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**Literature review on eco-industrial development initiatives around the world and the methods employed to evaluate their performance / effectiveness**

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# **Literature Review on Eco-industrial development initiatives around the world and the methods employed to evaluate their performance / effectiveness**

## **Introduction**

Industrial Symbiosis (IS) is based on the concepts of industrial ecology (IE) and eco-industrial development (EID). Industrial symbiosis refers to the network of product, by-product and waste exchanges that reduce the ecological footprint of industrial areas (Kurup *et al.* 2005). Recent developments in the area witness the usefulness of this approach in addressing the challenges of corporate social responsibility and inter-organisational environmental management. This approach is not sector specific and provides cross-sectoral opportunities for businesses along with boosting their environmental performance. The development of industrial symbiosis networks in most parts of the world demonstrates that there are benefits attached to them and there are more opportunities that could be pursued, but the exploitation of those opportunities are limited due to the lack of a comprehensive model to evaluate the industrial symbiosis projects, along with many other reasons. As both fields of industrial ecology and eco-industrial development are new fields of enquiry, it is important to concisely discuss these fields to provide appropriate background to the development of industrial symbiosis initiatives and the progress made in the attempts to develop methods to evaluate industrial symbiosis projects. Several different classifications of eco-industrial development initiatives and in particular industrial symbiosis initiatives have also been included in the report. This classification would assist in identifying suitable indicators for evaluation of particular type of industrial symbiosis projects. Literature and commentators in the field have identified several criteria that are complimentary and contradictory to each other in order to evaluate the success of industrial symbiosis projects. These criteria have been discussed in this report. Some models that have been proposed and / or used by researchers are also presented here with an aim to provide a basis to appraise / critique available models in order to take a step forward in the attempt to develop an integrative evaluation methodology for industrial symbiosis projects.

## **Industrial Ecology Concept**

IE is based on the metaphorical relation between the natural and industrial ecosystems. IE uses the metaphor of sustainable natural ecosystem as a model for transforming unsustainable industrial systems (Korhonen *et al.* 2004), which as noted by Korhonen and Strachan (2004) has become the distinct character of the concept of industrial ecology. IE first became popular as a theoretical concept and that concept's relation to industrial activities, in the article "Strategies for manufacturing" by Frosch and Gallopoulos (1989). Jelinski (1992) conceptualized IE as three development models, starting from the linear and immature ecosystem that is unsustainable to the semi-matured ecosystem through to a mature materially closed ecosystem that is ultimately sustainable. Ayres (1994) introduced IE as a metabolic metaphor as it aims to understand the circulation of the materials and energy flows linked to human activity (Erkman 1997). IE further developed as a biological or ecological metaphor (Allenby and Cooper 1994) to determine how the industrial system should be restructured to make it compatible with the way natural ecosystems function (Erkman 1997).

Several definitions are available but it is not easy to fully understand the holistic concept of IE. Erkman (1997) identified that most authors more or less agree on at least three key elements of IE. The first element is its systems approach where IE studies the whole system that includes the material and energy flows, rather than just studying a component of the system. The second element of IE is that it takes into consideration the material and energy flows in and outside a company boundary. The third element is the use of key technologies as a crucial component to achieve the

transformation from an unsustainable industrial system to a viable industrial ecosystem. Jelinski (1992) conceptualized IE in three development models i.e. type I, II and III. Type I as explained by Korhonen and Strachan (2004) is a linear, immature and unsustainable model; type II is a semi-matured state; and type III is a mature and materially closed ecosystem (Korhonen 2005) that is ultimately sustainable (Jelinski 1992). Korhonen (2001) argues that the goal of the IE community is a move towards the type III ecology i.e. an ecosystem that has evolved from linear and quasi-cyclic material flows into a situation where the resources of life are limited and therefore the system operates through almost the complete cyclic nature of the material flows. Korhonen (2005) notes that unfortunately we are still in between the type I and type II model. Korhonen et al. (2004) raise the question: 'How can public policy and corporate environmental responsibility be harnessed to realize the type III eco-industrial development vision in practice?' Deutz and Gibbs (2003) have stressed the importance of cooperation between local authorities and public and private actors for progress towards eco-industrial development.

### **Eco-industrial Development**

Literature on eco-industrial development is clumsy and fragmented despite a growing interest in the field. Eco-industrial development refers to a broad and multi-faceted set of ideas, and has been evolving and deepening over the years (Spiegelman 2001). Cote (2000) interprets EID as a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resources issues including energy, water and minerals.

Eco-industrial Development strategies have been practiced by businesses for centuries to conserve valuable resources, encourage innovation, and maximize financial profit (Trillium Planning and Development 2003). Cohen-Rosenthal (2003) also states that eco-industrial connections occur all of the time in all kinds of businesses and communities. In one of his articles, Desrochers (2002) presented historical evidence from the literature of 19<sup>th</sup> and 20<sup>th</sup> century demonstrating that one of the eco-industrial activities, which he phrased as inter-firm recycling linkages, were a dominant characteristic of the past economic development. He argued that most of the commentators (Simonis 1994, Ayres 1994, Cote and Smolenaars 1997, Frosch 1995, Lowe 1997, Ehrenfeld and Gertler 1997) from the field of industrial ecology and other related fields failed to believe so. Desrochers (2002) indicates that it is due to two main reasons, one of which is the lack of research into the spontaneous formation of inter-firm recycling linkages and the other is the progressive and cumulative implementation of market distortions and regulatory barriers to resource recovery over the last century. Desrochers (2002) provided ample historical evidence against the belief that past economic development was characterized by a linear model of extraction, use and disposal. Eco-industrial development strategies did not comprise a new idea though as Desrochers (2002) argue they were practiced on a smaller scale based on the level of technological innovation and regulatory barriers in the past. What is new is the emphasis on the comprehensive application of these strategies with the multiple objectives of maximizing financial returns, improving connections between businesses and their communities, and reducing environmental degradation (Trillium Planning and Development 2003). We will argue in favor of Desrochers' (2002) view based on available evidence, which is also supported by Trillium Planning and Development (2003), Cohen-Rosenthal (2003) and Sterr and Ott (2004), that eco-industrial development strategies were possibly practiced in the past may be on a smaller scale, which were perhaps not conscious and / or systematic. Cohen-Rosenthal (2003) raised questions about the on-going eco-industrial activities if they are conscious and systematic, and if they add value to shareholder, stakeholder and the environment. A further issue was the knowledge of stakeholders about how to adjust to the changing business environment such as new markets, technologies and materials. There are several ongoing eco-industrial activities that are neither conscious nor systematic. Progress in the field of

industrial ecology, particularly the move from the material and energy flow aspect of industrial ecology to the human dimensions, strategic management and policy perspective aspects is playing an important role in assisting in the realisation, systematisation, further development and management of such activities. Though it is not yet clearly outlined in the literature if these activities either planned or unplanned add value to shareholders, stakeholders and the environment. Further research is required to identify cases where eco-industrial activities are developed, how they are managed and if they add value to shareholders, stakeholders and environment.

Eco-industrial development approach is very diverse as characterised by broad definitions and several classifications in different contexts. Research Triangle Institute (2001) produced a classification of eco-industrial development based on different group of actors and emphasis:

- *a single by-product exchange pattern or network of exchanges;*
- *a recycling business cluster (e.g., resource recovery, recycling companies);*
- *a collection of environmental technology companies;*
- *a collection of companies making “green” products;*
- *an industrial park designed around a single environmental theme (i.e., a solar energy-driven park);*
- *a park with environmentally friendly infrastructure or construction; and*
- *a mixed use development (i.e., industrial, commercial, and residential)*

Whereas Trillium Planning and Development Inc. (2003) in feasibility study focused on four concepts of eco-industrial development which were considered the most relevant specific for the planning area in the US context:

- *Bio Based Industry Cluster:* It would produce alternative fuels, lubricants and co-products increasing the value of agricultural resources such as corn and soybean (e.g. *Biodiesel from soybean oil*);
- *High Performance Warehouse and Distribution Centers:* It would be used for logistics division of retailers and wholesalers by co-locating combination of firms with complementary distribution channels;
- *Research and Technology Park:* It would focus on commercialization of research; and
- *Eco-Park (Planned Mixed-Use Commercial Park):* It would be branded and marketed as an eco-industrial park (EIP) and planned according to eco-industrial development principles including business-to-business and business-to-community networking, energy and resource efficiency, pollution prevention, sustainable land use and building design etc.

Chertow (2002) discussed eco-industrial development as Types 1-5 which is perhaps based on size and geographical coverage of the eco-industrial activities: *‘Through waste exchanges’*, that is, businesses recycling or selling recovered materials to other firms e.g. scrap dealers. *‘Within a firm’*, it occurs either in big organizations that often behaves as if it were a collection of several different entities or by integrating operations further up the life-cycle chain. *‘Among firms co-located in an eco-industrial park’* businesses located in a set geographical area exchange energy and material and share information and services such as transportation. *‘Among local firms that are not collated’*, is the model that relies on using existing business and inviting some new ones to create a synergy though this type of eco-industrial development does not require strict geographical proximity. *‘Virtual eco-industrial parks’* allow the businesses to share waste stream however use of energy at large distances would perhaps be impossible or inefficient.

Musnikov and Schlarb (2002) categorised most eco-industrial activities into one of the following four categories: *eco-industrial park* – It utilizes the format of traditional industrial parks and collocates several businesses on a specific property; *transformed existing industrial park* – Existing

parks are converted into eco-industrial systems by adapting the park to incorporate eco-industrial principles and activities; *Virtual eco-industrial network* – creates materials link and other connections among industries within a region without relocating businesses; *and a combination of forms* – this employs some or all of the three types of eco-industrial initiatives mentioned earlier. Whereas Roberts (2004) utilises a different approach by outlining EID at three distinct levels: *Company Level, Eco-industrial Park Level (or IS Network Level) and Networked Eco-industrial Parks Level*. Applying industrial ecology at the “*Company Level*” can achieve significant operational savings; however, there may be limitations related to scale and quality of waste and materials by-products that affect recovery cost (Roberts 2004). According to the report Laybourn (2002), “*Eco-industrial Parks or Industrial Symbiosis Networks*” (see section 2.3) cover a wide array of issues including material, energy and water balances for companies, their production processes and capacities, needs for support functions and infrastructures, human and knowledge resources etc., and aim to develop long-term continuous partnerships based on direct communication of network companies. Mirata (2004) in agreement with the statement in Laybourn (2002) argues that Industrial Symbiosis Networks can allow improvements in the efficiency and effectiveness by which different resources and capacities are utilized going beyond that which can be achieved by fragmented pursuit of improvements in individual units. “*Networked Eco-industrial Park Systems (NEIPS)*” are the clustering of industrial symbiosis networks. NEIPS are a step ahead of industrial symbiosis networks. NEIPS represent industrial symbiosis macro-level developments that have strategic links or alliances with other industrial symbiosis networks across regions (Roberts 2004).

Based on the range of classification of eco-industrial development initiatives in literature e.g. Roberts (2004), Chertow (2002), Research Triangle Institute (2001), Trillium Planning and Development Inc. (2003) and others, it is very clear that the definition of eco-industrial development has not developed well to set boundaries in order to identify what kind of initiatives can constitute an eco-industrial development initiative. Though it is obvious that most of the classifications include the concept of eco-industrial park and / or industrial symbiosis. Literature of industrial ecology and eco-industrial development has used both terms in conjunction with each other whereas some others clarify the distinction in between the two. Based on thorough investigation of 13 projects that were undertaken by groups of students during two year period, Chertow (1999) claimed that eco-industrial parks are a part of industrial symbiosis. Despite the common usage of the term “eco-industrial parks”, it is important to note that industrial symbiotic relationships do not necessarily exist within the confines of a park (Harper and Graedel 2004). Therefore it can be suggested that eco-industrial park is a subset of industrial symbiosis. Industrial symbiosis, based on the concept of IE and EID, is an approach that is practiced to achieve sustainable development. This approach has been in existence for many years but Mangan and Groberg (2005) argue that different names have been used in order to apply the same prescription for practicing sustainable development such as ‘by-product synergy’, ‘green twinning’, ‘zero waste / zero emissions / 100% product operations’ and ‘cradle-to-cradle eco-efficient manufacturing’. Industrial symbiosis networks aim to increase business performance while reducing pollution and waste (Cohen-Rosenthal 2004). Korhonen and Strachan (2004) have identified that the clearest link between industrial ecology and business studies comes through industrial symbiosis. They also emphasized that industrial symbiosis is, by far, the easiest to understand and the most popular industrial systems application of the natural ecosystems metaphor that enables us to consider the potential of the metaphor in practical corporate environmental management. Industrial symbiosis is achieved when two or more businesses cooperate and collaborate with each other by using by-products or throwaway material from each other. This would not only improve business performance by improving profits and attaining competitive advantage but also protect the environment by reducing waste and reducing use of natural resources. Chertow’s (2002) classification of EID initiatives based on the size and geographical coverage of eco-industrial

activity has been an effective one. Musnikov and Schlarb (2002) and Roberts (2004) have used a similar approach in classifying EID activities i.e. based on size and geographical coverage. Whereas classification of EID initiatives by the Trillium Planning and Development (2003) and Research Triangle Institute (2001) mainly focus on particular contexts and sectors, which complicates the understanding of industrial symbiosis. Context oriented classification does not allow the development of a generic approach and sector oriented approaches do limit the exchange of by-products and may restrict the development of industrial symbiosis. Industrial symbiosis as Korhonen (2002) argues requires diverse actors in the system to complement by-product synergy. Therefore, it can be suggested that the classification based on size and geographical coverage (e.g. Chertow 1999, 2002; Musnikov and Schlarb 2002 and Roberts 2004) would serve as the best for the further development of industrial symbiosis. Chertow (2002) argued that the last three types of eco industrial activities in her classification above can be identified as industrial symbiosis i.e. *utility sharing and symbiosis among firms that are co-located (eco-industrial park)*, *symbiosis among firms that are not collated and do not require strict geographical proximity (eco-industrial network)* and *symbiosis among firms that are virtually networked and could be spread at large distances (virtual eco-industrial network / park or industrial symbiosis network) e.g. regional network*. ‘*Transformed Existing Industrial Park*’ which is also known as ‘*brown-field development*’ has been included in the classification by Musnikov and Schlarb (2002), has been a very important component of industrial symbiosis. It is also however important to know that eco-industrial park, as used in Chertow’s (2002) classification, included both kind of parks that are newly developed “green-field development” and the existing industrial parks that are converted into an eco-industrial park “brown-field development”, though these terms were not used in her classification . Based on the above classifications of eco-industrial development initiatives and the associated discussion, a more focused classification is developed that includes approaches that only fall in the IS category (see table 1). This classification omits any industrial sector-wide approaches and appreciates the diversity of the industrial system which is a key feature of industrial symbiosis. It is aimed to include initiatives that focus on achieving utility sharing and symbiosis among diverse sectors of industry.

*Table 1. Classification of Industrial Symbiosis Initiatives*

- **Green Twinning** (*single material and/or energy exchange*)
- **Greenfield Eco-industrial Development** (*geographically confined space*)
- **Brownfield Eco-industrial Development** (*geographically confined space*)
- **Eco-industrial Network** (*no strict requirement of geographical proximity*)
- **Virtual Eco-industrial Network** (*networks spread in large areas e.g. regional network*)
- **Networked Eco-industrial System** (*macro level developments with links across regions*)

*Source: Author*

Industrial symbiosis has gained prominence among other sustainability strategies for industry (Altham and van Berkel 2004). It is evident from the most often cited example of Kalundborg IS in Denmark that the industrial symbiosis approach could be a very successful one, though the limited examples of such successful initiatives to date prove that it is not easy to plan, develop and manage IS networks. Kalundborg IS is built as a networking co-operation among six processing companies, one waste handling company and the municipality of Kalundborg, and they are successfully able to exploit each other’s residual or by-products on a commercial basis, minimizing pollution and optimizing the use of various resources (Industrial Symbiosis at Kalundborg<sup>1</sup> 1995). The symbiosis evolved gradually and without a grand design over the past 25 years, as the companies sought to make economic use of their by-products and to minimize the cost of compliance with new, ever-

<sup>1</sup> Industrial Symbiosis at Kalundborg available from <http://www.symbiosis.dk/> and <http://www.indigodev.com/Kal.html> [Accessed 2nd March 2006]

stricter environmental regulations (Ehrenfeld and Gertler 1997). Bilateral exchanges of waste materials were primarily motivated by economic benefits, although as a result, tangible environmental benefits have been gained (Christensen et al. 2000). Influenced by the example of Kalundborg, IS initiatives are being launched in the USA, Australia, the UK and most countries of Europe which symbolizes the revolutionary development of industrial symbiosis.

### **Evaluation of Industrial Symbiosis Initiatives**

Mirata (2004) claims that IS initiatives offer the potential for environmental, economic and social benefits. He also states that there is no agreed upon success criteria regarding the development of IS initiatives and there is very limited evidence of initiatives taken to evaluate the industrial symbiosis initiatives.

There is no system-wide evaluation of performance and it is felt that it is difficult to achieve one (Indigo<sup>2</sup> 2003). However there are several discussions in the literature that guide the development of indicators to evaluate the performance of industrial symbiosis initiatives. Ausubel (1991) advocates that there are indicators of environmental quality and economic performance (OECD 1991) though a very few of them represent effectively the networks of industrial processes and how they are changing (Duchin 1992). Recently some efforts have been made in this direction to evaluate IS initiatives. Some models are discussed here which have been proposed / used to evaluate industrial symbiosis initiatives. Though it should be made clear that there is very limited literature about the actual evaluation of any IS initiative. In most instances, literature identifies the factors that determine the success / effectiveness of industrial symbiosis initiatives though there is very limited information about measuring the actual environmental gains and economic benefits. There are methods available that have been proposed and / or used to evaluate the IS initiatives. Most of the methods employed in the evaluation of IS initiatives have been used to conduct comparative study of the success of IS projects; and not a comprehensive evaluation to clearly outline the environmental gain and economic and social benefits of an IS project. Models that have been used by some researchers are presented here with an aim to appraise / critique the existing models to gain a better understanding for developing a new and comprehensive evaluation methodology.

It is more than a decade since Ausubel (1992) suggested identifying major transitions that would take place in the application of industrial ecology and assess standing in relation to these transitions, in order to evaluate performance. He sought two main transitions: 'materialization to dematerialization' and 'decarbonization'. Dematerialization is defined by Ausubel (1992) as the decline over time in weight of materials or 'embedded energy', and he argued that dematerialization could translate into less waste from both production and consumption. Increasing reliance on carbon fuels to decarbonization might be another key transition, as carbon is the main element used to spin the industrial web (Ausubel 1992). It can be measured through a ratio of carbon used to total energy consumed or to economic activity. He emphasized that it is important to include moral and aesthetic criteria in the evaluation of system performance. Bauman in Korhonen and Strachan (2004) also argue that it is critical to measure not only the physical flows of matter and energy, but the effects that the organizational, administrative and management approaches have on these flows. Korhonen and Strachan (2004) also emphasized that it is important to bridge the physical material and energy flow analysis to analysis of economic effects.

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<sup>2</sup> <http://www.indigodev.com/Kal.html> (The Industrial Symbiosis at Kalundborg, Denmark)

Chertow (2003) argued that although every IS project is quite different from others, it is reasonable to develop a generic criteria for evaluating their success. Based on a definition<sup>3</sup> of eco-industrial park by the President's Council on Sustainable Development, Chertow (2003) revealed five objectives and developed accompanying baseline questions as a guideline for evaluating EID projects. These are outlined below (Table 2):

*Table 2. Objectives and accompanying questions to evaluate the success of an EID*

<p><i>Objective 1: efficient sharing of resources</i></p> <ul style="list-style-type: none"> <li>- <i>How does co-location play a role in the success of a project? If there are not synergies based on some measure of geographic proximity, the project is unsuccessful as an EID, even if it is economically successful.</i></li> <li>- <i>What symbiotic exchanges take place? Although every project need not have large quantities of physical waste being shared as in Kalundborg, exchanges are a good indicator of the level of co-operation being achieved.</i></li> </ul>
<p><i>Objective 2: economic gains</i></p> <ul style="list-style-type: none"> <li>- <i>Is the development commercially viable or does it requires outside subsidy? Often the public sector serves a catalytic role in EID, but after a defined time a project will not be sustainable if it is significantly dependent on such subsidies.</i></li> <li>- <i>Is the EID project structure more or less costly than conventional methods? Analysis concerning costs must be performed but should also include monetization of environmental benefits.</i></li> </ul>
<p><i>Objective 3: gains in environmental quality</i></p> <ul style="list-style-type: none"> <li>- <i>In what ways is environmental performance enhanced collectively as well as for individual firms and organizations? Addressing the question of performance involves operational effectiveness of the parts and the whole.</i></li> <li>- <i>What are the costs and the benefits to the ecological community? New development can be restorative or degrading to the broader ecosystem beyond the question of improved environmental performance for operating entities.</i></li> </ul>
<p><i>Objective 4: equitable enhancement of human resources for the business community</i></p> <ul style="list-style-type: none"> <li>- <i>What strategic advantage accrues to individual companies to justify their participation? It is unreasonable to expect companies to choose EID only because they may wish to be 'green'. A clearer understanding of possible strategic advantages such as risk reduction, employee engagement or reduced waste or energy costs should be evaluated.</i></li> </ul>
<p><i>Objective 5: equitable enhancement of human resources for the local community</i></p> <ul style="list-style-type: none"> <li>- <i>Is there a specific community involvement programme based on awareness of place? A successful EID is not a 'cookie-cutter' project imported from outside but must include a nuanced view of community factors.</i></li> </ul>

Source: Chertow (2003)

Chertow (2003) emphasized on the two main evaluation questions: Whether the EID has met its own goals determined during the planning process and what was achieved overall. This brings us back to the objectives and questions outlined in table 1. During an analysis of two eco-industrial parks in US, Chertow (2003) realized that the objectives and questions identified have been clearly the components of these projects. These objectives and the accompanying questions in table 2 are focused on specific categories of industrial symbiosis projects and are subject to changes for use in the evaluation of different types of industrial symbiosis.

<sup>3</sup> A community of businesses that co-operate 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 enhance of human resources for the business and local community (PCSD 1996).

Some of the approaches as suggested by Chertow (2003) that would facilitate the evaluation of IS projects are outlined below:

- examination of the type of design standards adopted would provide a benchmark for measurement
- means of recognizing and valuing communal benefits should be developed
- means of measuring the benefits achieved by individual companies and concerns choosing to participate in industrial symbiosis
- How long the benefits of IS will be retained or would they fall victim to various market pressures

Chertow (2003) has provided some guidelines on how to evaluate IS projects. Whereas Kurup et al. (2005) has taken a step forward by proposing a method that can assist in identifying the full spectrum of potential benefits of industrial symbiosis projects; the economic, social and environmental costs and benefits to industry and the community. They contend that this method can be used as an aid for project evaluation by decision makers to gauge the industrial symbiosis project's effect on regional sustainability. This method has been developed to aid the decision makers that face a number of barriers in the development of industrial symbiosis and one of the barriers identified by Kurup et al. (2005) is the limited evaluation of the complete costs and benefits of industrial symbiosis projects.

Kurup et al. (2005) have developed a set of indicators based on the triple bottom line accounting, allowing for improved identification and reporting of the economic, social and environmental benefits of industrial symbiosis projects. Before we go further to discuss these indicators in detail, it would be useful to highlight the criteria developed by Richards and Galdwin (1999 cited in Kurup et al. 2005) that need to be satisfied by the indicators selected:

- *Relevance:* Ensuring that the entrepreneurs consider the indicators selected important to their future i.e. they would consider the indicators in their decision-making.
- *Practicability:* Ensuring that the measurement and monitoring of the indicators is practical, reliable and within the resources available to the business.
- *Appropriateness:* Ensuring that the indicators reflect actual environmental impacts, and coincide with the company's long-term aims.

Kurup et al. (2005) has emphasized that the economic, social and environmental implications are needed to be considered for each stage of the synergy project life cycle (i.e. planning, design, construction, operation, maintenance and decommissioning). Because of the diversity of indicators available, there is a need to select a practical number of indicators that reflect the major impacts of the projects, however they argued that this might result in a temptation to select those which brings the project in good light and could be misleading. Kurup et al. (2005) also emphasized that it would be difficult to measure many indicators in financial terms however they encourage the quantification and ranking of impacts where possible. The indicators developed by Kurup et al. (2005) are listed below:

### ***Economic Indicators:***

- *generate local business opportunities*
- *generate capital works*
- *sales*
- *profit*
- *wages paid*
- *taxation revenue*
- *tangible environmental costs*
- *transport costs*

Before moving on to another set of indicators, Kurup et al. (2005) found it essential to indicate that the direct costs are often a poor indication of total waste disposal costs. When calculated, it should include loss of raw material within the waste and their replacement, labour to collect and transfer the material for collection, cost of management systems, licencing and administration cost and cost of equipment to handle or treat waste etc.

### ***Environmental Indicators:***

- *land use*
- *biodiversity*
- *energy consumption*
- *water consumption*
- *air, land and water emissions*
- *material consumption*

Kurup et al. (2005) argue that these environmental indicators should comprehensively reflect on short and long term environmental impacts of the project throughout the project life cycle stages. They also suggest that environmental indicators can be very difficult to quantify and it would be useful to list the potential impacts and assign the direction of the impact with an estimate of the size ranging from minor to major.

### ***Social Indicators:***

These indicators are described by Kurup et al. (2005) as the least developed of the three pillars of sustainability indicators. They have listed below the publicized indicators for social impacts of industrial symbiosis projects:

- *job creation*
- *job security*
- *skill level*
- *health and well being*
- *community stability*
- *education standards*
- *level of community services*
- *crime rates*
- *sensory stimuli ( such as, aesthetic or visual, noise, dust and odour)*

Like environmental impacts, it is difficult to quantify social impacts as well. Kurup et al. (2005) argue that they should be listed with an indication if the impact is negative or positive and some indication of the magnitude from minor to major to assist decision makers.

An example of the Kwinana Water Reclamation Plant (KWRP) is presented here that lists the economic, social and environmental impacts of the project during its life cycle using the indicators and criteria discussed above (see table 3). Kurup et al. (2005) have attempted to develop a triple bottom line accounting method for evaluating industrial symbiosis and also presented example indicators of which environmental and social are not that well established if compared to the economic ones. However, it should be noted that these indicators are presented here as examples and the appropriate ones should be chosen, satisfying the criteria developed by Richards and Galdwin, based on the type of industrial symbiosis initiative that has to be evaluated.

Table 3: Life cycle economic, social and environmental implication of KWRP

Life Cycle Stage	Environmental	Score	Social	Score	Economic	Score
Planning and Design (1998-2002)	Material & energy use and impacts from pilot tests.	-	New skills developed for planning and designing of the water reclamation plant.	+	Wages for planning & designing team.	+
			Community commitment in planning.	+	Generate business for local suppliers.	+
					Capital investment.	-
Construction (2003-2004)	Land for plant and infrastructure.	-	Job creation as construction and manufacture of supplies.	++	Wages for construction workers.	++
	Material & energy use for plant and pipe infrastructure.	--	Skill enhancement as the result of a new technology.	+	Generate business for local suppliers.	++
					Tax generated from wages paid.	+
Operation (Nov 2004 +)	Scheme water conservation.	+++	Improved recreational value of coastal zone and reduced health risks to community.	++	Water security for industry users.	++
	Water quality and eco-system improvement in coastal zone.	+++	Job creation and security. *	++	Better opportunities for tourism and aquaculture in coastal zone.	++
	Energy use and GHG emission.	-			Tax generation.	+
	Chemical use.	--			High grade water for industry.	+
					Increased water cost for industry.	+
Refurbishment Every 5 years[28]	Waste from refurbishment.	-	Maintain water security.	+++	Wages.	+
	Material and energy use for refurbishment.	-	Job creation (temporarily).	+	Generate business for local suppliers.	+
					Capital investment.	-
Decommission (2029)	Land reclamation.	+	Temporary job creation.	+	Wages from temporary employment.	-
	Recycling of material.	+	Permanent job loss.	--		
	Waste from decommissioning.	-	Loss of water security.	---	Loss of business for local suppliers.	+
				Value from recycled material.	-	

--- major negative, -- negative, - minor negative, 0 neutral (may involve a shift in impact ie. a shift of jobs from mining to recycling), + minor positive, ++ positive, +++ major positive

GHG: green house gas

+Efficient technology compared to 20 years ago which is 30% cheaper now and could be considered an economic benefit [28]

\* Job creation and security will principally be because of industries using the KWRP water, together with increased tourism and aquaculture in waters of coastal zone and not the plant itself which will be fully automated.

Source: Kurup et al. (2005)

During a review of EIP studies such as Kalundborg (Denmark), Brownsville (Texas), Londonderry (New Hampshire) and Matamoros (Mexico), Hollander and Lowitt (2000) identified substantial economic and environmental gains with eco-industrial park development. Based on the review, the following characteristics are considered to be crucial to the success of EIPs: (i) material, water and energy flows; (ii) companies within close proximity; (iii) strong informal ties between plant managers; (iv) minor retrofitting of existing infrastructure; and (v) one or more anchor tenants<sup>4</sup>

Whereas Harris and Pritchard (2004) argue that placing too much emphasis on input-output matches can isolate some companies from the network, they stress that a project needs to appeal to a wider audience and not just to companies with a large volume of wastes. Harris and Pritchard (2004) give more importance to a closer integration between the facilitators, Regional Development Agency and an Environment Agency in the case of a country like the UK. They emphasize that the success of IS networks will depend on this closer integration as it would help combine tasks and goals and free up further funding and provide on-going training to company employees. A model is developed by Harris and Pritchard (2004) that aims to help in understanding how actors can become aware of IS possibilities, associate it with their objectives and/or operations, assimilate it and then proceed with the application. This model can help understand the many relationships, markets, processes and interactions that occur in a regional industrial ecosystem (Harris and Pritchard 2004).

Based on the Danish experience, Christensen (2000) suggests a number of preconditions for the success of industrial symbiosis: (i) the industries must be different (not competitors), but complement each other in their materials production and use; (ii) bilateral agreements must be voluntary and make economic and commercial sense; (iii) there must be a close proximity between the industrial partners to enable effective transportation of materials; (iv) management at the different industries must build a personal rapport; (v) the community must be small enough that they all feel that they have a stake in the outcomes.

Eilering and Vermeulen (2004) developed a framework of analysis and applied that framework to a comparative study of eight industrial symbiosis initiatives in Netherlands. These eight cases were eco-industrial parks with a combination of green-field and brown-field sites. These are listed below:

- Ecofactorij Eco-Industrial Park in Apeldoorn
- Agro Industrial Complex in Dinteloord
- Business Park South Groningen in Ter Apelkanaal
- The Kleefse Waard Eco-Industrial Park in Arnhem
- The Trompet Eco-Industrial Park in Heemskerk
- Emmtec Industry and Business Park in Emmen
- Wavin Eco-Industrial Park in Hardenberg
- VAM MERA Eco-Industrial Park in Wijster.

The developed framework combines the material and energy flow approaches and tools to business, management and organizational studies (Korhonen and Strachan 2004). Eilering and Vermeulen (2004) determine the degree of success in achieving symbiosis and / or utility sharing in eco-industrial parks, through literature study and case study research. The framework is focused on the process 'from ambition to performance' (see Figure 1). This framework focuses on (i) goals that developers are seeking to achieve (e.g. the vision of sustainability), (ii) location and business specific features, (iii) social features, (iv) the organization of decision-making process, (v) policy instruments employed, and (vi) performance. Eilering and Vermeulen (2004) have made an attempt to answer the question whether the difference between the level of ambition and the level of

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<sup>4</sup> Anchor tenant denotes a prestigious company with a potential for other companies to be suppliers or customers.

performance can be explained through the above factors. They have further elaborated these factors to explain how they influence the process from the ambition of such an initiative to performance:

*'Ambition' relates to the initial ideas about the type of industrial park to be developed and the goals that the developers are seeking to achieve. How the concept of 'sustainability' is put into practice serves as a frame of reference to show the significance of perceived options. Not all measures designed to increase sustainability are feasible in all industrial parks. The location-specific features of the industrial park and the business-specific features of the companies in the industrial park affect the types of measures that can be chosen and therefore have an impact on the performance of industrial parks. Policy instruments may be employed to ensure the proposed measures are carried out. The organisation of the decision-making process influences the entire process of translation from ambition to performance via the proposed measures. (Eilering and Vermeulen 2004)*

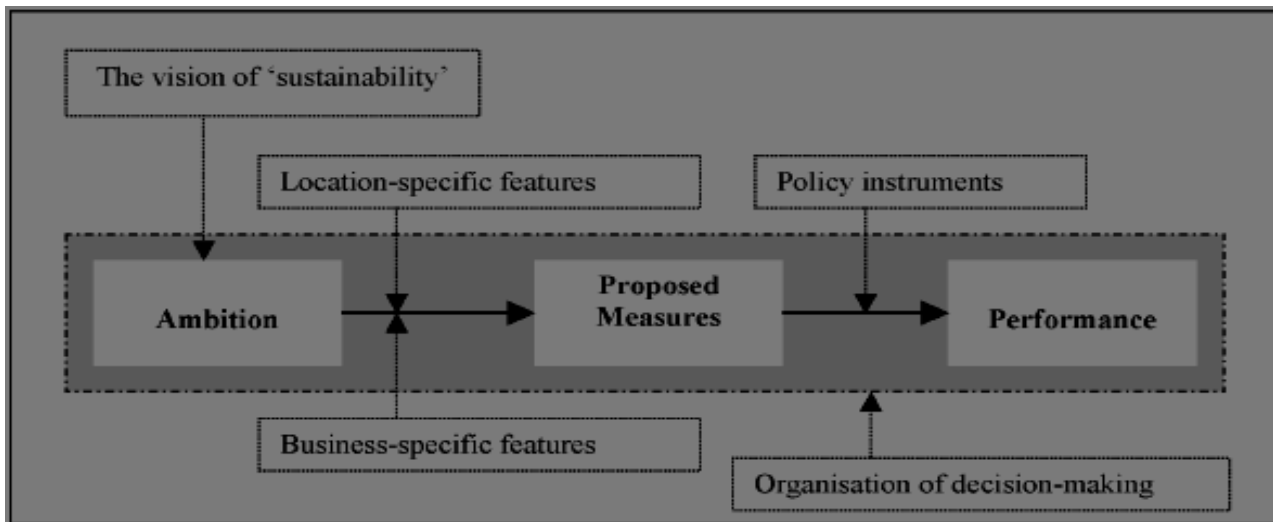


Figure 1. Framework for evaluation of IS initiatives  
Source: Eilering and Vermeulen (2004)

Each if these aspects are further discussed here in conjunction with the findings from the case study research, clarifying to what extent these factors actually influence the proposed measures to be carried out to achieve a certain level of performance:

### ***The vision of sustainability***

The first factor in the framework is the goal that developers are seeking to achieve. If for example this goal is sustainability then to what extent the options of symbiosis and utility sharing are taken into consideration. Here Eilering and Vermeulen (2004) have used the following criteria to measure the level of ambition:

- 'low': the measures are targeted at individual companies
- 'Average': the measures relate to achieving utility sharing
- 'High': the measures relate to both realizing symbiosis and achieving utility sharing

The study revealed that the utility sharing and/or symbiosis can be achieved even without adopting a particular vision such as sustainability.

### ***Location and Business Specific Features***

Location specific features are about the type of industrial symbiosis initiative e.g. geographic coverage, physical distance between member companies etc. The extent to which companies are

involved in the network are of sufficiently diverse nature is also important in order to satisfy each others complementary needs to achieve symbiosis. Though on the other hand Eilering and Vermeulen (2004) argue, that diversity is not important for utility sharing as companies have similar supply and demand patterns for energy, water and (residual) substances. The research showed that there will be no utility sharing and symbiosis without having complementarity in the needs of the companies in the network

Business specific features are about the characteristics of the businesses seeking to achieve symbiosis and utility sharing e.g. companies should have stable (residual) substance and energy flows (Eilering and Vermeulen 2004). They particularly emphasized the importance of social features which were witnessed by the research findings. Findings revealed that the following social features appear to be essential for achieving symbiosis and utility sharing:

- mutual trust between the partner companies
- the presence of an anchor company
- the presence of a pioneer
- a short mental distance between the partner companies

Case studies showed that symbiosis can not be achieved if any physical or social features are missing. In most cases both of these features were identified among companies which shared a common past.

### ***The organization of decision making process***

The nature of decision making process is important for an industrial symbiosis network. Top-down process has been identified as a failure factor in the organization of decision making process as businesses are not consulted and the decisions are made by the government. Bottom-up and joint process are found to be the most effective where government and businesses involve in the process to make decisions, reducing problems and disagreements at a later stage (Eilering and Vermeulen 2004).

### ***Policy Instruments***

There was hardly any evidence regarding the relationship of a policy instrument and success of industrial symbiosis approach. Eilering and Vermeulen (2004) have therefore concluded that the use of policy instruments is a less decisive factor than the existence of location – business-specific features or the organization of the decision making process. In spite of the advanced technical and physical infrastructure for utility sharing and symbiosis, the system could fail if the participating members lack a common culture, sense of community and trust in cooperation. The factors discussed above strongly influence the proposed measures that need to be carried out which ultimately influences the performance of IS projects.

In a different approach by Heeres *et al.* (2004), a study was conducted to compare the success of six industrial symbiosis projects, three of which were located in the Netherlands and three in the US. Five out of six projects were eco-industrial parks out of which four were brown-field developments and one was a green-field development; and only one of them was a virtual eco-industrial network (VEIN) i.e. the member businesses were not located on a particular site. These projects are listed below:

- INdustrial EcoSystem Project (INES), Netherlands (EIP)
- Rietvelden/Vutter (RiVu) sustainable revitalization project, Netherlands (EIP)

- Moerdijk EIP project, Netherlands (EIP)
- Fairfield (Baltimore), US (EIP)
- Brownsville Regional Industrial Symbiosis Project, US (VEIN)
- Cape Charles Sustainable Technologies Industrial Park (STIP), US (EIP)

Established through the literature review, six aspects were identified to determine success criteria for an industrial symbiosis: (i) history and location of EIP; (ii) stakeholder involvement and project company structure; (iii) planned EIP development (development vision); (iv) economic and environmental impact of the project; (v) Results (established EIP development up till now, what has been realized?); (vi) factors essential to project success and/or failure.

In order to identify the comparative success of the chosen industrial symbiosis projects, each project was scored from 1 to 6 on all six aspects as identified above. Low scoring on a particular aspect did not mean that the project has failed on that aspect but is less successful if compared to other highly scored projects. Though it was clarified that the quantified order can not be definite since every project was in a different stage of development and they have their own strong and weak points. Heeres et al. (2004) stated that the sequence below (see table 4) is based on the perceived development potential and current project development of the projects studied.

*Table 4*

The six EIP case studies quantified based on developed criteria							
Project	Participation	Organization	Vision	Economy environment	Result	Success or failure	Total score
INES	6	6	5	6	4	5.5	32.5
Cape Charles	5	3	2	5	5	3.5	23.5
Moerdijk	3	4	6	1.5	–	5.5	20
RiVu	4	5	3.5	1.5	–	3.5	17.5
Brownsville	2	2	1	4	6	2	17
Fairfield	1	1	3.5	3	–	1	9.5

–, quantification not possible due to the fact that the project plans have not reached the realization phase.

*Source: Heeres et al. (2004)*

Table 5 below provides an example regarding the quantification for one of the aspects on which the projects were compared and this provides the basis for scoring the success of this aspect. Estimates of project realization costs and economic and environmental benefits are incorporated in this table, which provides the basis for scoring the success of this aspect for all projects.

*Table 5*

Estimates of project realization costs and economic and environmental benefits			
Project	Realization costs	Economic benefit	Environmental benefit
INES	>US\$ 100 million	>US\$ 16 million/year	157.6 MW <sub>th</sub> energy 152.2 M Nm <sup>3</sup> gas/year 272.5 ktons CO <sub>2</sub> 225.7 tons NO <sub>x</sub> , 158 MW waste heat, and additional reduced resource use
RiVu	US\$ 100,000 (planning)	Unknown	Unknown
Moerdijk	Unknown	Unknown	Unknown
Fairfield	±US\$ 62 Million (original project plans)	A minimum of 2500 jobs in the next 10 years	Unknown
Brownsville	US\$ 250,000 (computer program development)	Unknown	Unknown
Cape Charles	±US\$ 7.5 million	395 direct jobs	Unknown

*Source: Heeres et al. (2004)*

Heeres et al. also made a comparison between literature/theory and the Dutch and US projects. They compared the process and physical factors which were considered important in the industrial symbiosis development (see Table 6).

Table 6

The importance of various process and physical factors found in the literature and the Dutch and US case studies compared			
	Theory	NL	US
<i>Process factor</i>			
EIP as an environmental project	+++	+++	+
EIP as an economic project	+++	+++	+++
Involvement of local/regional government	++	++	+++
Involvement of national government	++	+	+++
Involvement of local entrepreneurs' association	-	+++	-
Involvement of local industry	+++	+++	+
Community involvement (residential)	+++	-	+++
Anchor tenant	+++	+	++
Local champion	+++	+	+
<i>Physical factor</i>			
Exchange infrastructure for wastes and by-products	+++	++	++
Energy cascading and cogeneration	+++	+++	+
Water infrastructure	+++	++	+
Telecommunications infrastructure (site-wide)	+++	+	++
Utility sharing	+++	+++	++

Source: Heeres et al. (2004)

They also identified different stakeholder groups that were involved in the development of these projects to provide clear insight of the differences in the Dutch and US approaches (see table 7).

Table 7

The stakeholders and their role in the EIP development process						
Stakeholders	INES	RiVu	Moerdijk	Fairfield	Brownsville regional IS	Cape Charles STIP
<b>Government</b>						
Local	F	I,P,F	M,A	I,M,P,F	I,M,P,F	I,M,P,F
Regional	F	I,P,F	I,P,F	F	F	I,P,F
National	F,C	C	C	F,C	F,C	F,C
Chamber of commerce	-	I,P	-	-	-	-
Companies	A,F	A,F	A,F	[F]	[F]	[F]
Entrepreneurs' association	I,M,P	I,M,P	I,P	-	-	-
Educational institutions	C	-	-	C	A,C	A,C
Consultant agencies	C	C	-	-	A,C	-
<b>NGOs</b>						
Labour	-	-	-	C	-	A,C
Environmental	-	-	-	-	-	A,C
Local residents	-	-	-	A,C	-	A,C

I, project initiator/commissioner; M, project manager; P, member of the planning group; A, active participant in project development (not financial); F, provides/provided funds to the project; C, consultant to the project; -, is not a stakeholder in the project concerned; [ ], the stakeholder was supposed to take up the role but has not done so yet.

Source: Heeres et al. (2004)

Overall findings of the research indicated that Dutch projects were comparatively more successful than US projects. The main differences that were identified between the US and Dutch projects were the following:

- economic factor was valued more than the environmental factor in US projects in general whereas Dutch projects were strictly aimed to improve both business and environmental performance.
- government initiated these projects in US as US businesses seem to have more distrust towards the motives and actions of the government whereas Dutch projects were initiated by the business communities and closely coordinated their actions with the government.

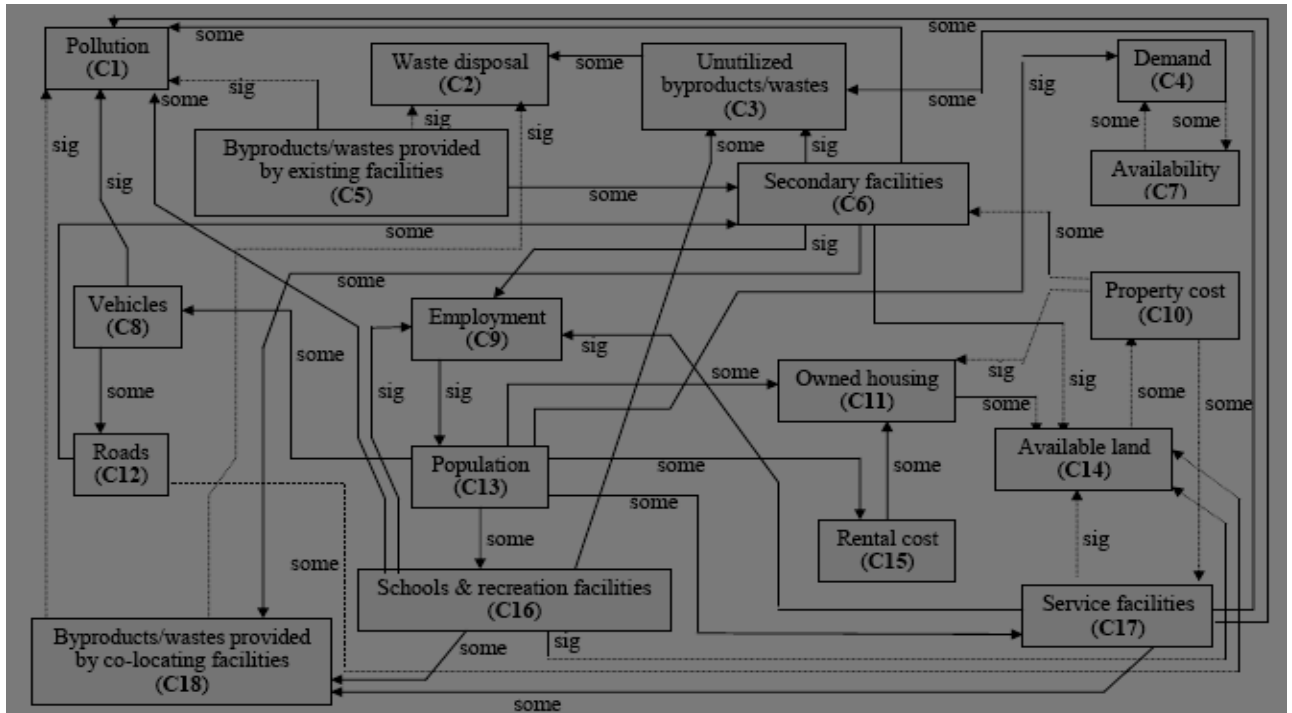
- community involvement was encouraged in US projects but in Dutch projects the development process was limited to the companies and direct stakeholders such as consulting agencies and / or educational institutions.
- in case of US projects, government and other interested parties were responsible for the planning costs but in the Dutch cases businesses contributed to 50% of the costs.
- in US cases the absence of a local champion and / or anchor tenant was felt however in the Dutch cases this role was fulfilled by the local entrepreneurs' / employers' association.
- in US projects the main focus from the beginning of the development was on the material and energy exchange, however Dutch projects were focused from the beginning on the establishment of pollution prevention with a utility sharing character, which were gradually developed further to achieve symbiosis.

As the environmental benefits are not known clearly and due to reluctance of companies to provide data, it was difficult to discover detailed information on the actual environmental gains (Heeres et al. 2004). They suggested that such information exchange can only be encouraged, in case with projects where government subsidies are provided, by requiring the companies to provide quantitative data about the environmental gains and economic benefits achieved.

A model suggested by Fons et al. (2004) is to ascertain whether EIP is going to provide a net positive benefit to the companies contained therein and to the local community which is building and maintaining the EIP. A fuzzy cognitive map<sup>5</sup> (FCM) approach is suggested for the impact assessment. The advantage of this approach is that it not only covers direct impacts but also takes into account indirect effects or interaction between impacts. An example has been included in their article to demonstrate the impact assessment of an eco-industrial park in Canada, using FCM approach. Fuzzy cognitive map of the impacts of Lloydminster eco-industrial park is presented in Figure 2.

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<sup>5</sup> Cognitive map is a type of network that offers a means to model interrelationships or causalities among elements within the model. Fuzzy cognitive map is a newer form of cognitive map that quantifies the interrelationships among elements of a network in a non-binary way, such as when linguistic hedges and quantifiers are used to characterize the causalities that are based primarily on linguistic information. (Fons et al 2004)



C- cause and effect variables, sig- significant, some-somewhat, solid arrow: +ve causal relationship, dashed arrow: -ve causal relationship

Figure 2. Fuzzy cognitive map of the impacts of an eco-industrial park

Source: Fons et al. (2004)

Using this FCM above, an adjacency matrix has been created which clearly demonstrates all direct & indirect and negative & positive impacts (see table 8).

Table 8: Adjacency matrix for eco-industrial park

Concepts	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	
C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C3	0	some (+)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C4	0	0	0	0	0	0	some (-)	0	0	0	0	0	0	0	0	0	0	0	
C5	sig (-)	sig (-)	0	0	0	some (+)	0	0	0	0	0	0	0	0	0	0	0	0	
C6	some (+)	0	sig (+)	0	0	0	0	0	sig (+)	0	0	0	0	sig (-)	0	0	0	some (+)	
C7	0	0	0	some (-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C8	sig (+)	0	0	0	0	0	0	0	0	0	0	some (+)	0	0	0	0	0	0	
C9	0	0	0	0	0	0	0	0	0	0	0	0	sig (+)	0	0	0	0	0	
C10	0	0	0	0	0	some (-)	0	0	0	0	sig (-)	0	0	0	0	0	some (-)	0	
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	some (-)	0	0	0	0	
C12	0	0	0	0	0	some (+)	0	0	0	0	0	0	0	some (-)	0	0	0	0	
C13	0	0	0	sig (+)	0	0	0	some (+)	0	0	some (+)	0	0	0	some (+)	some (+)	some (+)	0	
C14	0	0	0	0	0	0	0	0	0	some (-)	0	0	0	0	0	0	0	0	
C15	0	0	0	0	0	0	0	0	0	0	some (+)	0	0	0	0	0	0	0	
C16	some (+)	0	some (+)	0	0	0	0	0	sig (+)	0	0	0	0	sig (-)	0	0	0	some (+)	
C17	some (+)	0	some (+)	0	0	0	0	0	sig (+)	0	0	0	0	sig (-)	0	0	0	some (+)	
C18	sig (-)	sig (-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
some = somewhat																			
sig = significantly																			

Some -: negative somewhat, some +: positive somewhat, sig -: negative significantly, sig+: positive significantly

Source: Fons et al. (2004)

Fuzzy cognitive map above and the adjacency matrix can allow calculating the direct and indirect impact of any particular variable (please see Fons et al. 2004 for further details). However it should be clarified that the end result of using this approach is fuzzy though Fons et al. (2004) argue that it is more accurate than other conventional approaches.

## **Conclusion**

It is clear from the literature review that there is very limited literature available that can guide the evaluation of industrial symbiosis initiatives. This is due to the fact that the IS networks are in the early stages of development and therefore the methods / models to evaluate performance are not well developed. Literature in this area has been developed in last few years, most of which focus on particular industrial symbiosis initiative i.e. eco-industrial park. There is a need for the development of a generic methodology in order to evaluate industrial symbiosis projects. Researchers Kurup et al. (2005), Heeres et al. (2004), Harris and Pritchard (2004) Eilering and Vermeulen (2004), Fons et al. (2004) and others have similar as well as contradictory views about the measures to be implemented for evaluating IS projects. However, a model is required that outlines a predefined criteria for evaluating an IS project. The evaluation approaches proposed and used so far have provided a basis to make further attempts in order to develop a generic methodology to evaluate industrial symbiosis projects. Recommendations with regard to what is the best model are difficult to make at present. In order to make any recommendations for developing a comprehensive methodology, thorough analysis of the field work data will be required. The fieldwork for PhD project of one of the authors\* is planned to be carried out in the coming months. Altham and Van Berkel (2004) have also been involved in a similar research as they identified the need to develop and pilot test the evaluation tools that quantify the environmental, social and economic benefits of industrial symbiosis networks. A research project is being carried out by the Centre of Excellence in Cleaner Production at Curtin University of Technology to develop evaluation tools for industrial symbiosis. The true benefits of industrial symbiosis remain unidentified due to the lack of research on evaluation tools and effectiveness of IE practices, resulting in the industry and community underestimating IS opportunities.

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