q. 2 and Article (II) mainly deal with facilitating IS development in an industrial region by providing information about supply and demand potential of resources.

***How can providing information about supply and demand potential of resources facilitate IS development?***

It can be concluded that matching the supply and demand potential of resources between industrial actors could contribute to IS development. Provision, compilation, and coordination of relevant data by national and regional organizations can also play a vital role. Providing supply and demand potential of resources includes both quantity/quality and location. The example of providing information about $CO_2$ emissions and combining it with its availability and use provided a better basis for identifying an order of priority for a $CO_2$-providing company. While this work was ongoing, there was news about a letter of intent between the ethanol factory of the region and AGA, a gas provider.

## *6.3. Facilitating IS development by developing/handling of data/information in GIS format*

Provision of relevant data and information about amount of resources and resource allocation (physical resources, potential actors), in existing system and organizations is a considerable challenge. However, developing existing systems into a structured and coordinated format to support a GIS-based solution is another challenge. Hence, R.Q. 3 and Article (III) mainly deal with facilitating IS development in an industrial region by developing existing data and information in a GIS format.

***How can geographic information system (GIS) be used to facilitate Industrial Symbiosis development?***

Based on research findings in Article (III), it can be concluded that using GIS as a tool could contribute to facilitation of IS development. Developing existing information and data into GIS format could require some primary procedures. It can be commenced by building a regional-industry database as the starting point, including an inventory of industrial actors together with their inputs/outputs in the form of exchange of energy, material, water, and by-products. This could be followed by creating regional GIS-based maps and linking to the regional-industrial database. To support development of GIS solutions for IS, formation of a coordinating organization for data management seems to be a prerequisite. Several actors that could contribute to such a development existed in the studied region but there was no explicit focus on supporting IS facilitation.

General conclusions from this thesis elucidated that facilitation of IS development in an industrial region can be influenced by recognition, description and understanding the current situation of an area, and tracking existence of any form of IS in that area. Facilitation will occur by applying IS tools such as inventory of actors and stakeholders, mapping the interactions in the form of exchange of waste, by-products, energy and material, matching the supply and demand potential of resources, and structuring of data and information in GIS format. Furthermore, it is seen that not only exchange of by-products that represents IS development, but also exchange of data and information amongst potential actors in a structured way such as GIS, can lead to facilitation of IS development. In addition, the existing data, information, and organizations indicate that facilitating mechanisms and organizations are available and that there is no need to generate and start new things; it is more a matter of coordination.

# 7. Future Research

*In this chapter, possible future research paths are addressed.*

Since understanding of the social, cultural and institutional factors are necessary for understanding the dynamics of IS and its facilitation-fostering (Lombardi and Laybourn, 2012; Boons et al., 2011); Domenech and Davies, 2009; Brings Jacobsen, 2007), numerous scholars in this field have paid particular attention to facilitation of IS development using social network theory and the role of coordinating organizations and mechanisms in building trust and communication across firms for decision-making support, bringing actors together, managing and sharing data and information, as an essential component (Ehrenfeld, 2000; Heeres et al., 2004; Wolf et al., 2005; Ashton, 2008; Hewes and Lyons, 2008; Paquin and Howard-Grenville, 2009).

Based on this study, it has been shown that facilitation of IS development can be promoted by two different, yet related approaches: applying IS theory and tools as well as the social and human dimension of IS. It has been suggested that applying tools for facilitation of IS development is strictly dependent on the availability, provision, management and sharing of relevant data and information. This is related to some extent to social connections and dimensions of IS networks, trusting relationships, coordination and inter-organizational relationships amongst the actors and stakeholders. Since networking capability can contribute to partners having information and knowledge about each other, increasing inter-organizational collaboration, and improving relations between diverse actors and stakeholders, it seems that in order to fulfil this need, future research study could be concentrated on:

- Creating and improving networking capability, together with increasing institutional capacity and inter-organizational collaboration amongst the actors and stakeholders

- Applying social network analysis tools to map and identify the existing inter-organizational relationships

Accordingly some research questions could be investigated as follows:

- Do any coordinating organizations exist?
- What should be the role of a coordinating organization, which organization can play the role of coordinating organization, and how?
- What should be the main characteristics of the coordinating organization?
- What types of coordinating mechanism are available and how can they be further developed?

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