Planning and Uncovering Industrial Symbiosis: Comparing the Rotterdam and Östergötland regions

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ABSTRACT
Industrial ecology is defined as the study of material and energy flows through industrial systems and as such may focus on a geographic area, resource and/or industry sector. In these types of setting, industrial ecology is also often known as industrial symbiosis (IS). The proximity of companies in industrial estates facilitates the linking of utilities and the exchange of wastes and by-products, which may eventually be useful inputs for adjacent industrial processes. The typical model that has been applied in several regions of the world is one where an anchor-tenant organization with energy and by-product linkages is connected to companies physically located nearby. In the case of biomass symbiosis, however, the resource chains are not explicitly arranged by their industrial setting and the supply of waste and by-products is able to be organized in a more scattered way.

In this article, the role of industrial symbiosis is analyzed in respect of the planned industrial symbiosis activities in the Rotterdam Harbour and Industry Complex in the Netherlands and in the application of renewable energy in the Östergötland region in Sweden.

The objective of this article is to discuss the similarities and differences between the planned industrial symbiosis activities in Rotterdam and the unplanned biomass and industrial symbiosis activities in the Östergötland region. By presenting this knowledge in this article, it is anticipated that further development of industrial symbiosis application processes may be achieved. Copyright © 2011 John Wiley & Sons, Ltd and ERP Environment.

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Introduction

Industrial ecology (IE) was studied by the Japanese Ministry of International Trade and Industry in the 1970s and in respect to the open economy of raw materials and waste in Belgium in the 1980s (Erkman, 1997). However, the breakthrough emergence of the industrial ecology concept occurred with an article in Scientific American in 1989 (Frosch and Gallopoulos, 1989).

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A unique example of IE is the Kalundborg industrial site, which is located in Denmark. This site has been recognized to be the best example of the spontaneous (unplanned), and still developing, application of IE. Indeed, following its recognition and acknowledgement by various local plant managers, this site was actively promoted as an application of industrial symbiosis (IS). Kalundborg thus became the model for many IS initiatives world-wide. However, attempts to mimic IS activities world-wide were often thwarted by the long incubation times needed in order to make them practical (Brings Jacobsen, 2009). It often led to the question of whether the application of the IS concept was too complex to handle (Mirata, 2005). Time is a very important variable in this process (Baas, 2005). Complex business and governmental decision-making processes in the Northern industrial countries can include many different players with different/competing aims, which can result in slow IS developments (Lombardi and Laybourn, 2006). However, there are several new examples and initiatives available world-wide. In this article, the practices in the Port of Rotterdam in the Netherlands and the Östergötland region in Sweden are discussed below. These data are based on scientific research on the forestry industry (Wolf, 2007; Wolf and Petersson, 2007), biofuel links in Sweden (Martin, 2010) and industrial symbiosis projects in the Rotterdam Harbour and Industry Complex (Baas, 2005, 2008; Baas and Boons, 2004; Baas and Huisingh, 2008). The Swedish cases represent examples of uncovered industrial symbiosis activities (Chertow, 2007); they are illustrative of unplanned industrial symbiosis that is based on single steps of business links. The Industrial Ecosystems (INES) project in the Rotterdam Harbour and Industry Complex was initiated by the industry association Deltalinqs; the project is illustrative of planned industrial symbiosis in the whole industrial area.

Chertow (2007) stated that uncovering existing symbioses between businesses has led to greater sustainable industrial development than through attempts to design and build new eco-industrial parks incorporating physical exchanges and services such as utility-sharing. The statement is based on the examination of 15 proposed projects brought to national and international attention by the US President’s Council on Sustainable Development beginning in the early 1990s, and on contrasting them with another 12 projects observed to share more elements of self-organization. It was concluded that projects with a high degree of self-organization demonstrate potentially larger symbioses that can be nurtured and developed further. To test the validity of this statement through further investigation of the two cases noted above, the following questions form the basis of this article’s comparative analysis.

- What are the differences and similarities in planned and unplanned industrial symbiosis?
- Do planned and unplanned industrial symbiosis result in different outcomes?
- Are some dimensions of social embeddedness stronger than others in influencing the industrial symbiosis links in the compared regions?

Social embeddedness refers to the fact that people are social beings whose attributes and actions are conditioned by their locations within networks of concrete and ongoing personal relations (Granovetter, 1985). Industry and its social interactions in the two regions are investigated within their environmental context of relational, institutional and cultural aspects. In this article, planned industrial symbiosis refers to the intentional organization and management of activities that produce results beyond the companies that generate the IS links. Unplanned industrial symbiosis stands for IS business agreements on the simple basis of self-organization.

The two cases have been selected on the basis of research experiences in both regions, discussions with colleagues about planned and unplanned industrial symbiosis and recognition of the different IS links resulting from planned performance in the Rotterdam region and unplanned performance in the Östergötland region. The comparison is based on the generation and application of conceptual IS links in the two regions (Berg, 2007; Yin, 2009). The IS links are compared in a qualitative way. The comparison analyses the differences and similarities in the established IS links (Eisenhard, 1989).

Regional Characteristics of the Planned and Unplanned Industrial Symbiosis in Rotterdam and Östergötland

The concept of social embeddedness is receiving increasing attention in industrial symbiosis research (Baas, 2008; Baas and Huisingh, 2008; Boons and Howard-Grenville, 2009). The notion that firms have a close relationship with their production surroundings in the context of growing globalization (Macerinskas and Pakalniene, 2004) plays an
emerging role in this process. The way in which IS links in the two regions have been established raises the question of whether, in particular, the institutional and cultural dimension of social embeddedness (structural, cultural, cognitive, spatial, temporal and political: Baas, 2008; Boons and Howard-Grenville, 2009) differs between the regions.

Boons and Howard-Grenville (2009) concluded that in industrial parks – despite their geographical proximity – cognitive and cultural embeddedness can prevent individuals from seeking relationships for their businesses that might alter resource flows and improve efficiency. Furthermore, they state that different dimensions of embeddedness relate to each other and therefore have implications, such as path-dependency or technological lock-in, i.e. the view that technological change in a society is strongly determined by its own past and tends to be local (Mokyr, 1990). Effective dialogue about industrial symbiosis and product supply chains, in a mode of continuous learning loops about smaller projects, might influence such limiting routines (Snell and Chak, 1998; Lam, 2000).

Another conclusion considers the importance of spatial embeddedness, as material and energy flows are strongly influenced by distance (Boons and Howard-Grenville, 2009). Hence, regional context forms part of the industrial ecology concept (Chertow, 2000, 2007). It is also related to the fact that the greater the distance the materials are transported, the less environmental profit will be realized.

Baas and Huisingh (2008) also consider the importance of spatial and temporal dimensions of embeddedness with respect to the exchange of waste heat emissions. Breakthroughs such as the exchange of waste heat in the Rotterdam area have the potential to act as a substitute for the combustion of natural gas. However, the large size of the region and diverse range of stakeholders make these breakthroughs very difficult to achieve. Despite the potential of waste heat exchange to reduce fossil fuel consumption, which may lead to achieving one-sixth of the Dutch CO₂ reduction targets (i.e. 6% reduction compared with 1990), the significant transition to utilize waste heat has not been realized because of stand-alone, corporate decisions. For instance, three different energy companies have each planned new power plants in the Rijnmond region (greater Rotterdam area) instead of utilizing sources of waste heat. The new power plants are all based on fossil fuel, coal in particular.¹

In an earlier analysis it was concluded that the position of plant managers and the characteristics of Deltalinqs (the regional industry association) as change agent have been dominant aspects in the implementation of industrial symbiosis design within the Rijnmond industrial region. (Baas, 2005). In this example, it was found that the plant managers were limited to working within the system boundary of their own company – often a single production process facility within a larger multi-national company. As a result, the plant managers could not consider opportunities beyond their company’s system boundary, meaning that they were dependent on outside management for planned industrial symbiosis activities (Baas, 2008).

With respect to the characteristics of the change agent position of Deltalinqs, it was clear that their intermediary position on the one hand did not allow the association to coerce individual members into doing certain things, although on the other hand their social standing still left them in a powerful position for stimulating change in other activities.

A comparison between planned and unplanned industrial symbiosis in two different countries requires knowledge about the context in which human activities occur. For instance, regarding the ways in which common mental models or shared visions among players impact their economic activities (Simsek et al., 2003), it can be stated that this knowledge should be taken into account in planned industrial symbiosis activities. Indeed, it is part of successfully managing any project and may be used by individuals and organizations that collect and use information for making sense of industrial symbiosis in their environment (Weiss, 1979). However, we know that individuals and organizations have limited capacities for information processing and decision-making and that individuals have different strategies for problem solving and implementing new approaches. In unplanned situations it is anticipated that players find each other using more organic ‘growing’ links, in which personal relationships, networks and social contacts (and sometimes serendipity) play important roles.

With respect to structural embeddedness, rules and regulation have led to a complex maze of effects that can be counter-productive for industrial ecology. For instance, potential interest in ‘the waste of one company may be a resource for another’ (Frosch and Gallopoulos, 1989) may be hindered by a ban on transporting waste from one company to another. Such hindrances can have a greater impact in larger planned activities than in the case of an unplanned activity.

The environmental regulations in Sweden and the Netherlands share many similarities as they are both based upon the European Union environmental policy framework. While one impact of environmental regulations is to provide a more or

¹Presentation of Deltalinqs environmental management staff member on 19 May 2009.
less ‘level playing field’ across the European Union (and the implementation of new policies shows much analogy in Sweden and the Netherlands), differences in industrial symbiosis activities in the two countries might be dominated by other dimensions of social embeddedness. For instance, less attention is paid to cultural embeddedness; nevertheless, the effects of informal social networks on entrepreneurial behaviour and on innovation strategies of large companies have been found to be great (Simsek et al., 2003). The cultural context is rooted in historical developments and addresses the influence of collective norms and values in guiding economic behaviour, such as the shaping of preferences and the influence of ideologies in shaping future visions. There is a tendency to externalize normative issues, or to take normative positions for granted, both in our scientific activities and in our subject matter. However, it is also argued that three characteristics of organizational culture – trust, open communication, and joint problem solving – are the key elements for successful network embeddedness (Noorderhaven et al., 2002). In the case of planned activities in an industrial estate, this may be considered to be time consuming and therefore a difficult process. On the other hand, where there is agreement about the application of industrial symbiosis this might deliver a more holistic and comprehensive approach. Unplanned industrial symbiosis activities are often performed on a smaller scale, in a situation where the players know each other.

The two regions under analysis also differ in their industrial spatial embeddedness. The Rotterdam Harbour and Industry Complex is a heavily industrialized area of approximately 100 km² with about one million inhabitants in the urban surroundings. In contrast, the Östergötland region is approximately 10 000 km² with roughly 430 000 inhabitants. It is an agricultural area with scattered industry in Linköping, Norrköping and Finspång. Although only the Händelö industrial area in Norrköping can be qualified as a small eco-industrial park, it is a challenging region for further expansion on the basis of industrial symbiosis.

Waste Heat Application in the Rotterdam Harbour and Industry Complex

In 1994, the regional industry association, Deltalinqs, decided to implement an industrial ecology research programme in the Rotterdam Harbour and Industry Complex, called the industrial symbiosis programme (Industrial Eco System – INES – programme 1994–1997). Research teams from Delft University of Technology and Erasmus University Rotterdam were asked to undertake this research (Baas, 2005). Fifteen projects in total were defined on the basis of the information provided during a two-day industrial ecology workshop where a confidential questionnaire was handed out to companies (Baas, 2005).

One of the projects in the Rotterdam Harbour and Industry Complex was concerned with the issue of waste heat and CO₂. In attendance at the meeting were companies that were emitting waste heat and CO₂ into the air and/or surface water, and neighbouring companies that were producing heat necessary for their production processes. The need for an ‘open door’ proposal mechanism and project design for connecting these industrial systems was identified. However, the project finally selected for sharing waste heat actually laid the foundation for the emergence of strong (political) attention. At the end of the INES programme, the industrial association and an energy distributor jointly discussed how best to utilize approximately 2200 MW of waste heat that was emitted into the air and approximately 3000 MW that was emitted to water. The initial option identified for further study was a pipeline system for connecting the suppliers and buyers in the industrial region. It was calculated that such a pipeline system would cost € 112 700 000 and would require government funding for new infrastructure that would distribute this new source of energy to the industrial region. This waste heat project was further explored in the follow-up INES Mainport project 1999–2002 (Baas, 2005).

After it was determined that the establishment of a pipeline infrastructure for the whole area was uneconomic, smaller scale projects were initiated in the INES Mainport project. The Utilisation of Industrial Rest Warmth project involved eight partner projects in the Botlek and Pernis industry clusters. The estimated total investment required was € 83.6 million. The Dutch National Project Office for CO₂ reduction plans was requested to provide a 30% subsidy in March 1998. A 27% subsidy was secured in November 1998. A partnership of seven Deltalinqs companies tested the technical, operational and economic feasibility of the eight partners’ projects during 1999. Three projects were stopped because of poor results. Of the five remaining projects, four were rejected, three for economic reasons and one on the grounds of discontinuity of supply (see Table 1; Baas, 2005). These four projects represented 63% of the estimated investments for the total of eight projects. This also meant that 63% of the subsidy was rejected.
large remaining project was dropped because of the closure of the main partner, the Kemira Agro plant. It also meant that the pathway of smaller clusters for waste heat supply was not an option.

At the beginning, despite the enormous waste heat surplus, nearly all the large plant managers shared concerns for economic (the costs of the required infrastructure) or strategic (the perceived loss of independence) reasons. These concerns were the main reasons why, during the period 1997–2001, the waste heat supply project had to be downsized from a holistic regional approach to a number of smaller cluster projects. After the large-scale approach appeared to be economically unsuccessful, a feasibility study for heat delivery through a private ‘Heat Company’ was performed (ROM-Rijnmond, 2003). One of the drivers for the continuing effort to implement this project was pressure from the Water Management Authority, who made it clear that they would no longer accept more emissions of heat into surface waters.

In its mindset, industry has always seen environmental investments as efficiency improvements with an expected return on investment of two to three years (Baas, 1998). When environmental policy became better integrated into general industry policy, an expected return on investment of six years became commonplace. With the liberalization of the public energy facilities – electricity and natural gas (de Jong, 2006) – in the Netherlands around the turn of the 21st century, the situation reversed. The privatized energy companies now expect a lower rate of return on their investments than industry, although not as low as the traditional rate of return that was expected when they were acting as public energy companies. As a result, the difference in the ‘acceptable’ investment time frame between industry and energy companies hindered industrial ecology initiatives in the Rijnmond (broader Rotterdam) area.

At the end of the INES Mainport programme and in cooperation with the ROM-Rijnmond Energy projects (a joint industry–government programme), several new partners entered the ‘playing field’, including housing cooperatives and energy suppliers. They agreed to pursue the project on the conditions that de-coupling of the waste industrial heat of Shell Pernis refinery (and later of Esso/Exxon and BP refineries) to the Rotterdam city district heating system was economically viable, and that the responsibility for the coupling between industry and city should be clearly organized. In 2002, the Rotterdam municipality decided to provide a guarantee for the extra funds for a temporary heating system in a new residential area near the Shell industrial site in Rotterdam. They also decided to install a financial safety net for the construction phase in the event that the waste heat project should fail. The application of waste heat should substitute the natural gas supply in the Rotterdam area.

When all conditions for realization were finally met in 2004 (including liberalization of the Dutch energy market, and reductions of CO₂ demanded by the national government as part of the Kyoto Protocol agreement), the planned recovery of Shell’s 6 MW of waste industrial heat as a supply for the city’s district heating system would make the temporary equipment redundant, as 3000 houses would benefit in the Hoogvliet residential area. However, Shell withdrew from the project in 2007 and new arrangements had to be explored. After a delay of several years, new initiatives were taken to initiate the district heating system project in 2012. The heat supply system is still intended to provide 100 MW for application to 50 000 houses and the greenhouse sector (ROM-Rijnmond, 2005). In addition, future activities are planned to connect 500 000 houses and companies in the Southern part of the province of Zuid-Holland in 2020 (ROM-Rijnmond, 2006).

CO₂ recovery is also included as part of the project. A new private company, OCAP, has the ownership of the infrastructure and the responsibility to capture CO₂ emissions from the Shell plant (in Pernis), and distribute the waste

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<th>Waste heat supply project from</th>
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<td>Economic: pay-back time is longer than 30 years</td>
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<td>AVR to Dapemo</td>
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<td>Lyondell to Climax</td>
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<td>Esso to ORC</td>
<td>Economic: not feasible</td>
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Table 1. Waste heat supply sub-projects and the reasons for their rejection

Some experts state that in the decision-making process for the unification of the European Union market, for which obstacles to the optimal operation of the free market had to be taken away, it was forgotten that from an economic perspective the free market does not always provide the best solution. Sometimes a monopoly works better, for instance in the case of the electricity supply. This is because, with natural monopolies, the owner needs to have long-term investment perspectives.
emissions to 500 greenhouse companies at the North of Rotterdam. The CO₂ delivery project (as substitution for the combustion of natural gas) began in July 2005. In 2007, the greenhouse companies achieved a reduction of 170 000 tonnes CO₂ emissions by avoiding the burning of 95 million m³ natural gas.³ The designed future waste heat infrastructure is shown in Figure 1 (the red lines are the primary new pipelines as common carrier; the blue lines already exist in a district heating system, and the dotted red lines are to be constructed in a later phase).⁴ The factory examples include refineries, power stations and incinerators that will function as heat hubs within the district heating system. The district heating system will supply Rotterdam (1) and its surroundings (6), Dordrecht/Zwijndrecht (2), the greenhouse area Tinte/Vierpolders (3), the city of The Hague and its surroundings (4) and Delft (5).

There have been several ‘up-and-downs’ in the decision-making processes concerning the application of waste heat in a district heating system for Rotterdam city and its surroundings. In February 2011, the municipality of Rotterdam and E.ON started a joint venture for a new ‘Heat Company’ for waste heat application. Whilst the significant waste heat emissions cannot be ignored, the project cannot proceed if it is uneconomic.

A major lesson learned from the INES programme in the Rotterdam Harbour and Industry Complex was the spontaneous spin-off of initiatives that are inspired by information and the dissemination of results. New activities were observed, ranging from connecting waste heat from a chemical company to a neighbouring truck cleaning company, the privately initiated and constructed ‘Happy Shrimp Farm’ (a king-size shrimp breeding greenhouse water basin utilizing CO₂, NOₓ and waste heat from a power plant), the IS design of a new chemical plant and a new industrial site, Maasvlakte2, that is reclaimed from the North Sea and is designed following IS principles (Baas, 2008).

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### State-of-the-Art Industrial Symbiosis in Östergötland

In this section attention is paid to the Swedish forest industry and the biomass links in the Östergötland region as examples of unplanned industrial symbiosis links. Nature conservation has a long history in Sweden, as illustrated by the more than hundred-year-old slogan ‘Nature is everyone’s’. Production-oriented forest policies have dominated since the early 20th century and explored cascade flow management and industrial symbiosis under the label of integrated diversification for efficient resource use. In the 1960s and 1970s, however, many companies became too diversified despite creating more value (Hill and Jones, 2001). As a result, in the 1990s, the argument for changing the strategy of many larger corporations to focus on a limited number of forest products seems to have been influenced by globalization trends, and the need for decreasing bureaucracy and higher coordination costs. Nevertheless, Wolf and Petersson (2007) found that more than one-third of the companies investigated in the Swedish forest industry had some kind of material or energy exchange with adjacent entities, such as is demonstrated in the Mönsterås network. Although this network is outside the regions compared in this article, the academic study is illustrative for the forestry industry network in Kisa, Östergötland.

In Mönsterås, the pulp mill and pellet production plant are collocated; they share buildings and personnel and exchange material and energy. The pulp mill delivers steam and electricity to the saw mill, steam, electricity and bark for pellet production and waste heat to the local district municipal heating system. In turn, the sawmill delivers sawdust and wood chips to the pulp mill (Wolf, 2007; see Figure 2).

Another spontaneous development can be seen in the Östergötland region, where Cleantech Östergötland – an organization comprising the municipalities of Linköping and Norrköping and one hundred industrial organizations and promoting the region’s business – was established in 2008. This organization ‘markets’ the IS concept as an umbrella for environmentally driven regional development in Östergötland and define it as business practice: ‘...Characteristic for industrial ecology is to turn environmental problems into business opportunities by applying wide system boundaries, using resources efficiently and co-operate through resource sharing...’ (Cleantech Magazine, 2009). Several IS activities had already been developed prior to the establishment of Cleantech Östergötland, such as a 1.7 km pipeline for the utilization of nutrient rich waste water from a slaughterhouse into the biogas

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³Natural gas is burned in greenhouses for heating and the input of CO₂

⁴The picture of the Botlek Loop in the bottom left part of Figure 1 illustrates the waste heat exchange between companies, houses, greenhouses and an underground storage centre for cold and heat supply in the Botlek industry area.
production facility in Linköping. Cleantech Östergötland promotes these types of activity as business cases. In the same fashion, district heating companies such as Tekniska Verken in Linköping, and E.ON in Norrköping, use IS as a driver of regional sustainability innovation. For example, biogas production as affiliated or linked facilities of the district heating companies are providing biogas for all public bus transport and taxis in both cities. The local governments took this substitution decision as a means to solve the increasing city centre environmental pollution as a result of the use of traditional fuel driven transport. In addition to the 5% average biofuel addition to the petrol use in Sweden, the 5% pure biogas use in Östergötland meant that, in 2009, approximately 10% of the transport in

Figure 1. Future waste heat infrastructure

Figure 2. Mönsterås forest industry’s by-product network
Östergötland relied on biofuel. Out of the many biomass symbiosis links in Östergötland, IS in the Händelö region is illustrated below (see Figure 3; Martin, 2010).

The Händelö industry area in the Norrköping municipality is interesting: it combines an IS renewable energy cluster, a logistical centre and Natura 2000 conservation areas (Nicklasson, 2007). All links were developed step by step. Currently, the IS renewable energy cluster links the E.ON combined heat and power (CHP) plant with a biogas plant and an ethanol plant. The E.ON plant has a fuel mix of 95% renewable resources, including household waste, rubber, woodchips and wood waste. The biogas plant owned by the CHP plant produces biogas from sludge derived from Norrköping’s waste water treatment facility. After fermentation, the biogas is upgraded to vehicle fuel and distributed to local refuelling stations. 29% of the output of the CHP plant is delivered as steam to the ethanol plant. The ethanol plant uses wheat, triticale and barley as raw materials for the annual production of 210 million litres of bioethanol and 195 000 tonnes of protein pellets for livestock feed. The remaining part of the sediment that is not used for livestock fodder becomes raw material for another biogas plant.

Many IS links in Sweden are developed on the basis of a single business case. Planned IS activities in a bigger industrial park format are rare (the next example of a Landskrona industrial park has to be taken from outside Östergötland) and seems to be difficult to handle in Sweden. The Landskrona IS project was ‘created’ by the Lund University as part of Ph.D. research (Mirata, 2005). The creation approach of the IS Landskrona project for networks was based on the following definition: ‘...a collection of long-term, symbiotic relationships between and among regional activities involving physical exchanges or materials and energy carriers as well as the exchange of knowledge, human or technical resources, concurrently providing environmental and competitive benefits...’ (Mirata and Tareq, 2005).

The involvement of anchor organizations and key personnel in the field provide important drivers for the dissemination of IS activities within a region. It is very important to identify them as ‘owners’ of the project when the project is initiated from the outside. Unfortunately, in the Landskrona project the IS initiative was phased out when the research project budget, including external IS management, ended in 2006. Although the Landskrona industrial park was leading the introduction and dissemination of cleaner production in Europe between 1987 and 1989, the industrial ecology concept did not generate a similar spin-off (Mirata, 2005).

Besides the academic discovery of renewable energy and efficient material use on the basis of industrial symbiosis (Wolf et al., 2005), new IS approaches recently began in Östergötland. A four-year Sustainable Norrköping programme (2010–2013) will investigate the IS development of an energy cluster and a logistics centre in the Händelö industrial area. A visualization centre for the popular science communication of industrial symbiosis through the visualization of material flows and connections in the Händelö area is also part of this planned project. It is argued that the citizens’

Figure 3. Industrial symbiosis network in the Händelö industry region

Natura 2000 is the name of the EU network of protected nature areas.
willingness, commitment and support for these changes are very important dimensions for further developments; their empowerment, continuing engagement and support are essential to ensure that this region continues on its transition journey.

In a further example, the Linköping district heating company, Tekniska Verken, and Linköping University agreed to fund a 10-year Industrial Ecology Research Programme with Tekniska Verken connected to a new chair of Industrial Ecology (www.iei.liu.se/envtech). In the Industrial Ecology Research Programme, industrial symbiosis is defined in the following terms: ‘Industrial symbiosis is seen as a process whereby materials, water, energy and informational flows between and among companies are investigated with the objective of developing and improving co-operative links between/among them’. The long term Industrial Ecology Research Programme 2009–2019 will contribute to focused research, education and knowledge dissemination with respect to clean technology, industrial symbiosis, waste to energy and biofuel applications on a sound economic basis through the results of Ph.D. research and continuous evaluation of sustainability projects in practice. Research projects such as the utilization of waste heat, CO₂ and nutrients from the district heating company in greenhouses, biofuel synergies, landfill and urban mining started in 2010.

It is remarkable and encouraging that the policies and activities developed in Östergötland have already resulted in more than a 20% CO₂ reduction compared with 1990’s level of emissions in the region. District heating systems and biofuel applications seem to be basic elements in the emergence of a ‘silent’ transition to a ‘100% renewable energy’ region.

**Observations and Analysis of Industrial Symbiosis in Rijnmond and Östergötland**

For several decades, the regional Dutch industrial association Deltalinqs, the Rotterdam Port Authority, the Rotterdam Municipality and the regional environmental protection agency (EPA) have been linked in various organizational frameworks for stimulating better economic and environmental performance. The various stakeholders in the region share an environmental management ‘history’ from the introduction of environmental regulations requirements in the 1960s to joint environmental regulation/sustainability facilitation activities in the first decade of the 21st century (Baas, 2005). Despite the cognitive dimensions of embeddedness of routines that are restricting new links in a holistic approach of the region, there is space for new concepts such as the design of compressed air systems for a group of companies (Baas, 2005). New concepts as part of planned activities have led to new markets for existing companies, such as Linde gas (multi-company compressed air systems) and new companies like OCAP (for the delivery of CO₂ from Shell refinery to 500 greenhouse complexes) and the Happy Shrimp Farm.

Since 2003, the staff bureau of ROM-Rijnmond has developed a strong change management position by building trust between the different strategic platform members representing government, industry, expertise centres and an environmental advocacy organization through reflexive learning processes of sustainability projects in the region.

As the environmental regulations in Sweden and the Netherlands are both based upon the European Union environmental policy framework, the structural regulatory basis is more or less similar. The industrial policy of Sweden has always been open for adapting to changing economic situations and innovation. Their industrial policy has traditionally focused on large enterprises such as Volvo, SAAB and individual sectors. In the 1970s and early 1980s, the industrial policy mainly focused on supporting sectors that experienced problems brought on by structural changes in the economy. However, the importance of small enterprises and entrepreneurship has been increasingly recognized in the industrial policy over the last two decades. The main reason for this shift in policy focus was the result of SMEs representing an increasingly important source of employment and growth (NUTEK, 2004). Nowadays, the Swedish industrial structure is characterized by a limited number of well known large companies and many SMEs.

A key difference between Sweden and the Netherlands concerning _cultural and political_ embeddedness can be seen by performing a review of their R&D investment policies. Sweden has a high ‘innovation level’ of 3.6% (Statistics Sweden, 2009) to 3.7% (European Union, 2010); in contrast, the Netherlands suffers from a low ‘innovation level’ of 1.8% within the European Union (2010). This is a longer existing trend that might also influence the players’ sensitivity towards new approaches such as industrial symbiosis.
At the local level in Sweden, links between government, industry and knowledge centres are commonplace in order to develop common solutions. In this context the local authority is a very strong actor because it is involved in many decision-making processes affecting economic activities and to ensure continuity. Their important position in the Swedish tax system provides strong economic power incentives for having a role as facilitator of local integration projects (Baas, 2011). In the Netherlands, the institutional environment in which this innovation system needs to function is unstable and very often not stimulating for new initiatives (Negro et al., 2007). Discontinuity in renewable energy stimulation programmes, scattered research funding and the lack of local research funds contribute to this problem. Furthermore, there are few network and lobby activities, initiatives between academia, research institutes and local projects and a misalignment between government actions and the needs of entrepreneurs (Negro et al., 2007).

In analysing IS developments, the different approaches of planned versus unplanned industrial symbiosis activities have been described. An important issue is the question of whether IS produces better results when business cases are developed in a more or less organic way, or whether intentional approaches create more optimal frameworks for these projects. Chertow (2007) states that uncovering existing symbioses has led to a more ‘sustainable’ industrial development than has been achieved through attempts to design and build new eco-industrial parks incorporating physical exchanges. In this regard it is important to understand how new eco-industrial parks are designed. For example, those designs with a common industrial symbiosis infrastructure and cleaner production based companies seem to demonstrate optimal sustainability. However when the design is open, for example because it is uncertain which companies should start production in the new industrial estate, optimal IS realization is more difficult to achieve. In case of the existing Rotterdam Harbour and Industry Complex, Deltalinqs and the member companies are partners in Dutch national sustainability programmes.

Despite the significant difference in the size and type of industrial structure, the distance between industrial symbiosis links can sometimes be more or less the same in the two regions. Although the biofuel symbiosis links between companies in Östergötland are scattered in several geographical locations, it is possible that the distance of an IS link between the western and eastern parts of the Rotterdam Harbour and Industry Complex is similar.

Conclusions

With respect to the question of the differences and similarities between planned and unplanned industrial symbiosis, it can be concluded that uncovering and mimicking existing symbiosis seems to better suit the small-scale Swedish business concept than planned developments in new or underdeveloped eco-industrial parks. The thinly populated Östergötland region provides proximity such that representatives of industry, government and academics frequently meet each other. In contrast, the industrial estate density and their local industry associations in parts of the Netherlands seem to better suit the planned industrial symbiosis. Meetings of representatives of industry, government and academics have to be arranged, for instance in a sustainability decision-making platform.

The conditions required for implementing both planned and unplanned IS facilities share many similarities, such as a trust-based inter-firm relationship, long-term interdependence and personal relations as an intermediary in knowledge exchange (Macerinskas and Pakalniene, 2004). IS activities were developed and showed results within the context of the specific institutional embeddedness of both regions. Creating a personal relationship is another important driver for new developments both at the micro level for links between companies and at the meso level (the level beyond single companies in a region) of regional embeddedness. In unplanned situations, the insight in industrial symbiosis is more dependent on players at the micro level of personal contacts and knowledge sharing. In planned situations, information and dialogue at a meso level can provide more insight to individual players while social pressure can present these players with the possibility of their organization being involved in new industrial symbiosis links. Both situations require a longer timescale for acknowledgement, information and application of the concept.

Strong IS links are found in the historical settings between companies both in the spin-off integrated industrial activities in the Swedish forestry industry (Wolf and Petersson, 2007) and in the Rotterdam Harbour and Industry Complex (Baas and Boons, 2004). The Rotterdam links have become the basis for the development of mutual trust and the formation of a network of key stakeholders, who have initiated many new sustainability projects (Baas, 2005). The sustainability concept has developed into a common topic of interest as operationalization of the
decoupling of economic growth and environmental burden in the Rijnmond region has occurred. Industrial symbiosis possibilities are discussed and researched in the framework of a collective focus group platform, but the IS applications are decided on as a single business case.

The unplanned industrial symbiosis links in Östergötland have developed despite the presence of such a platform. Significant co-operation between industry and the university helped to uncover several existing links and detected new relationships between companies. Generally, the issues of having trust and an innovative attitude are very important variables in Swedish society. Levels of trust and innovation are reported to be very high in Sweden (Statistics Sweden, 2009) and help to create excellent bonds between government, industry and knowledge centres, which enable common solutions to be developed. In this context the local authority is a very strong player, because it is involved in many decision-making processes affecting economic activities. The significant role it plays in the Swedish tax system also provides strong economic power incentives for the creation of a co-ordination role in local integration projects. On the other hand, in an analogy of Selman’s ‘Canons of sustainability’ analysis (2000), such a role is impeded by the weak integration of the municipality’s various departments.

With respect to the question of whether planned or unplanned industrial symbiosis results in different outcomes, it was found that the various differences and similarities between planned and unplanned IS processes make it difficult to effectively compare the impact of the final results. For example, for the planned situation, CO₂ delivery from the Shell refinery in Rotterdam as substitution for the burning of natural gas to one-third of the Dutch greenhouses has a significant impact. It saves about 95 million m³ of natural gas and it reduces CO₂ emissions by about 170 000 tonnes per year (OCAP, 2009). However, in the unplanned situation, the delivery of slaughterhouse waste water as a resource for biogas production in Östergötland is also considered to be significant. The delivery covers approximately 40 000 tonnes of organic materials processed annually, providing 37 000 tonnes of certified bio-fertilizer and 5.4 million Nm³ biogas sold annually on a regional market. Hence, these examples answer the outcome of planned or unplanned industrial symbiosis in terms of significance of results, albeit not in a ranking (or comparative) way.

It is suggested that well integrated companies can be key players when developing more integrated networks. For example, Östergötland’s district heating systems, which have been used since the 1950s, and increased biofuel applications in the early 21st century are basic elements in current IS development. Moreover, later policies on landfill tax and landfill bans have strengthened the waste incineration system’s transformation in adopting a ‘waste to energy’ philosophy. The philosophy moves from the linear approach to the circular method, where wastes become ‘resources’ as part of the new business case way of thinking.

Finally, continuous academic research and energy supplying company initiatives are exploring how to increasingly apply renewable energy in Östergötland. Regional sustainability programmes such as the Cleantech/Industrial Symbiosis programme are also helping to stimulate industrial symbiosis concepts and renewable energy. Past and ongoing initiatives have resulted in the expanded consciousness that clean technology and industrial symbiosis can provide a synergy mode for innovative approaches beyond the adaptive capacity of single organizations.

Regarding the question of whether some social embeddedness dimensions are stronger than others in influencing the industrial symbiosis links in the compared regions, it can be concluded that different pathways can achieve industrial symbiosis providing that there are suitable links, such as personal relations and knowledge, about the concept. The different positions of actors and organizations in the two regions determine the regional characteristics of institutional and cultural embeddedness that leads to an improved learning process in a region-specific way. From the Rotterdam example, it has been seen that planned industrial symbiosis activities have also provided space for unplanned spontaneous actions. From the Östergötland area it has also been seen that the analysis of uncovering the unplanned industrial symbiosis activities can actually be a basis for new activities. A combination of planned and unplanned industrial symbiosis can intentionally generate new industrial symbiosis links. Conditions for such processes include

- the proper analysis of the context of historical links between companies,
- a social learning network of key stakeholders,
- a high level of mutual trust and
- an industrial culture that contains a strong sustainability innovation focus.

Along with the insight gained, this combination of processes can positively influence industrial symbiosis development.
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