Literature study on Industrial Ecology

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1. Industrial ecology

1.1 Introduction (2,15)

In the XIX century, the industrial revolution started. Environmental impacts are essentially linked to the circulation of material and energy flows which feed the running of our industrial society. These impacts are essentially pollution and waste. The effects of this large number of environmental impacts linked to human activities are locally perceived. However, local impacts are accompanied by global impacts. Some of the main problems that humanity will have to face in this century are: global warming, the greenhouse effect, the hole in the ozone layer and biodiversity erosion.

Facing this disturbing observation, a lot of research projects are now devoted to the global environmental preservation focused on industrial development based on the concept of "sustainable development" (Brundtland et al., 1987). To this end, we need to identify new uses and innovative techniques for using waste materials. This is the domain of industrial ecology.

Industrial ecology is based on the study of flows and stocks of material, of energy and information within a clearly confined system. This concept suggests considering industrial society as a system, a "special ecosystem of the biosphere" composed of elements and their interactions. In harmony with the idea of a more sustainable development, this concept puts forward working on a new organization of different persons of the growth economy. In this approach, it's not possible to distinguish between resources and waste, inasmuch as the waste from a component is the resource from another one.

1.2 History (1,2)

Sporadically evoked since the 1950s by certain ecologists (Erkman, 1997), this global approach of the industrial society and its place in the biosphere properly took shape with the birth of the sustainable development concept in the beginning of the 1990s. Nevertheless, earlier attempts towards sustainability in countries like Belgium and Japan in the 70s and 80s are also known.

In November 1989, a founding article "Strategies for Manufacturing" (Frosch, 1989) was published by two Research and Development executives of General Motors (R.Frosch and N.Gallopoulos) in the Scientific American journal. In 1991, a conference organized by the National Academy of Science was focused on it. Then in 1996, the "Presidential Council for Sustainable Development" suggested to Bill Clinton the creation of eco-industrial parks (PCSD, 1996).

Towards the end of the 1990s, this new scientific field was equipped with communication tools and became structured. The "Journal of Industrial Ecology" (MIT Press) was created in 1997 and the International Society for Industrial Ecology came to light in 2000. A second international journal was born in 2004: "Progress in Industrial Ecology".

Little by little, industrial ecology also sees itself integrated into several American university degree courses and European ones.

1.3 Present tools (1,2)

End-of-pipe solutions are usually adopted by companies as a means to de-polluting the flows susceptible of having an impact in the biosphere. Without a doubt essential, such measures are

however insufficient faced with the size of the problem. Besides this, the most common tool used by the administration to try to manage impacts caused by industry is through environmental regulations. Furthermore, another approach naturally fell into place for the regulation of environmental impacts: impact prevention. Before the impact even exists, the intention is to reduce, even eradicate it completely.

The only future solution is to look for and implement new leverage with the aim of limiting ever-increasing impacts. Nowadays, ambitious steps are developing towards this idea. The first family of tools is focused on a new conception of products and services so that not only impacts related to production, but also those related to phases before and after production can be taken into account. The second family of tools proposes considering different production entities within a given perimeter to work on the organization of this system. Afterwards, it is necessary to reduce the impact of this system for each entity via, not "individual" solutions, but "collective" ones.

1.4 Necessary approaches

1.4.1 Growth dematerialization tools (2)

To minimize the impacts on the environment according to a company's priorities several types of choices can be made such as the reduction in fossil fuels usage, the use of recycled materials, and improvement to processes or end-of-life recyclability. This type of approach has been baptized "eco-conception" or "eco-design".

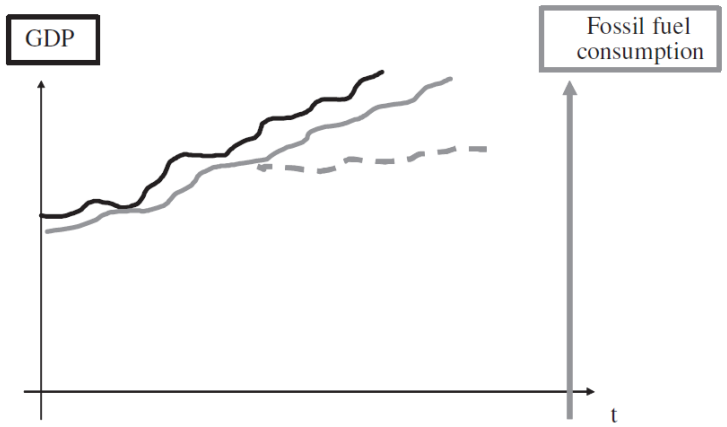


Figure 1. The correlation of growth and fossil fuel consumption

It is known that one of the sources of environmental problems caused by the running of modern industrial society originates from the narrow correlation between growth and the use of fossil fuels. The use of these resources is in fact one of the main culprits of emissions. One of the leverages available to man to evolve towards a more sustainable functioning is that of economy dematerialization. The simple idea is to find solutions in order to consider economic growth curves separately to those of fossil fuel usage. Dematerialization therefore becomes the "decarbonisation" of the economy. A type of leverage available to reach this objective is going towards a service economy. The idea would consist on selling a service instead of a product (Stahel, 2000). This approach, centred on the functions of the object can radically change industries' production logic. This conception can also spare the client from the inconveniences caused by a used product and guarantee correct product treatment until the end of its life.

1.4.2 Material and energy flow loops (1,2)

The model of material and energy flow loops, where any waste created is immediately re-used by another organism, relies upon two pillars. The first consist of reducing individual consumption of each entity, for example the creation of processes requiring fewer materials and less energy. The second pillar consists of an alternative organization where residual flows are looped. The originality of this proposed industrial ecology approach is to try and systematize the material and energy loops within a given perimeter.

The term “eco-industrial synergy” designates the material and energy flow exchanges between two or more industries for which their waste flows, by-products or unrecovered energy substitute regularly used flows.

Material and energy flow loops reveal examples which illustrate the pertinence of the idea. The most well known and most documented example is the Kalundborg industrial symbiosis (Denmark). There, over the last thirty years, the main Kalundborg companies began to exchange waste spontaneously: steam, water and various by-products. In the late 80s, responsible for local development realized that they had progressively and spontaneously created a system called as industrial symbiosis.

Kalundborg symbiosis comprises five main partners, separated by some hundreds of meters from each other, and connected together by a pipelines network. The water (liquid or steam) is the main recovered waste and is used in the most systematic way. The main environmental advantages of Kalundborg industrial symbiosis are: reduced consumption of resources, reduced greenhouse gas emissions, and reuse of waste. The economic advantages are also substantial.

Another relevant example is in Austria, Styria, where the province put forward a relatively complex waste exchange system. This network that spontaneously formed over a period of several decades has enabled the recovery of thousands of tons of waste and energy.

1.4.3 Industrial ecology through Internet (11)

IE research can often be very data intensive due to the nature of the systems that we study. In trying to gather information about a particular system, we need proper data and knowledge management. When using data, we face several problems. To begin with, we may find that data about certain aspects are missing. Then, once this information is found, it is not always clear what the quality of the data is, and there is no easy way to know whether the data have already been superseded or if others have disagreements with certain aspects of them.

We need to be using tools that enable our ambitions. Beyond IE, progress has been made through various methods of Internet-enabled collaboration. Concerns have been raised that IE lacks a major online presence and exists primarily as an offline community (Hertwich, 2007).

While concerns were raised above about IE being an offline community, there has been a range of discussions about and working examples of tools that leverage IE through the Web: eiolca.net, Stocks and Flows (STAF) Project, GoodGuide.com, AMEE.com and so on. These examples are encouraging, and show that the IE community and others are exploring different options available through the Web.

One of the ways that researchers are facilitating collaboration on the Web is through wikis. In a wiki, there are easy ways to monitor changes, revert to previous versions if necessary, and hold a community discussion about topics.

A large opportunity also exists for creating applications that better leverage the combination of human and computer strengths. To enable this, Web pages and information should also be machine readable and processable where possible (Antoniou and Harmelen, 2008); in other words, software can decode it, make out meaning, perform queries, and essentially perform something useful with the data. Presently, advanced methods are deployed to combine "machine readability" and "human readability", notably through the development and application of novel (open) standards. One of the most important standards developed is Resource Description Framework (RDF).

The next step in the evolution of wikis has emerged in the form of semantic wikis. They differ from the classic ones because they allow for special annotations on the content of pages, which can be directly mapped to an RDF format.

A key advantage of semantic wikis is that they allow people without a background in information technology to take advantage of the trends to both users and contributors. Users may simply contribute plain text, semantically annotate sections of text, or enter information into premade forms. One of the limitations of traditional wikis is that it constrains users to viewing contents of a single page at a time. With semantic wikis, you do not manually create lists, but rather you query them. In other words, you create lists by grabbing structured information spread across many pages.

In moving forward, we need to be aware of opportunities that allow for better self-organization and sharing of knowledge. This process of self-organization in using the Web and these new technologies is a type of socio-technical evolution where we learn how to use the tools, and the tools shape the way that we work.

To initiative, drive, and shape this evolution, several requirements and guidelines have been identified (Nikolic, 2009), which are applicable for using the Web for fostering collaborative research, data, information, and knowledge storage and sharing. First, there must be what can be called "local optimization", or enabling optimization based on local needs. Second, we should accept that in generating knowledge, there is no termination criterion. Third, the evolution of knowledge requires that we not place barriers on the continued use of knowledge, as research will always lead to further questions. Fourth, we also must recognize path dependency: each line of scientific inquiry represents a chain building upon previous knowledge and technologies, which represents only a single pathway that is explored. A fifth requirement is that of "modularity". While path dependence is needed to build structure, we also need the ability to branch from it when necessary in order to explore new pathways and lines of inquiry. Sixth, we need to accept that there is no single correct way of looking at the system, since there are various static, dynamic, and ontological ways of describing and measuring it (Allenby, 2006). Finally, this entire process must involve a shared effort because it is too large for a single person to accomplish alone.

The most appropriate starting point in our view is with sharing data online. Suppliers of data should also be more effectively connected with the users of the data.

For creating community dialogue, registered users of a database should be able to comment on data sets and flag information that they believe needs attention, and moderators should be in place to help facilitate various activities. This is a significant advancement and enabler for peer review and improving the quality of data.

A further enabling factor is the use of machine-readable formats, such as RDF, where possible. Also, another factor is the use of open standards, open source and open data.

The collective development of ontologies may accelerate the process of building a truly interdisciplinary community, where data, information, and knowledge are discussed and represented not only in shared, standardized machine-readable formats, but also in shared human-readable formats that foster unambiguous interpretation.

2. Eco-industrial parks

2.1 Introduction (1,2)

Eco-industrial development overrides the simple material and energy flow loop. It is a real local economic development tools which integrates information and human resource flows into a global industrial ecosystem. Industrial ecology can be applied to eco-industry development at three levels. The boundaries can be defined at the micro-level (firms), the meso-level (eco-industrial parks “EIP”), and the macro-level (regional and wider global networks of manufacturing activity centres). Opportunities are most apparent for applying industrial ecology at the EIP manufacturing area level where the clustering of complementary industries/businesses provides the required complexity of functions.

The concept of eco-industrial park emerged in the early 90s, thanks to the aforementioned Kalundborg model. Such parks provide a catalyst for real estate developments to bring together principles and ideas of industrial ecology, cleaner production and value-adding to waste management. They encourage environmentally sustainable design, architecture, and construction; cooperation and innovation; novel technologies and knowledge sharing among businesses.

Although not always sufficient, the economic importance for the affected parties (the producer of the exchanged flow, whose user and the territories) is absolutely necessary for creating a substitution synergy.

The social component of sustainable development covers a range of questions from equity between countries and generations, to questions regarding the identity of humans whilst confronting questions about education, work, habitat… The contributions from eco-industrial parks have therefore had to be observed through this social prism. Furthermore, synergy social acceptance is a crucial point for the success of eco-industrial development. Taking affected parties into account by a synergy can make easier the acceptance by the population and the local councillors.

Notwithstanding positive effects of eco-industrial synergies have been observed, other effects concerning health impact of synergies and synergy acceptance should be monitored. The health impacts of synergies needs to be examined so that the reduction of “global risks” does not create new “local risks”.

2.2 Information

2.2.1 General ideas (2)

Synergy searching is divided into many phases. The first consists of identifying the potential synergies. One condition is absolutely necessary for this identification. Information on the nature of the potential synergy should exist and be shared by the concerned entities. The analysis of the sequence of events of different eco-industrial development projects (Duret, 2004; Lowe, 1998; Chertow, 2002) shows that the creation of this particular piece of information comes from information exchange between entities. There exists two ways for doing this information exchange: directly or indirectly.

Information exchange of the production and distribution sub-system flows which each entity use and discard is not spontaneous, whether bilateral or multilateral, inasmuch as conditions of trust need to be created. Direct exchange is therefore only conceivable for “ready” projects, organized and structured with an objective of lasting quality.

Information exchange can also be indirect: a third entity collects for example information, tries to identify the synergies and returns this information to the concerned entities. The objective is to create a contact between potentially synergic companies. This acquisition-restitution work implies a good industrial culture, an effective management of the data collection of material and energy flows in the companies as well as a developed sense of communication. In short, it’s an expert’s field.

This indirect approach remains the most efficient for starting a project. Nevertheless, such a system of indirect exchange has however one serious limitation: the dependency on one element: the expert. Hence, to maximize the chance of longevity, an eco-industrial development approach should depend on a direct information exchange between the concerned entities.

The companies interact with other types of participants of the territory such as local authorities and the devolved State services. Information exchange already exists within these entities. They are essentially of a regulatory or fiscal nature.

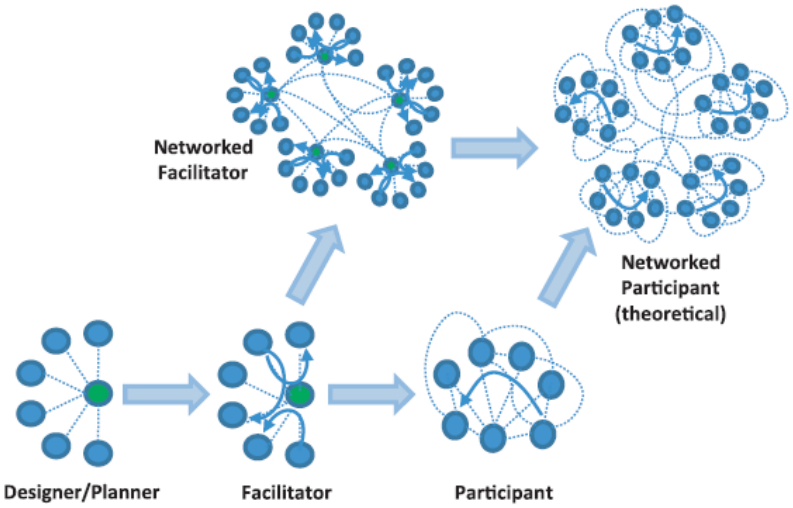
2.2.2 Technology for Industrial Symbiosis (3)

Modern information and communication technology (ICT) has significantly reduced transaction costs. However, in some cases application of ICT is less successful. The failure of ICT tools for IS is due to the necessity of tacit knowledge, and given that tacit knowledge sharing requires relationship or community, ICT systems built to supplant rather than support a community will fail to archive IS.

Understanding how knowledge is communicated requires a distinction between two types of knowledge: explicit knowledge or information and tacit knowledge or know-how. Explicit knowledge or information is easily communicated, codified, or centralized using tools such as statistics. However, tacit knowledge is complex and is not codified. It is revealed through application and context and is therefore costly to communicate between people (Kogut and Zander, 1992).

The ability of ICT to enable communication of explicit knowledge is commonly understood. Much recent research focuses on the ability of ICT to promote explicit and tacit knowledge sharing through the creation of community, social capital and trust.

Each ICT system functions to transfer knowledge within a larger IS development process. Through reviewing the tools within the context of their associated development processes, five primaries IS developmental phases emerged: (1) opportunity identification, (2) opportunity assessment, (3) barrier removal, (4) commercialization and adaptive management, and (5) documentation, review, and publication. The development process is far from linear and certainly contains many nested



Dimensions	Designer/ Planner	Facilitator	Networked Facilitator	Participant	Networked Participant
Role of Broker or Core Firm:	• Coordination	• Support collaboration, establish network ties	• Establish and support ties between regional networks	• Same as facilitator	
Structure:	• Central hub	• Developing toward participant driven network	• Multiple hubs developing regional participant networks	• Less emphasis on central hub, multiple nested ties	• Multiple regional networks connected beyond cultural and geographical proximity
ICT Platforms and Requirements:	• GIS, design, process flow, and optimization packages available off the shelf	• Project management, Collaborative software environments	• Emphasis on distributed multi-user systems, required investment in usability	• Online community, social networking components, required investment in sociability and usability	• Heavy investment in sociability and usability in a robust online community
Knowledge Transfer:	• Low-volume Explicit	• Explicit and low-volume tacit	• Low-volume Explicit	• Explicit and tacit	• High volume explicit and tacit
Motivation:	• Strong commitment to central authority or mission	• Demonstrate commitment to network goals	• Demonstrate commitment to network goals, improved access to relevant knowledge	• Learn faster than competitors, benefits of participation far outweigh isolation, reciprocity	

Figure 2. ICT interaction models and associated attributes

feedback loops. The surveyed ICT systems predominantly focused their resources toward opportunity identification. The emphasis on opportunity identification may have several explanations. First, opportunity identification appears as a logical starting place. Second, there are clear opportunities for ICT within this phase. Third, perhaps a naïve perspective led planners and facilitators to believe that, once identified, synergies would naturally take off or become implemented of their own accord. Furthermore, it is also necessary to point out that closing the loop between commercialization and opportunity identification is a critical step in transforming IS from an ad hoc process to an evolving community of practice.

Five distinct user interaction models emerged from the system studied. These models – planner/designer, facilitator, networked facilitator, participant, and networked participant - are based on the targeted users who interact with the ICT system.

The most critical challenge to the systems surveyed was their lack of sociability. Although the tools produce technical opportunities between firms, the earlier tools overwhelmingly catered toward a master designer, planner, or broker and away from the individual participants who are expected to form highly invested, symbiotic relationships.

The second immense challenge faced by the existing tools is usability. Many of the tools require sophisticated computer and programming skills in addition to a comprehensive knowledge of a multitude of industrials organizations.

No standardized classifications restrict searchability, create noise or meaningless results, and prohibit automated or suggestive matching that could significantly save time for the user. An industrial classification system that transcended continents would go a long way toward facilitating explicit information transfer to target synergies for diffusion throughout the world.

Lastly, creating a successful knowledge network requires establishing a critical mass as networks' value is in the user participation.

2.3 Analysis of the territory system (2)

There exist profound differences between eco-industrial development projects' operations. Organization, leadership or even leader's motivations are different. However, a constant also appeared: the territorial anchorage of these projects.

The territory can be seen as a group embedded in a zone in a real or symbolic way. It is a place where different kinds of interactions are superimposed. It also supposes feelings of belonging, and it is the object of collective and individual affection.

Efficient eco-industrial synergy searching implies a deep understanding of the system in question.

We distinguish two interacting sub-systems:

- The production and the consumption sub-system, whose objective is to increase their wealth. This sub-system represents a privileged investigation field in the search for substitution or mutualisation synergies for his use and discard of a large variety of flows of large sizes.
- The social sub-system composed of territorial and devolved authorities, whose principal objective is to increase the well-being of the consumer-citizen. The flows in this sub-system are relatively homogenous and their recycling is increasingly better.

2.4 Systems engineering for EIP formation (12)

As the premier organization of practicing systems engineers, the International Council on Systems Engineering (INCOSE) strives to define and disseminate awareness of the practice and value of systems engineering.

Members of the INCOSE Principles of SE Working Group concluded that: (1) systems engineers are responsible for the social consequences of the systems they help create; and (2) the primary products of systems engineering are knowledge and communications (Alessi and McCumber, 1998).

An essential principle of systems engineering is the use of "due process" to create systems (Haskins, 2006). Due process focuses on the ways in which decisions are made that affect the product life cycle. Another principle is that systems must be viewed in a holistic way –at the same time recognizing that every system is also made up of parts. This principle guides the systems engineer to balance the variety of needs – many times conflicting – and to optimize on the whole versus optimizing one part (Blanchard, 2006).

The EIP quickly qualifies as a topic of interest for systems engineering (Sage, 1999). Systems engineers can influence EIP formation in the following ways:

- EIPs require the coordination of diverse stakeholders – expert communications skills are a prerequisite for success.
- EIPs require the cooperation of experts from diverse disciplines – solutions will require people familiar with the technological industrial base, people able to analyse the social consequences of decisions, people knowledgeable in the ecological consequences of decisions, people who know how to conduct integrity-based negotiations and create fair contracts, and people who can bring the constraints from regulatory agencies and other sources into the mix.
- EIPs will require a unifying set of straightforward processes to stay on track and create communities with which all stakeholders are satisfied.
- EIPs are complex; true systems of systems in which every stakeholder is an independent actor who must collaborate with the others to realize the final objectives.
- EIPs take time to form – this means that common systems engineering practices such as configuration management, risk and opportunity management, and information management will make positive contributions to the process.

Next figure proposes an extended focus and contributions from systems engineers under the environmentally desired scenario. This involvement is justified by the need for constant revaluation of the processes to feed learning back into the organization, and the desire for constant innovation within the processes to capitalize on opportunities to reduce cost, or insert new technologies.

Accepting this challenge will mean that systems engineers will be faced with new lexicons associated with manufacturing, transportation, inventory, marketing, finance, and customer service, to name a few. Even architecture and design will be redefined as holistic product design focuses not only on functions performed during useful life, but also on the creation and disposal processes as a source of waste and the key to the solution for waste avoidance. Entirely new

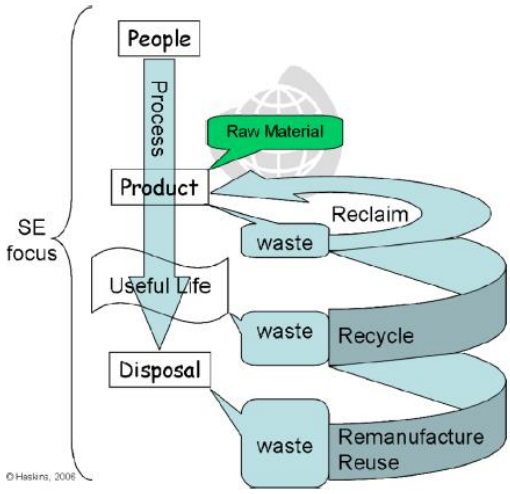


Figure 3. Industrial park model

systems to fulfil the reuse, remanufacture, and recycling demands will also be created, and subject to constant evaluation. Moving from a linear to a circular model will raise the questions of locked-in capacity and expansion within the closed-loop systems – new challenges for the systems engineer.

The next step is to consider how systems engineering should contribute to the formation of EIP. As the "glue" (Duren, 2005) that holds projects together, systems engineering could provide a unifying framework for EIP formation. The framework proposed to support the formation and sustainment of an EIP is called iFACE. The first letter is set in small typeface to indicate an initiation point after which the life cycle stages are both continuous and interchangeable. The acronym iFACE corresponds to the following description:

- i – Identify stakeholders and their needs.
- F – Frame the problem(s).
- A – Alternatives – identify and study the options.
- C – Choose and implement a course of action.
- E – Evaluate continuously.

The iFACE framework incorporates the systems engineering principles of systemic collection of information, constant communications to keep stakeholders informed, and ongoing process development to establish guidelines for how to define the problem, consider alternatives, make a decision that balances the requirements, monitor the resulting situation, and make adjustments as needed – within the situation at hand.

Fairbairn (2004) contends that intelligent activities within an enterprise are often guided by systems thinking and thus observe the rules of requisite meaning, requisite saliency, and requisite variety. Requisite meaning demands a systemic understanding of the requirements (the i in iFACE); requisite saliency establishes mechanisms for balancing the relative merits of issues when choosing between alternatives (the C and E in iFACE); and requisite variety requires that the system solution must possess at least as much variety as the problem situation (the F and A in iFACE).

2.5 Process analysis of eco-industrial park development (29)

A discontinuous three-stage IS model was extracted by Chertow and Ehrenfeld (2012) to describe the process of EIP evolution. Doménech and Davies (2011) explored the main mechanisms that forge trust and embeddedness during the three IS stages: emergence, probation, and development and expansion. After examining some case studies, Scientifics point out a knowledge gap: how to trace the determining factors unfolding over time and elicit their integrative effect at the EIP system level. Hence, this research aims to develop a generic approach which allows analysts (1) to structure the key activities that influence change of EIP systems, and (2) to track the process of the system development over time.

Process analysis aims to capture and explain the different types of forces and mechanisms that can influence the evolution of a firm or a network of firms (Poole et al., 2000). Here, we focus process analysis to better understand the drivers of change of an EIP, and how changes unfold over time. The study of EIP development requires us to tailor process analysis. We first need to develop a framework that consist of the key activities as variables that determine the development of EIP/IS, and specify the corresponding indicators for each variable. Second, the framework is applied to detect the events from the empirical data to build the database. Then the system analysis of EIPs'

development is delivered based on the main events description and event sequence analysis. We use the following criteria in our tailored process analysis for EIPs: (1) institutional activity, (2) technical facilitation, (3) economic and financial enablers, (4) informational activity and (5) company activity. As we are interested in the process of EIP development, we use a list of indicators to represent what drives the changes of an EIP, in order to identify these activities from empirical material. The framework can help detect the vents from raw data related to EIP/IS development. The events are stored in a historical database to create a time series. Consequently, the trends of the 5 key activities influencing an EIP's development are illustrated and analysed.

The approach requires case study to testify whether it is adequate. Hence, it is used to illustrate Tianjin Economic-technological Development Area (TEDA) development and to analyse its evolution process between 2000 and 2011. TEDA was established in 1984 as one of the first Chinese national level economic development zones, and its eco-transformation dates back to the year 2000. From this case study, we learned that understanding the eco-transformation of industrial parks requires dynamic systems thinking. When steering the eco-transformation, the strategies and decisions should be underpinned with a holistic understanding about what drives the transformation by what mechanisms, and how various drives and mechanisms interact. The development of TEDA across the years has shown that each of these five activities does matter, but not equally in every phase. It appears that one can draw valuable lessons from mapping the events using the approach we developed.

We conclude that the process analysis approach led to a structured and documented analysis that is open to adjustment, expansion and critique. Through developing a systemic analytical framework, a major step has been taken to deconstruct EIP development and to enrich our understanding about the underlying mechanisms and drivers of eco-transformation. Further work is required to flesh out how this framework is to be deployed or adjusted in the different institutional contexts.

2.6 Creating a collaborative dynamic (2)

Before being accepted and assimilated by the protagonists of the territory, an eco-industrial development first needs to "prove itself". It is thus necessary to show to these persons that synergies can be implemented within a territory and that they feature economic, social and environmental advantages. The idea is to work with companies who can serve as an example to others practicing the same type of activity, but also to look for a certain variety in the activities studied, in order to increase the number of synergy leads.

The objectives of phases 1, 2 and 3 in order to create a collaborative dynamic within a territory are:

- To have a precise vision of all the protagonists and the key participants.
- To identify the locally feasible synergies in order to attract interest and members to the approach.
- To establish the foundations to create a lasting approach that can develop.

The first phase enables the identification of the key industrial and institutional persons involved either by their function or by their potential interaction with the approach. To begin with, a very detailed analysis of the situation of these interactions is essential so that all blockages are prevented. A good understanding of the situation and the links between the stakeholders therefore enables the adoption of a communication strategy adapted to the needs of key stakeholders.

The second phase is a determining factor for the success of the study and for its future. Essential questions are to be settled in order to limit the span of cultural blockages. Questions regarding the manner in which the manufacturers will be approached and regarding the terminology to be used are important. The answers should be suited to the situation, to the sensibility of the interlocutors and can integrate some of their priorities. Post can be an efficient support; it can explain the meaning of the approach and insist on the benefits that the participants can gain. The question regarding the "confidentiality culture" should also be taken into account in this phase.

Phase 3 is a demonstration. The objective is to analyse the potential of the territory in terms of creation of eco-industrial synergies and to identify attainable synergies in order to make the approach credible, to entice interest and membership. Synergy searching requires a lot of detail on used and rejected flows by the studied entities. For drawing up the Input/Output flow summaries data should be real, coming from administrative documents or site visits. The formalization of data is related to the use of computer tools for the research of synergy leads. The most efficient tools use precise rules for describing each identified material or energy flow since the software used compares chains of characters. Finally, the next step is to identify among the obtained leads, those which, at the information level attained due to the survey, seem credible with regard to the different feasibility criteria.

If the results are conclusive, a continuation to this initial study can be envisaged. Once the dynamic has been created, the organization and the means necessary for its long-lasting and for its development can be implemented (phase 4). Several formulas exist to do so. From a more functional point of view, the creation of an association seems to be the most interesting formula: an "object" is clearly defined, the creation of the entity enables the founder members to be equal and generally all entities involved can join. The second important point of this phase concerns the organization and coordination. A full-time coordinator who can manage a few technical files concerning synergy leads is crucial. Organization and coordination plays a central role in maintaining a collaborative dynamic.

2.7 Access of enterprises (8)

It is a challenge for the developers and management teams of an EIP to select suitable enterprises into the existing industrial chains among candidates which all have both advantages and disadvantages. It is proposed an access indicator system for enterprises into an EIP to enhance its stability and systemic efficiency and an evaluation model using extendable optimal degree evaluation theory which provides a practice tool for EIP managers. To be more specific, the objectives are to establish an access indicator system for candidate enterprises, and to provide a quantitative method for evaluating the suitability of an enterprise integrating into an EIP to enhance its stability and systemic efficiency.

The indicator system comprises four broad indicators including economy, eco-environment, eco-network and society. We classify indicators along two dimensions. First, they can be classified into two categories based on their indicative function: positive indicator (P) and negative indicator (N). Second, they can also be classified as a quantitative indicator (L) and a qualitative indicator (X). All this provides straightforward evaluation items for the EIP developers and administrators.

The optimal degree evaluation method focuses on the interrelation between indicators and their goals. The general process of the optimal degree evaluation method is constructing an evaluation

indicator system, confirming the weighting coefficients, establishing conjunction function and calculating the optimal degree of the indicators.

Nevertheless, there are two challenges in using this method. The first challenge is the unavailability and unreliability of data, inasmuch as the data providers have the incentive to manipulate the data. The second challenge is to select enough qualified experts. Their professional knowledge and career experience have vital impacts on the scores and weights assigned to indicators.

2.8 Optimization methods applied to the design of EIP (15)

In the case of EIP, optimization helps to design better systems that can satisfy one or several objective functions while following constrains. One of the major issues is the lack of multi-objective optimization studies applied to the design of EIP. This field is a great challenge because the design of an EIP implies, by definition, the satisfaction of three essential pillars: environmental, economic and social. The problem of EIP design is typically a multi-objective problem.

Exchanges of water, energy and/or materials through a sharing network between companies of an EIP are the main way to design an optimal EIP. The research studies focus most of the time on the optimal design of an EIP network while taking into account separately water, energy and material.

Water-using network is the most common type of cooperation in the literature. In these studies, the rules and methods applied to optimization for single-plant integration (Takama et al., 1980; El-Halwagi, 1997; Olesen and Polley, 1996; Karuppiah and Grossmann, 2008; Boix et al. 2011) are used to deal with inter-plant integration (El-Halwagi et al., 2003; Lim and Park, 2010; Rubio-Castro et al., 2012), as long as the approach supports large-scale problems (Rubio-Castro et al., 2011). The case is often solved as a water-allocation problem where water needs to be distributed, treated and discharged in an optimal way between the process units of each company included in the park (Lovelady et al., 2009; Chew and Foo, 2009; Boix et al., 2012). There are several kinds of approaches to design an integrated inter-plant water network. Chew et al. (2011) defined two types of schemes: direct inter-plant integration and indirect inter-plant network. Water-using system in an EIP is generally optimized thorough two main approaches (Yoo et al., 2007): (1) Conceptual graphical design (pitch technology) and (2) Mathematical programming optimization.

Energy savings in an EIP can also be achieved by using pinch analysis or mathematical programming approaches. Nevertheless, there are relatively few studies that deal with energy management in an EIP thorough mathematical optimization. The main barrier to optimize an EIP by taking into account energy flows is the difficulty to acquire reliable process data from the plants included in the EIP. Furthermore, the difficulty to be complete, the model must include binary variables to represent the presence of a particular flow. This formulation is of MILP (mixed integer linear programming) type and is often difficult to solve with complex problem, which is the case of EIP's, this is for this reason that the majority of authors need to simplify the problem in order to have an LP (linear programming) formulation, which is easier to solve.

Regarding the material exchanges in an EIP, they can be of different types: by-products (Lowe, 1997), wastes or real-value products. In an EIP, the wastes form a company can serve as a feedstock to another company of the park. The main difficulty to optimize the material sharing network of an EIP lies on the multiplicity of the materials produced or used in a park composed of a lot of very different companies. Consequently, very few studies propose a real optimization of these exchanges.

The final aim is to optimize all the components (water, energy and/or materials) simultaneously in order to obtain an EIP as ecological as possible. An important issue in the field of optimization lies on the characterization of the objective function(s).

A presentation of the different criteria taken in the literature is exposed. Although more often qualitative as quantitative, the societal/managerial objectives are fist described followed by economic, environmental and technical objectives.

Some research has been devoted to develop quantitative indicators to evaluate the satisfaction of each participant of an EIP (Tiejun, 2010; Zhu et al., 2010). However, even if the degree of satisfaction can trigger the development of such a project, it is not really an indicator of social effects. The social criterion is the most difficult to mathematically formulate because it involves non quantifiable concepts. A social objective should include quantitative indices of quality of life for workers, quality of life for those in community, noise, health and safety for workers and also local employment level. It is also important to underscore that the social aspects can be considered at different levels: plants, site, regional or higher levels. Finally, it can also be relevant to consider the social impacts induced by job creation thorough remanufacturing if it is necessary.

Contrary to social impacts, it is the easiest to evaluate through a mathematical formulation is the economic objective. It is also probably the most important for the stakeholder's point of view because if the cost is reduced, there is a real short-term interest to be involved in the EIP. Even if there are many and varied ways to formulate an economic indicator and in mono-objective optimization problems, the cost remains the more often used objective to minimize.

Preserving the environment is one of the main motivation of industrial symbioses or development of eco-industrial parks. Several criteria have been formulated in order to minimize environmental impacts of an eco-industrial park. They can be classified into different categories: objectives formulated to minimize natural resources consumption, impacts formulated through a life cycle assessment approach or objective functions based on the water footprint approach.

Highly linked to the cost of a network, another objective is the evaluation of the complexity of the network. The network complexity, that is to say, the number of connections in the total network needs to be considered as it represents an investment cost, and directly traduces the feasibility of a network. By taking into account pipes, binary variables are introduced into the problem formulation, which becomes an MILP (Aviso et al., 2011; Taskhiri et al., 2011b; Rubio-Castro et al., 2011; Boix et al., 2012). In previous studies, the number of connections between processes is often formulated as a topological constraint to avoid some impossible links (Rubio-Castro et al., 2011).

Future researches will focus on the development of robust optimization methods that can allow to deal with complex problems (which is the case with EIP), with multi-objective optimization and that will take into account several periods formulation. At last, another important development will also consider the surrounding environment of an EIP. The natural resources available, as well as social and economic situation of the region, are fundamental to evaluate total impacts of EIPs.

2.9 Eco-efficiency: concept and methodological aspects (25)

Eco-efficiency for symbiotic transactions has recently attracted attention it is one of the key issues and challenges for eco-industrial development, along with sustainable consumption and production. Eco-efficiency encourages business opportunities and allows companies to become more environmentally responsible and profitable. The concept of eco-efficiency provided by the World Business Council for Sustainable Development (WBCSD) can be adopted to evaluate the performance of industrial symbiosis networks. This concept offers a framework that is flexible enough to be widely applied and easily interpreted across a variety of industries, while providing a common set of indicators. Eco-efficiency is customarily defined as (Verfaillie and Bidwell, 2000):

$$Eco - efficiency = \frac{Product\ or\ service\ value}{Environmental\ influence}$$

The eco-efficiency concept has been applied to various products and processes (Korhonen and Luptacik, 2004; Park et al., 2007; Aoe, 2007; Syrrakou et al., 2006). In addition to products and processes, the concept and indicators have also been applied to the design of industrial parks by using process re-engineering (Grant, 1997).

The WBCSD has identified a range of possibilities that encourage eco-efficiency in the business sector: (i) reducing material requirements for goods and services, (ii) reducing the energy intensity of goods and services, (iii) reducing toxic dispersion, (iv) enhancing material recyclability, (v) maximizing the sustainable use of renewable resources, (vi) extending product durability, and (vii) increasing the service intensity of goods and services. Most eco-efficiency measures or indicators focus on the consumption of energy, materials, and water, and the emissions of greenhouse gases, wastewater, and pollution.

The methodology adopted for calculating and reporting eco-efficiency can assist the participating companies in industrial symbiosis networks to set new eco-efficiency improvement targets. Good cooperation among companies can enhance the value of by-products, which eventually helps companies to become more-efficient (WBCSD, 2000).

The main advantage of the eco-efficiency concept is that it allows companies participating in symbiotic transactions to monitor their performances with regard to eco-efficiency trends. Thus, continuous monitoring and assessment of eco-efficiency is critically important for developing cost-effective measures of reducing environmental pressures through the development of symbiotic transactions among companies.

Eco-efficiency has the ability to combine performances along two of the three axes of sustainable development, namely, environment and economics (Ehrenfeld, 2005). In order to explain the direction of progress toward the goal of sustainable development, the social dimension of symbiosis implementation should be included in future research. In addition, the most significant limitation of the eco-efficiency evaluation is the availability and quality of the data required for calculations.

2.10 Evaluation of an EIP based on a social network analysis (10)

An eco-industrial park can be extracted as a symbiotic network, so it is reasonable to use social network analysis. The basic measurement variables of social network analysis have become the important method in the study of industrial symbiosis. An industrial symbiotic network is a network that consists of vertical and lateral links as well as social connectedness. Up to now, social network analysis has developed into a comprehensive method, not only on the side of information relations but also materials, energy, and information relations. Based on this, social network analysis could be used to analyse the social relation structure and patterns behind the exchanges (Zhong et al., 2010).

The conceptual model for eco-industrial parks is the following:

- Firstly, we establish eco-industrial chains and networks according to the constitution of the members, and the flowing situations of materials, energy, and information between members of eco-industrial parks.
- Secondly, we add some members out of the park who exchange resources with members within the park. On the basis of confirmed members and communications among members, we establish a relational data collection. Then we use the directive dichotomous assessment system to judge whether the relation existed or not, we called our system the adjacency matrix.
- Finally, with social network analysis, we abstract the park into a network system. The system consists of nodes and paths and it is called the symbiotic network. The models are useful for analysing social essence reflected in the delivering of materials, energy, and information. Nodes in the network represent members in the park; directed line segments between nodes represent the transferring directions of materials, energy, or information.

2.11 Vulnerability analysis of symbiosis networks of EIP's (22)

In the modern society, we know that symbiosis networks of eco-industrial parks seriously affect the economic development. If one enterprise malfunctions, huge economic losses of the society will happen. So the safety of industrial ecology parks is the most important issue and we must pay more attention to it.

It is used complex network theory to go into the interior of symbiosis networks and analyse the vulnerability in symbiosis networks of industrial ecology parks. It is extracted an industrial park as the symbiosis network and is built a model for the symbiosis network according to the industrial ecology park's characteristics. Under the proposed model, it is furthermore raised a measure to quantitatively evaluate the power and status of the nodes. As a result, some potential critical nodes are found. Moreover, it is investigated the relationship between the vulnerability of the symbiosis networks and the two parameters in our symbiosis network model. The results could be beneficial to protect the critical nodes effectively and also enhance the reliability and robustness in symbiosis networks of industrial ecology parks. The study will promote the construction of symbiosis networks of industrial ecology parks.

It is taken the Gongyi system in Henan Province of China as a case to build a symbiosis network model. It is a relatively complex industrial symbiosis network as it has a lot of exchange of matter or energy existing in the system. It is therefore investigated both (1) the interrelations about the members of the industrial ecology system to obtain the adjacency matrix, and (2) the cascading failure behaviours on the symbiosis network of the industrial ecology park with respect to the initial

removal of each node. Hence, it is found out the potential critical nodes in the symbiosis network. The simulation results also show that symbiosis network display the strongest robustness level against cascading failure. The result could help to select the optimal value of the parameters to attain the optimal robustness. In summary, the work may have practical implications for protecting the key nodes selected effectively and avoid cascading-failure-induced disasters in symbiosis networks. It is very useful for the construction of symbiosis networks of industrial ecology parks.

2.12 Cities and industrial symbiosis (19)

The geographical concentration of economic activities is one of the most pervasive characteristics of all growing economies. Economic geographers, urban economists, and other experts of regional economic development have long explained the spontaneous colocation of industrial activities as the result of the interplay of economic forces such as factor costs, proximity to markets and raw materials, local taxes, regulations, infrastructure, and the preference of the entrepreneur. The persistence throughout history of urbanized patterns of economic development demonstrates that the savings and/or productivity advantages derived from the geographical concentration of industries are often more important than increased land, housing, commuting, pollution, and other urbanization costs. However, regional economies have never existed in a geographical vacuum and have always depended to some extent on interregional trade, including that of by-products.

Kalundborg's industrial symbiosis is often described as a local network, but it is worth pointing out that it is neither self-sufficient nor limited to what could be labelled a local economy. Much historical evidence on by-product recovery similarly suggests that interregional trade has always been significant. So, thanks to the experience of Kalundborg and other cases studies, we can affirm that although transportation costs have always played a role in determining whether a by-product was used locally or not, perhaps the most important determinant of the interregional trade in by-products was the capacity of individuals in a particular location to create the most value out of it.

Some analysts who have examined Kalundborg's recycling linkages through the symbiosis metaphor have adopted a geographical scale that is too narrow in scope and/or that promotes local linkages at the expense of interregional trade. Notwithstanding, not all industrial ecologists downplay the role of interregional linkages. For example, Chertow (2000) points out that "the symbioses need not occur within the strict boundaries of a park, despite the popular usage of the term eco-industrial park to describe organisations engaging in exchanges".

Although Kalundborg and other similar cases developed entirely through market forces, some commentators have argued that public planners could improve on the spontaneous outcome of market transactions. To assess whether eco-industrial park developers can significantly outperform private-company employees in a mixed economy, one must consider the outlook and incentives facing both groups. The first difference is the manner in which they view the activities of a firm. Planning-team members must view private firms as producers of particular waste or users of established by-products. Private-company employees, on the other hand, are paid to create the most value from given inputs, not to produce a regular supply of particular by-products.

Knowledge of by-products and of production processes and how this knowledge affects resource recovery will also differ between a planning team and private-company employees. The kind of knowledge that planners can acquire is a synthesis of what they learn about various by-products

from individuals working within firms (Kincaid and Overcash, 2000). In contrast, in a private firm, employees who have to deal with by-products typically look at a much smaller set of waste products. Of course, industrial symbiosis planners can act as useful intermediaries between firms and sometimes discover potential linkages that have been overlooked by market actors.

Many authors have pointed out that some environmental regulations view industrial by-products as a nuisance to be destroyed rather than as potentially useful resources. Kalundborg provides an interesting lesson in this respect. The flexibility of the Danish regulatory framework made possible exchanges that would have been prohibited in the United States (Gertler, 1995; Ehrenfeld and Gertler, 1997; Schlarb, 2001). Also, the stricter environmental regulations that have been the driving force for some linkages have been performance standards rather than technology standards. Regulatory reform should be given higher priority than the planning of localized industrial symbiosis.

2.13 An emergy-based hybrid method for assessing industrial symbiosis of an EIP (27)

It is critical to seek an innovative method by combining the advantages of different methods so that more feasible IS policies can be raised to address waste and emission management, reuse and recycle strategies. This paper tries to fill such a research gap by raising an emegy-based hybrid model, in which emergy analysis, IPAT formula and IDA (Index Decomposition Analysis) methods are merged.

Emergy is the sum of all available energy inputs directly or indirectly required by a process to generate a product (Geng et al., 2013a). Emergy synthesis provides an integrated evaluation method for ecological-economic systems and has been successfully applied to systems of different scales (Brown and Ulgiati, 2004). In recent years, emergy analysis has been applied in industrial parks especially in the field of industrial symbiosis. In this study we focus on waste reutilization induced by IS to evaluate the waste efficiency of an industrial park. The transformation of the reutilized waste is equal to the raw materials, no matter it is one by-product or co-product.

Ehrlich and Holdren (1971) proposed the famous IPAT equation, in order to uncover the relationships of environmental impact (I), population (P), affluence (A) and technology (T).

Decomposition analysis has been widely used to analyse different drivers of industry-related emissions. IDA is a decomposition analysis method raised in the late 1970s in order to study the impact of changes in product mix on industrial energy demand (Ang and Zhang, 2000). The main advantage of IDA compared to other analysis methods is that it doesn't need an input-output table.

A case study approach is employed in order to test the applicability of this emergy-based hybrid method. Dalian Economic Development Area (DEDA), a larger industrial park in Dalian, Northeast China, was selected as one case industrial park since this park has made a great effort to promote the application of EIP. The research results reveal that DEDA experienced a rapid development and consumed a lot of natural resources. Although industrial symbiosis activities help reduced the total wastes, more efforts should be made in order to further reduce the total material and energy consumption, such as energy structure optimization, energy saving, etc. Appropriate evaluation methods can therefore facilitate park managers to self-check their problems and prepare feasible development targets by considering their own realities. Consequently, it is critical for more industrial parks to apply such an evaluation approach so that more industrial parks can move forward sustainable development.

2.14 Reflections on implementing industrial ecology through EIP development (17)

The major finding from studies bear out that there is an absence of inter-firm exchanges and interactions within the EIP's. In some cases, there is evidence that environmental impacts have been reduced. Notwithstanding, the surveys reveal that very few sites have any plans to either monitor or develop targets for waste, emissions or energy use, calling into question the extent to which any environmental improvement can be measured. Overall, in most cases, industrial symbiosis synergies are only potential and in the very early stages of planning.

Given the relative absence of interchange and networking within EIPs, very few locations could be said to be operating as any form of closed system. On the question of scale, the difficulty of establishing interchange and networking at specific bounded locations may suggest that a more fruitful eco-industrial strategy might be to build upon existing waste and energy interchanges at a wider scale. With respect to dynamism, there is certainly evidence that EIP developments have had to respond to changes in economic circumstances, although not in the ways that the industrial ecology literature envisages.

Much of the IE literature emphases trust and co-operation as key factors influencing networking and interchange activity (Gibbs, 2003). Issues of trust arise particularly in relation to fund raising to develop the EIPs, where pre-existing links are often the crucial deciding factor. In addition, good personal relationships between those involved in establishing the EIP and the key role of certain individuals taking a dominant position is also of central importance to EIP development.

The research reveals high levels of public sector involvement in EIP development. Indeed, EIP locations are frequently found in areas eligible for public sector assistance and/or in areas of need of economic and social regeneration. The majority of EIPs are being developed as part of a local economic development strategy. However, they rarely appear to be a central plank of policy, but are rather isolated responses that may allow policy makers to "tick the environmental box" while getting on with the main business of economic development which may continue to be environmentally and socially destructive. There may be more potential benefit to be gained by identifying and building upon existing networking activities involving the exchange of waste and energy at a wider spatial scale to develop a "local-regional industrial ecosystem".

The contribution of the EIPs studied to environmental goals is clearly limited by the lack of success at establishing industrial symbiosis. In some cases EIPs recorded improved economic performance. Several developers were strongly of the opinion that designation as an EIP had helped to speed up the development process because of its benefits as a marketing device and a means to create a "unique selling point". The limitation of eco-industrial development as a marketing tool is that lack of initial success could result in the abandonment of any pretence of IE in favour of an alternative strategy. The social expectations around EIPs are typically focused on the creation of jobs. The lack of economic success also clearly limits the potential contribution of EIPs to social goals.

Making industrial ecology operational through EIP development is at an early stage of development. Hence, the results of our case studies revealed the problematic nature of developing into EIP. Certainly the results bear out a view that EIP development has been concerned mainly with infrastructural provision and has assumed that relational assets will emerge with time. The general view from respondents was that the concept sounded good on paper at the development stage, but

that recruiting companies to participate was problematic. In some cases, the difficulties involved had led to the abandonment of any attempt at EIP activities. Expecting firms to relocate to a site specifically to procure secondary materials is unrealistic when the "minor importance of waste costs and relatively low costs of attaining secondary materials" means that these play a small part in firms' location decisions.

Involvement in what were perceived by firms as low risk and both economically and environmentally beneficial projects had encouraged participation in further EIP developments with greater risk. They suggest that setting up pollution prevention projects related to utility sharing, such as combined treatment of wastewater or combined cogeneration of heat and power, instead of focusing on developing physical energy, water and material waste interchanges, may be a good entry point into industrial ecology, where EIP development "is a long-term process and in order to stimulate development it is important to focus on the establishment of low cost and simple exchanges" (Heeres, 2004).

Despite these problems, interviewees claimed that eco-industrial development had contributed to local economic development at the case study sites, although it proved more difficult to distinguish the exact benefits.

2.15 The way of success (5)

2.15.1 A successful approach to EIP development

The successful development of an EIP would require the active participation from a number of stakeholders:

- Public sector stakeholders from local, regional and national government agencies
- Representatives of local companies and potential future tenants in the EIP
- Leaders in the industrial and financial community
- Local chamber of commerce
- Labour representatives
- Educational institutions
- Practitioners with the full complement of capabilities needed in the project: architecture, engineering, environmental management, and education and training
- Community and environmental organizations

When the participation of the stakeholders in the project is assured, the first step in the actual EIP development process is gathering of information. The necessary information can be gathered through a survey and/or personal interviews with future EIP members and participants. The areas that should be addressed in the survey and/or interviews include:

- Basic company information
- Products and markets
- Employee information
- Raw materials
- Waste streams
- Energy

- Environment
- Manufacturing networks
- Future plans

However, many problems need to be overcome before an EIP development is successful. In the establishment of such exchange relationships, a company may run into five different types of barriers: technical, economic, informational, organizational, and regulatory/legal.

2.15.2 Key success factors

First and foremost, one should assure active company/industry participation in the planning stages of the project. Company participation in the project should be assured through the involvement of local entrepreneurs'/employers' association or through an active recruitment procedure by the project initiator.

Second, the costs of EIP planning should not be solely carried by the government. Companies should also be financially committed to the planning phases. This will also enhance company commitment in the realization phases of the project.

Furthermore, the initial focus of the EIP project should not be on the establishment of physical energy, water, and material waste exchanges but on the establishment of utility sharing projects. The project should initially be focused on such projects because these projects, compared to the physical waste exchange projects, require relatively small economic investments while at the same time they offer a possibility for a reasonable economic and environmental benefit. When such projects are deemed successful, companies will be more eager to explore the possibilities for the establishment of more symbiotic energy, water and waste exchanges.

Finally, when the project is well established, the development can move along to the more company-specific and economically challenging projects, although the projects should always render an economic as well as environmental benefit.

2.16 Case studies

2.16.1 Australia Synergy Park (6)

In 1998, the Department of State Development of Australia embarked upon the planning and development of Synergy Park, a 37 ha eco-industrial park at Carole Park. Synergy Park was the first major integrated eco-industrial development project to be developed in Australia. The Synergy Park Unit Trust to develop and market the Synergy Park was executed in December 1998. It also has the role of long-term lessor to companies seeking to lease on the site.

An important concept proposed in the design is the development of a large common use warehouse facility. This facility allows manufacturers located in the park to secure storage space on a take and pay basis, rather than building their own storage amenities which might not be fully utilised.

Another relevant element was the park's development code. The key provision in the code is that Synergy Park is dedicated to manufacturing in food and beverages or pharmaceuticals, or service industries closely related to these sectors. The code is intended to support the development of an industry cluster whose core business is related to food and pharmaceuticals.

The overall development of Synergy Park is guided by a Master Plan. The Master Plan was developed using a consultative process, with the overall layout based on what each food processing industry needed. The approach was to seek out the common denominators in order to share infrastructure.

Part of the philosophy of synergy is to reduce establishment and operational costs. The park was designed to support several key scale economies. The first is the central warehouse, which will allow shared logistics and controlled movements of vehicles. The second is the sophisticated logistics management which is intended to be developed as part of the common use warehouse facility. The third scale of economy arises in energy supply. The co-generation plant to be developed offers savings to business. The fourth scale of economy is effluent disposal.

A number of useful lessons have been learned from the planning of this project. These include: the importance of an industry catalyst, the Synergy Trust which at an early stage develop the concept of the park and bring together key industries and utility players that might benefit from an industrial synergy, the need for strategic planning that has foresight and flexibility to enable mixed industrial developments rather than a segregated land use, the necessity for developers to engage the community early in the planning process in order to avoid misunderstandings and to develop trust and community support for the concept, and finally the essential importance of government support and direct involvement in projects of this kind.

2.16.2 Daedeok Technovalley (7)

The Daedeok Technovalley (DTV) is located in Yongsandong Yusong-Gu, Daejon Metropolitan City, approximately 150km from Seoul, the capital of Korea. Daejon City established a citywide industry development structural plan in 2001 linking Daedeok Science Park, DTV, existing conventional industrial estate and Expo Science-oriented amusement park.

The research done about DTV eco-industrial park states that in the aspects of ‘external/internal built environmental design’, the EIP plan could achieve significant level of sustainability progresses. In addition, due to the increased concerns on ‘cultural identity creation’, residents have strong sense of community within the site. However, some limitations are still apparent not only in ‘symbiotic industrial network construction’ and ‘energy and material flow planning’ aspects but also in the aforementioned two aspects: ‘external/internal built environmental design’ and ‘cultural identity creation’.

First, and most importantly, the EIP plan has failed to establish detailed sustainability targets, indicators and benchmarks, maintenance and monitoring plans. Due to this problem, many innovative design strategies and technologies were simply adopted as a decorative practice. Second, the EIP plan failed to specify any systematic support mechanism for resources and information sharing industrial network construction. The lack of financial support required promoting industry cooperation and public participation is also important barrier to the implementation of EIP. Finally, it is still unclear as to whether the EIP development plan can obtain sufficient level of public interests and participation, which is essential for achieving long-term maintenance sustainability of the city. Solving these issues is the most important task for future EIP development project’s progress towards sustainability.

2.16.3 Macheon Industrial Park (9)

The study discussed the promotion process of the EIP project in South Korea through the case of Macheon Industrial Park (MIP). The approach was adopted to deal with environmental civil complaints caused by the industrial plants in the case of MIP instead of constructing organic materials flows and a resource-symbiotic network. This might pervert the aim of the project and finally threaten the sustainability of the project itself.

The public sector and even "the Center", the operating body which manages the project, had some conceptual confusion or groundless compromise in promoting the project. Hence, the selection of MIP in the pilot project appears to be the result of some misunderstanding or arbitrary understanding of the concept.

Another limitation on the possibility for success of the project is that the government understands the needs of businesses inadequately. The government generally depends on a regulation-based approach rather than a substantial incentive program. Also, the public sector should play a more active role for the environment and economies in connection with EIP project. Furthermore, private companies seem too passive and are fence-sitting in the promotion of the project. They are likely to wait for governmental action and to simply want to get a free ride on the support. However, in actuality, it is difficult to expect an active governmental initiative in South Korea. Businesses need to know that EIP project is not a philanthropic work but a profitable business.

In conclusion, this study emphasizes the importance of the public sector in constructing EIPs despite some theoretical notions to the contrary.

2.16.4 Chinese national eco-industrial park standard (20)

In China, there are now over 100 EIP projects, of which 26 have been chosen by the State Environmental Protection Administration (SEPA) as national EIP demonstration projects (SEPA, 2007). This program includes initiatives related to cleaner production and eco-design, industrial symbiosis and EIPs, and, more broadly, the regional eco-industrial network (Geng and Liu, 2006). The general objective of SEPA's new program is to encourage, manage, and monitor EIP projects by setting up criteria and indicators. Under this program, industrial parks participating in the EIP projects are to play an important demonstration role and create a positive impetus for other industrial parks in China.

Although SEPA prepared three separate groups of criteria and indicators for three different types of parks, for any type of park, the agency categorizes all the indicators into four groups – namely, indicators for economic development, indicators for materials reductions and recycling, indicators for pollution control, and indicators with respect to park management.

This new program could provide comprehensive economic, environmental, and societal benefits. First of all, in terms of economic benefits, given that this new regulation encourages more efficient materials and energy use, cost savings can be archived through potentially lower insurance costs as well as reduced environmental responsibilities. Second, ecological benefits of applying this standard include conservation of natural resources and a reduction of the environmental impact of industrial operations, achieved through more efficient material and energy use, reduce waste discharge, and substitution of toxic materials. Third, some societal benefits of applying this standard could be also

achieved, such as improved public awareness through capacity-building programs and improved public health through reduction of waste emissions. Next table is a summary of key benefits.

Economic benefits	Environmental benefits	Societal benefits
Lower insurance costs	Conservation of natural resources	Improved public health
Lower waste treatment costs	Reduced environmental emissions	Improved public environmental awareness
Increased revenues from the sale of wastes	More efficient materials and energy use	New business and employment opportunities
Increased sales of green marketing	Less use of toxic materials	Improved community relations
Avoidance of penalties	Improved environmental quality	

Table 1. Summary of key benefits

Several challenges, however, also exist and need more discussion, including a lack of indictors on industrial symbiosis and diversity; vagueness in some indicators, which makes evaluation difficult; institutional barriers to implementation; and a lack of indicators on broad collaboration.

2.16.5 Devens eco-industrial park (26)

Devens is a regional enterprise zone created by the Massachusetts legislature in 1993 to aid the redevelopment of the former Fort Devens. By identifying and addressing local firms' key sustainability challenges and priorities, the Devens Enterprise Commission has been able to help support and advance these challenges and priorities by implementing local government policies and initiatives that have resulted in an increase in access to rail, more green buildings and more companies in Devens collaborating to maximize efficiencies. While some parks report challenges in getting companies to relocate, Devens has been more successful as a result of building on successful spatial planning and infrastructure sharing (Deutz and Gibbs, 2008). Devens Eco-Efficiency Center has played a critical role in promoting shared knowledge and learning, building trust and encouraging environmentally favourable behaviour among firms located in Devens and neighbouring communities. Devens can provide valuable lessons on how industrial ecology can serve as a tool for establishing environmental and social goals, promoting education, trust and collaborations among firms that lead to both business and social benefits. The Devens case confirms that developers should focus on what they can control and provide flexibility and support for the growth of social interactions and networking activity (Deutz and Gibbs, 2008). By creating a separate entity focused on promoting industrial ecology principles and greater collaborations among local firms, Devens has established the necessary institutional infrastructure to ensure eco-industrial activities will continue, even in the case of personnel changes or the loss of key industrial ecology champions (Tudor et al., 2007). The fact that despite its two-decade long redevelopment Devens still does not have any major exchanges of materials or by-products, confirms earlier studies that have identified a range of technical, legal, economic, and organizational barriers to such exchanges (Gibbs and Deutz, 2007). So, the case of Devens also supports the idea that "developing EIP's is likely to be a long process where immediate results are unlikely to be forthcoming" (Lowitt, 2008; Gibbs and Deutz, 2007). The study findings confirm the importance of indirect economic benefits for participating companies (Jacobsen, 2006) including development of collaborations and green networks as instruments for learning and innovation (Stormer, 2008). By simultaneously pursuing environmental and community goals, Devens EIP provides empirical evidence in support of Porter and Kramer's (2011) recent theory on creating

shared value. The case demonstrates in practice how the right kind of government approach can encourage companies to pursue shared value. Understanding and addressing the main business needs in addition to promoting sustainability practices is key for attracting and retaining firms.

Key to Devens EIP success is its vision that serves community and business interests, a plan to achieve that vision, a collaborative structure to implement the plan and a viable process to measure progress, revisit goals and refine plans and strategies as conditions change. The case of Devens EIP demonstrates that eco-industrial parks today are more focused about infrastructure and knowledge sharing, joint sourcing, building local supply chain and reducing the risks from weather and other business disruptions. All of these elements are critical components of business competitiveness in the 21st century knowledge-based economy.

3. Eco-industrial synergies

3.1 Synergy Tools (2)

The creation of information on feasible synergies between varied entities of a territory generally requires, in whichever stage of the approach it is, the use of computer tools. The tools have the role of creating this information on the potential synergies that only very rarely exist "spontaneously". Synergy searching tools create information on the potential of the re-use of waste, other types of materials, water or energy flow. Several computer tools have been created since 1998, although the majority of them are no longer used by the community. One of the tools that nowadays are commonly used by different participants is Presteo.

Presteo was invented by the company Systèmes Durables in 2005. It uses the MySQL database management system and it does not contain sectorial data. It is a tool aimed at the participants of an eco-industrial development approach, based on clear data formalization method for which the users and administrators require training. It is therefore exploitable by both experts for the launching of a scheme and the participants of the scheme. The clear and rigorous flow data characterization method enables the tool to be used by several people without too much performance modification.

A summary of the main tools used by stakeholders in EIPs nowadays are presented in the next table. As this research is based on France, a big amount of them are in French.

Name	Language	Description
CRISP/REDIBIS	English	These tools were developed by International Synergies in the program NISP (National Industrial Synergies Program). They allow the sharing of bibliographic information and projects within a community of experts. They also allow detection of synergies. This is a national tool and shared across the UK.
NOVA	English / French	This is a program developed in 2008 by Trinov in partnership with the CETIM which helps to optimize spending and revenue related to waste. The solution applies to industrial waste, tertiary waste, commercial real estate, hospitals and construction.
Opti/Waste	English / French	This is a web platform rolled out in an area of activity and on the production and management of waste. It is used by the port of Le Havre.

EDITER	French	Developed by the Department of Research and Development of EDF in 2005, the tool gathers data from the literature on material flow / energy in a sectorial approach (code NAF). EDITER allows describing in a structured way flow balance within a territory and detection of synergies. The tool is available in the Poitou-Charentes region.
NOVA Light	French	This is a program developed in 2010 in partnership Trinov CETIM, which assesses the scale of a business area or territory, products waste and devaluing their associated solutions.
OPC	French	This is a program developed in 2013 in partnership with Trinnov CETIM which evaluates potential sources of waste territory, from the NAF Code of companies.
Presteo	French	This is a collection of software flow during industrial ecology approaches. Presteo has a pooling and substitution synergies detection engine. It allows the capitalization of information while ensuring confidentiality.

Table 2. Summary of the main tools

3.2 Agent-based modelling simulation (21)

This computational study focuses specifically on the application of a simulation tool within industrial ecosystems. Indeed, in this case, industrial ecosystems are viewed as self-organizing systems whose evolution is a function of complex interactions among multiple organizations pursuing individual objectives. The challenge is to determine how organizations and industrial eco-systems can be stimulated to make those decisions that are not only in their own best interests, but also stimulate the overall benefits associated with the entire industrial network. An important role for agent-based modelling in Industrial Ecology (IE) should be to explicitly treat the incentives that face behaviourally realistic agents in empirically credible environments. Here we focus more closely on the methodological aspects of agent models as well as the ways in which industrial ecologists may begin to exploit their capabilities for systems modelling.

The goal of this agent-based model is to see the emergence of symbiosis within an industrial ecosystem. Industrial ecosystems constitute an obvious field of application of ABM because it allows for bottom-up simulations of organizations constituted by a large number of interacting parts (Fioretti, 2005). An important role of agent-based modelling in IE should be to explicitly treat the behavioural characteristics that favour the emergence of sustainability of an industrial ecosystem.

The model description follows the ODD (Overview, Design concepts and Details) protocol for describing individual- and agent-based models. The model consists of core entities called agents, represented here as industrial plants within a regional network (potential symbiosis) and links, which represent the exchange of materials. If materials (inputs and outputs) are available, links will be created between the plants. The emergent effect we are looking for in this model is the ability of the plant managers to develop this exchange of materials. The ability of the plant manager is measured by the number of links created and the total number of plants that become partnered.

Simulations so far have revealed that the model still needs some improvements as well as enhanced validation in order to deliver more realistic results. However, its design is seen as an approach to modelling multi-agent network systems that may serve as the basis for the development and sustainability of industrial symbiosis. The consequence of individual behaviour on the sustainability of a system is difficult to measure with traditional assessment methods. Ultimately, the use of Agent-based modelling will be to generate and explore alternative futures and scenarios that may develop

under different conditions. The goal is to allow several simulations that can explore various “what if” scenarios under different economic, social and environmental goals. They can show the possible evolutionary trajectories of given scenarios under different conditions and varying geographical context.

3.3 A heuristic visualization tool (Looplocal) (24)

The Looplocal tool was built with the specific aim to support the facilitation of material and energy industrial symbiosis – especially in countries with geographically disperse industry. To achieve this aim, three objectives were set as desired functions of the tool:

1. Simplify the identification of regions susceptible to new industrial symbiosis facilitation activities.
2. Enable proactive and targeted marketing of potential exchanges to key actors in specific regions.
3. Assist facilitators to assess the various strategies and consequential engagement and analysis methodologies suitable for additional industrial systems development in specific regions.

The Looplocal method takes the approach of heuristically (quickly and imprecisely – yet perhaps sufficiently for some purposes) estimating the material and energy flows of industrial facilities in a region of interest. Consequently, the tool then looks to identify potential industrial symbiosis connections between these flows by referring to a compatible industrial symbiosis dataset. Potential new connections identified by the tool along with other key information can then be visualized for various strategic uses. The framework of the methodology consists of 5 processing stages and 5 stages of data.

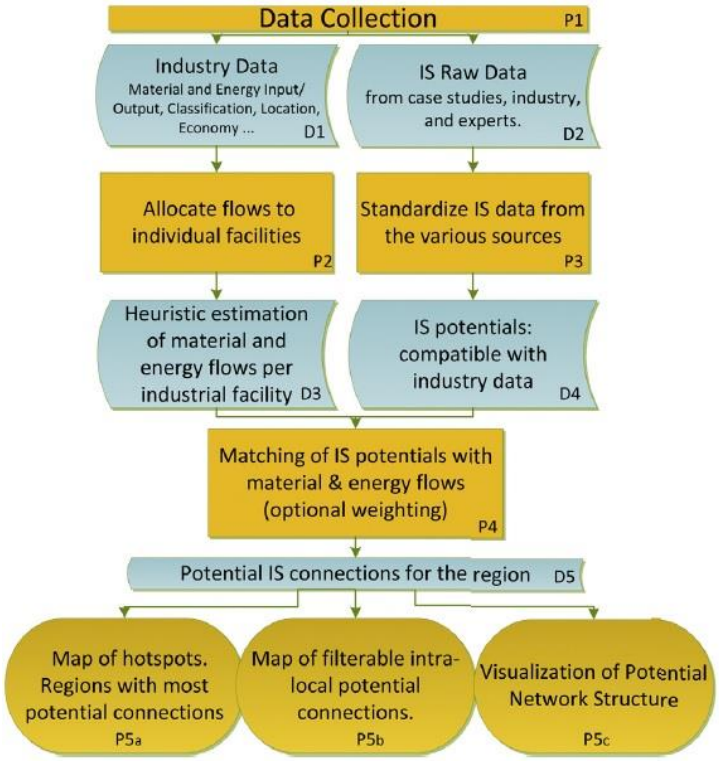


Figure 4. The methodological process flow of Looplocal

Once the information on industries and industrial symbiosis potentials are correlated and run through a matching process the output may be presented through tables, graphs, maps, or other means.

Notwithstanding, it is encountered some limitations in achieving these three objectives of the tool. Major limitations were: (1) The difficulty to highlight the most interesting potentials identified within the large output of the tool, (2) the need for sufficiently populated and detailed data, and (3) the financial resources required for testing and implementing the tool within wider use contexts.

When industrial symbiosis matching tools are used in a wider framework they have some interesting implementation potentials. With active facilitators, Looplocal and similar tools might serve a range of actors in various regions with aims such as strengthening waste management business models, helping authorities to attract complimentary business to their regions, or utilizing stock materials.

3.4 Technology-enabled support for industrial symbiosis (14)

IS practice currently relies on manual interpretation of data in the course of face-to-face communication and case-by-case analysis by IS practitioners assigned to assist in projects. Data have to be exploited in the context of specific knowledge domains, the description of which can be rather complex and daunting. The systematic and thorough analysis is impossible with a manual manipulation of data. The acquisition and the classification of data is critical to the development of IS synergies. Even structured data require separate and significant effort to process as useful information.

Ontology engineering features capabilities to unlock the potential of IS by offering semantics with powerful modelling capabilities that could enable the effective monitoring and exploitation of resource flows at various use levels, also to build sharing communities. The approach is able to simplify the inclusion of SMEs (Small and Medium Enterprises) offering technology to advance existing IS networks towards systems aligned with Industrial Ecology standards. Moreover, the systematisation of the approach builds capabilities to support and scope for innovative solutions. The work is an EU collaborative project, the e-Symbiosis, that combines expertise by IS practitioners, developers and academics familiar with IE in general and IS and ontology engineering in particular.

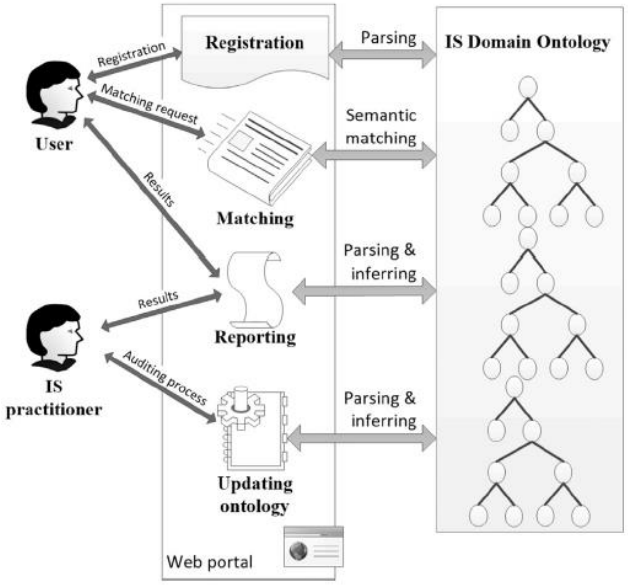


Figure 5. Service functionality

Ontology models are used to represent: (1) tacit knowledge in the form of description of waste streams, description of enabling technologies and description of the IS process; and (2) explicit knowledge about participating companies in the form of IS relevant data (Raafat et al., 2013). The IS knowledge is modelled using ontologies, which are widely accepted tools for knowledge representation and processing. Ontologies are formalised as interlinked and otherwise characterised group of terms and

concepts describing a specific domain, the IS domain in this work (Gruber, 1995).

Ontologies are used to share and expand knowledge in participating communities and over the Internet. In the case of e-Symbiosis, the proposed paradigm includes classes, object and data properties and axioms, all structures to model knowledge in the domain of IS as acquired by IS practitioners and experts. e-Symbiosis ontology is designed in English using established vocabularies of standardised classifications.

e-Symbiosis service is implemented as a web service accessible through web portals. The service shares proprietary and to some extends public information using ontologies that invite links between partners ranging from SMEs and large industries to government agencies and the general public.

The domain ontology for IS is implemented using Web Ontology Language (OWL), which is an established and widely used language enabling the service to expand, share and reuse other ontologies over the Internet. The domain ontology coordinates the whole process of IS.

Each user is described by user description ontology translated from the respective instance and which enables input – output matching with technology, economic and environmental semantic relevance.

The identification of potential synergies between different industries, namely the input – output matching, is translated into an ontology matching process. The matching is performed using (1) the explicit knowledge provided by the user in the course of the registration, and (2) the tacit knowledge captured by the domain ontology. Inference and matchmaker engines relate user description ontology of requestor to user description ontologies of all other registered users (Trokanas et al., 2004). In the present implementation of e-Symbiosis service matching process is reviewed on the basis of the metrics defined within the user description ontologies.

Semantic matching allows for suggestive matching within the e-Symbiosis service: when an exact solution is not identifiable, this matching identifies solutions which are proven for similar types of resources, presenting the choices to the user together with reports of their semantic similarity. The semantic matching also allows for a partial matching in cases where the registered industries satisfy the request only partially. In the case of partial matching the options are listed to select. Options are sorted with respect to relative advantages and offer room for optimisation and multi-criteria analysis.

3.5 Enabling processing technologies participation in industrial symbiosis (16)

The processing technology participation in IS is addressed through formation of IS networks where it becomes a constitutive element justified by its technological, economic and environmental terms. For the need of IS, a simplified model of processing technologies is used which includes the conversion itself, input in the form of feedstock, targeted output presenting the product, auxiliary inputs supporting the conversion, i.e. energy, water and material, and by-products, as shown in the figure.

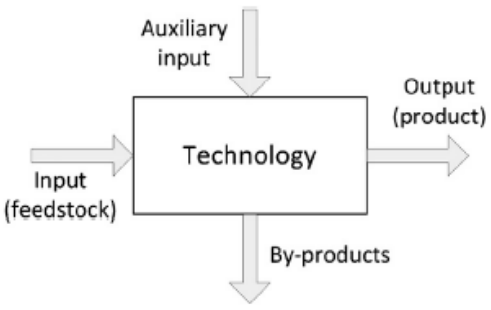


Figure 6. Technology representation

In the proposed approach, processing technologies are modelled as knowledge using ontologies. Every processing technology is represented as an SWS (semantic web service) ontology which is cross-related to the IS domain ontology and with users being the respective instances.

Based on existing classification and in response to the need of IS for easier identification and discovery of processing technologies to form symbiotic networks, we propose classification based on three distinct streams: by the targeted product or the output, by the technology type and by the technology input. Furthermore, to reflect IS practice and formations of symbiotic networks, processing technologies are characterized to enable partial input – output matching by type of input and output, as well as other properties.

The synergy identification and formation of IS networks is referred to as the input – output matching. In the current implementation the matching is controlled by purposely build matchmaker which not only automates the process but also builds in intelligence for automated discovery of potential and IS relevant technologies to establish synergies, assesses their relevance in IS terms and hence enables creation of innovative and structurally more complex symbiotic network. The direct matching between two processing technologies (or between resources and technologies) is based on four groups of metrics modelled in the SWS ontology, which include characteristics, industry formation, preconditions for the processing technology and environmental and economic synergy performance. The direct matching between two technologies is performed in three stages, which includes the semantic matching between technology input and output types and properties, verification of the matches in IS terms and ranking by the level of match.

3.6 The dynamics of industrial symbiosis (13)

Industrial symbiosis is best conceptualized as a process. The work that analyses empirical evidence continuously stresses the factors that hinder or stimulate the process through which industrial symbiosis comes about. We aim to provide a theoretical basis for understanding the dynamics through which regional industrial systems change their connectiveness in their pursuit of reduced ecological impact.

For this, we distinguish two levels of analysis. First we have the level of the regional industrial system (RIS), a more or less stable collection of firms located in proximity to one another, where firms in principle can develop social and material/energy connections as a result of that proximity. As a result of increased popularity of industrial symbiosis, actors beyond the regional level sought to stimulate its practice. We will call this the societal level. Here we are not interested in the dynamics that directly produce linkages among firms, but instead in the ways through which industrial symbiosis, and its associated philosophy, diffuses through society.

Regional industrial system level

To theorize at this level, we build on the idea that the ability of communities to deal with collective problems depends upon the extent to which they have built up institutional capacity (Healey et al., 2003; Innes and Booher, 1999). Institutional capacity building is the process through which different forms of institutional capital are formed, “an array of practices in which stakeholders, selected to represent different interests, come together for face-to-face, long-term dialogue to address a policy issue of common concern” (Innes and Booher, 1999). To further specify the results of this process we

will make use of the analytical distinction between three forms of institutional capital by Healey et al. (2003):

- Knowledge resources: the availability and structural sharing of explicit and tacit knowledge.
- Relational resources: the embeddedness of agents in social networks.
- Mobilization capacity: the structure and means by which knowledge resources and relational resources are formed and mobilized.

The overarching hypothesis here is that the coming about of industrial symbiosis is aided by a high level of institutional capacity. It depends on specific knowledge that actors acquire through experience and learning of the specific potential for industrial symbiosis in their system, as well as about the process of realizing that potential. In addition, they need to develop the linkages among actors whose activities need to be coordinated to make it actually happen. These actors include firms, as well as local governments and communities, knowledge institutes, and NGOs. We also draw attention to the capabilities of individual actors to build and maintain the linkages between them (Boons, 2004). Finally, the system needs to be able to mobilize resources that are currently not part of the system. These may include local actors and resources, but it may extend also to the wider political and economic context, such as national governments, or the headquarters of local production plants.

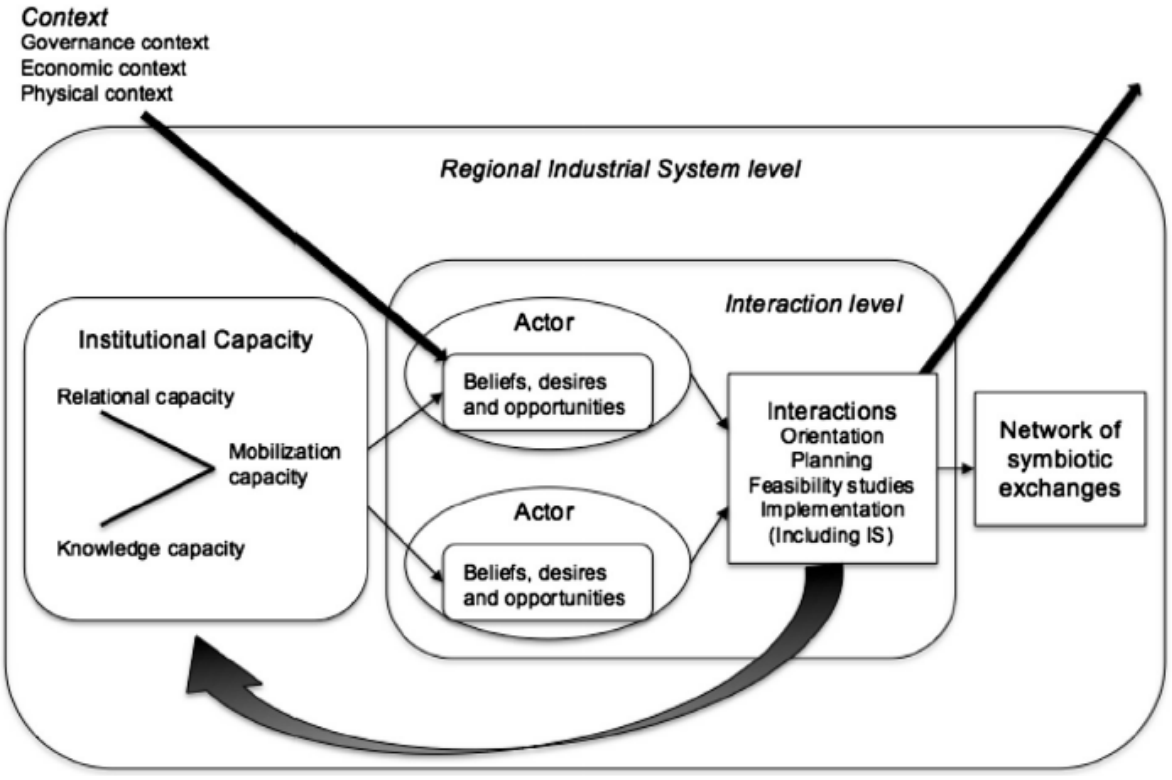


Figure 7. Conceptual framework

Societal level

At the societal level actors may be involved in the diffusion of industrials symbiosis, including the underlying philosophy and rationale. To address this level and its linkage to the level of RIS's we base ourselves in institutional theory (Czarniawska-Joerges and Sevón, 1996; DiMaggio and Powell, 1983). This theory deals with the mechanisms that are responsible for the diffusion of a concept,

innovation, or idea among a set of organizations. Here we will focus on the process of transmission, which is the most relevant to the diffusion of industrial symbiosis.

DiMaggio and Powell (1983) distinguish a number of mechanisms of transmission which can lead to the diffusion of organisational characteristics in an organisational field. Building on this, the following list of mechanisms can be proposed: coercion, imitation, private interest government, demonstration projects, training and professionalization, and altering boundary conditions. These mechanisms may all play a role in the diffusion of industrial symbiosis concepts and routines throughout a society.

Analysing outcomes

In the industrial symbiosis literature there seems to be an underlying assumption that increased connectiveness leads to reduce ecological impact. In this study, ecological impact refers to the effect of human activities on living organisms and their non-living environment.

Two main categories of approaches to quantitatively analyse this ecological impact of product/activities may be identified: those which seek to convert the emissions of hazardous substances and extractions of natural resources into impact category indicators at the midpoint level (such as ecotoxicity, land occupation, climate change etc.) and those which employ impact category at the endpoint level (such as damage to human health, ecosystem diversity and resource

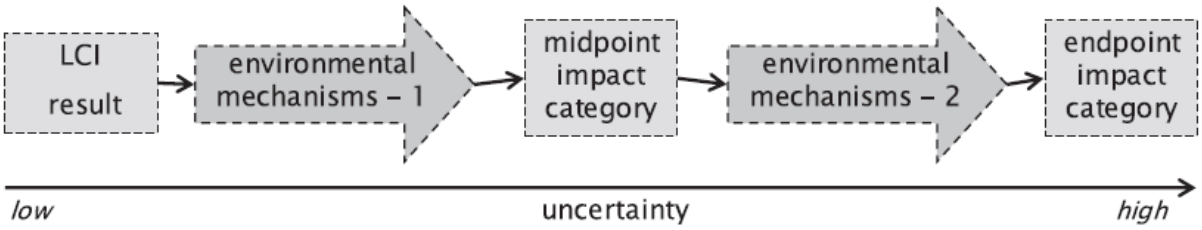


Figure 8. Relationship between LCI parameters, environmental mechanisms and midpoint/endpoint indicators

availability). A group of Dutch universities and consultancies has developed an integrative method called RECIPE 2008 which combines the above approaches and comprises two sets of impact categories at both midpoints and endpoints levels (see next figure).

When assessing the ecological impact of a symbiosis, it is difficult to move beyond the boundaries of the very left side of the figure. In addition to changed ecological impact, outcome variables include the diffusion of concepts and routines of industrial symbiosis at the society level, and changes in the institutional capacity of regional industrial systems.

3.7 Regional policies and eco-industrial development (28)

The policies adopted to disseminate EIPs can be categorized according to two main types of environmental approaches: (1) direct regulation (also known as “command and control”), and economic instruments (especially financial subsidies); (2) voluntary tools. Direct regulation and economic instruments seem to be preferred by governments, while local authorities are more likely to adopt voluntary tools. Direct regulation and economic instruments have been applied in many countries in Europe (Eilering and Vermeulen, 2004; Heeres et al., 2004), North America (Cohen-Rosenthal, 1996; Hendricks and Giannini-Spohn, 2003) and Asia (Geng and Doberstein, 2008; Shi et al., 2010) to promote specific eco-industrial initiatives. Voluntary tools are adopted less often to

implement industrial ecology concepts and are discussed minimally in the literature regarding the policy approaches linked with IE (Tudor et al., 2007; Gibbs and Deutz, 2007). Despite this, these instruments have proved effective in enhancing both environmental and economic performance in industrial companies (Iraldo et al., 2009; Daddi et al., 2011) as well as in the public administration (Daddi et al., 2013). According to Gibbs and Deutz (2007), public intervention should aim to facilitate voluntary co-operation between the firms located in the EIPs in order to achieve economic benefits. The policies should help companies to identify these opportunities by creating the "appropriate conditions for inter-firm networking to take place".

In December 2009, Tuscany, which is one of the Italian regions that is most engaged with the IE approach as a policy tool, launched a new initiative that sparked an innovative policy stream based on the voluntary approach. This approach have demonstrated, thanks to the Tuscan experience, to have both strengths and weaknesses. The greater strength is that the approach represents a concrete effort to implement a "holistic vision": if local actors want to obtain a voluntary certification and the related benefits they are "forced" to cooperate in designing local development strategies and policies. These include improved image and consequent attraction of investments, the possibility of obtaining priority public funds from the regional government, along with a shared environmental improvement plan for the area. Another strength of this approach is the ample sharing of goals by the various regional departments in issuing the certification scheme. The main weakness is linked to the audit that checks whether the criteria required for issuing a certification have been fulfilled. Another weakness lies in the criteria and indicators included in the standard.

To sum up, we draw some suggestions concerning the outcome of this relatively innovative "holistic" approach. Firstly, if the voluntary and co-operative approach is to be effective, it must rely on strong incentives. Secondly, the degree of ambitiousness of the criteria for voluntary certification seems to be key in making it a truly effective policy tool. Finally, the effectiveness and future uptake of this innovative voluntary approach depends on the extent to which the holistic vision is put into practice through the rules and roles involved in the scheme.

3.8 Institutional capacity building and process analysis (23)

As we have mentioned in the previous section, institutional capacity is built through recurring interactions between a growing group of actors. The recurring interactions allow the actors to strengthen their personal and professional relationships or build new ones (Inees and Booher, 1999). The actors may also identify and involve additional key players that have the resources and power that are necessary to "get things done". The stronger personal and professional relationships offer a basis for sharing experiences and jointly producing knowledge that aid the actors in the development of plans for dealing with the issue. The actors may also work together to draw on expertise and resources from outside the group (Healey, 1998). After developing plans the actors will typically gather additional knowledge to investigate the feasibility of their plans before the plans are actually implemented. If the plans are found to be feasible, the actors may mobilize the generated capacity in efforts to implement the plans they have developed, such as the development of symbiotic exchanges. The involved actors may find new ways of solving common problems or reassess their purposes and goals and come to see their interests and problems as interconnected. This can become concrete in the development of shared strategic visions, which give direction to further interactions between the actors.

The expectations on the development of institutional capacity are:

1. The interactions between actors in the process of institutional capacity building proceed through a cycle of orientation, planning, feasibility studies and implementation.
2. The number of actors involved in the process of institutional capacity building will grow throughout the process of institutional capacity building.
3. The range of actors involved in the process of institutional capacity building will grow throughout the process of institutional capacity building.
4. In later stages of the process of institutional capacity building actors that acted autonomously before may start working together based on shared strategic visions.
5. In later stages of the process of institutional capacity building actors engage in symbiotic exchanges that require larger investments in terms of people, knowledge and financial resources as compared to symbiotic exchanges earlier in the process.

The network of by-product synergies and utility synergies that emerges and develops at the level of the RIS can be understood as an outcome of the process of institutional capacity building. The stability of the network largely depends on the efforts of actors to sustain symbiotic exchanges.

Event Sequence Analysis is a research approach that offers a set of methods and techniques for the systematic longitudinal investigation of process phenomena (Spekkink and Boons, 2011; Boons and Spekkink, 2012). It builds on an ontological and epistemological position that views reality in terms of entities and events and that puts change and creativity in the forefront as fundamental aspects of reality. Processes are seen as fundamental and substances, as outcomes of these processes, are seen as ontologically secondary (Rescher, 1996). This position offers a philosophical basis for methodologies that focus on the analysis of change, where research questions concern how entities emerge, develop and dissolve again. To define something as a process is to define a central subject as well as the different types of events that the central subject endures or makes happen (Poole et al., 2000). The central subject can be any kind of entity, such as an individual actor, a group of actors, a lineage, a social movement, a machine, (Hull, 1975) or a RIS. The central subject is not a fixed entity because it may evolve as a result of the events that it endures. Events can be understood as the theoretically significant occurrences that the central subject endures or makes happen. In addition, the theoretical or conceptual framework should specify the mechanisms that link the different types of events together into sequences (Abbott, 1990).

After defining a suitable central subject and the relevant types of events, ESA proceeds through the following steps. First, longitudinal data are gathered on the process of interest. ESA is very data-intensive, as it requires the researcher to collect, process and analyse longitudinal data that can span a long period of time. The gathered data are recorded as incidents into a chronologically ordered event sequence dataset. Incidents are short empirical descriptions of things that happened in a process. In ESA, these descriptions are used as indicators for the occurrence of events. After the coded data have been prepared the researcher can use different methods for analysis to analyse the data for temporal patterns. Examples of methods for analysis are stochastic modelling, phasic analysis, event time series analysis (Poole et al., 2000), template matching, visual mapping, narrative analysis (Langley, 1999), and optimal matching (Abbott & Tsay, 2000), although for the different methods for analysis additional preparations are usually required.

3.9 Feasibility analysis (2)

It is rarely possible to directly use a companies' output flow in a particular process where specific requirements are concerned. Two large sources of qualitative inadequacies can be observed: on the one hand, the different types of materials contained in a single flow from a process; on the other hand, the physical characteristics of a potentially re-usable flow. Modern technology possesses many solutions for resolving the majority of these qualitative inadequacies. However, some of them do not find technical solutions.

The adaptation from demand to supply is a feasibility criterion essential for a synergy lead. In actual fact, the quality of the available flow can be adapted to the requirements of the receiving process after eventual transformation. A difference in the order of magnitude between supply and demand can also prove to be problematic.

To be implemented, a synergy should have also an economic interest for each of the protagonists of an exchange of mutualisation; hence a study based on economic feasibility is necessary to be undertaken. The costs of finalizing a synergy depend directly on the necessary investments to adapt the quality of the output flow to the receiving process. Next, the distance between the synergic entities and regulations influences the cost of transport of flows. These costs and benefits directly depend on the size of the flows concerned by the synergy.

Regulations are internationally recognized as a key factor for the development of eco-industrial synergies (Lowe, 2001; Duret, 2004). They have a considerable impact on the benefit of an exchange of material flows as well as on the motivation of the involved parties. The legislator possesses an important leverage for the development of material flow exchanges.

Status influences the administrative steps to be taken by the synergic manufacturers and directly affects the value of the synergy. It is the entry point into a complex trap of interlocking regulations which will have direct consequences on the value of the synergy.

When implementing a synergy, several extremely important factors need to be taken into account: the difficulty in communicating information on the processes, the capacity of the executives to believe in this type of solution, to get involved in and moreover to collaborate amongst them.

Communication flow information goes against the company's interests and poses a problem. More widely, this confidentiality or secrecy culture of is solidly anchored in the industrial world. It is at the source of an instinctive reticence to communicate information regarding the company's production. This reticence, whether justified or not, can dissuade certain entrepreneurs from participating in an eco-industrial development approach. Furthermore, the idea of eco-industrial development remains original. This originality can prove to be a nuisance. Scepticism can lead to refusing to participate in an approach initiated in the territory.

To affirm a priori that an eco-industrial synergy is beneficial for the environment is therefore difficult. The solution put forward is in fact susceptible to resulting in the transfer of an impact from one environment to another, from a global impact to a local impact. Hence, it is essential to ensure that the implementation of a synergy does not increase the impacts of concerned entities. It implies carrying out impact measures of situations with and without synergies in order to be sure that suggested "remedy" is not "worse than the pain".

3.10 Environmental assessment of synergies (2)

The problem related to a synergy is to evaluate the environmental impact of a modified process within a territorial sub-sub-system of production. The diagnostic tools are therefore the best suited to answer this need.

The following table presents the principal diagnostic tools:

Method	
Quantitative Assessment	Life Cycle Assessment (LCA) Simplified LCA: inventory only Ecological Footprint MIPS Indicator (Material Input Per-Service Unit) Input-Output Analysis
Monetized Quantitative Assessment	Cost/Benefit Analysis Total Cost Assessment Life Cycle Costing
Qualitative Assessment	ESQCV (Afnor FDX30-310) MET Matrix (Material, Energy, Toxicity)

Table 3. Principal diagnostic tools

The Life Cycle Assessment (LCA) is a standardized rigorous analysis method of the environmental impacts of products or activities. It enables comparing products, processes and practices, quantifying their impacts on the environment by taking their whole life cycle into account. In this way, many types of impacts are quantifiable. The LCA is therefore the tool that seems more suitable for the environmental assessment.

4. Future perspectives (2)

The number of applications of eco-industrial developments is furthermore in the process of multiplying. The idea of “flow loops” spreads globally, as much in industrialized countries as in the emerging economies. The considerable environmental and economic stakes have led certain countries to take exceptional measures.

The local or national public authorities should activate the regulatory and fiscal leverage necessary in creating a favourable context for such projects. Next, through programming action, they can give the financial impulsion for a certain number of pilot projects.

Regulation mechanisms are to be imagined and implemented in order to really enable “capitalizing” the efforts approved to set up a more pragmatic management of resources consumed.

The materialization of eco-industrial development projects within territories will finally require new skills. The nature of the projects demands original profiles combining at a minimum the capacity to coordinate a network of industrial and institutional participants to certain technical skills which enable the understanding of the functioning of a production process.

4.1 Eco-industrial development: many inquiries still to be made

A certain number of methodological and computer science tools enable henceforth accompanying the implementation of eco-industrial development territorial projects. Many paths are to be explored in terms of research.

Concerning synergy search tools, improved communication between laboratories or companies having developed such software is above all necessary. The integration of geographic tools is also primordial for synergy searching.

Functional modelling is a new field ready to explore that can provide certain re-conception tools of production systems that integrate flow loops. This subject area can support a certain number of other strategies of limiting environmental impacts. The creation and diffusion of conception methods of industrial systems based on functional modelling could therefore revolutionize the evolution of production systems.

4.2 Essential connections with other approaches

The dematerialization of human activities based on product policy is another leverage put forward by industrial ecology. The principal advantages of the “product” approach are related to its facility to implement and its field of action. Its scope is defined by a precise product flow.

Eco-industrial development imposes on the participants a global and complex apprehension of all the flows which cross their processes, replaced within a system greater than the production site. This approach does however offer an original scope. The suggested consideration at long last touches all the entities’ activities of the production and consumer system, and not only the manufacturing of a few products. It opens an acceptable gap in the classical organization of a contemporary production system. Whilst the “product” approach attempts to optimize the performance of certain production cycles, eco-industrial development offers a new field of investigation in which their rethinking can take place.

The two different approaches would enable, by being combined, the construction of a truly global and local approach. Such association introduces a link between territories, but mostly enables initiating a transition of our industrial society towards different ways of organizing and operating.

5. Personal commentary

After analysing several books and articles on Industrial Ecology, and especially its application in eco-industrial parks, thus gaining some maturity on the subject, I am about to make a personal assessment.

It is an undeniable fact that the current industrial production system is not sustainable, and therefore the necessity to apply the concepts of Industrial Ecology is an obligation. Some tools implemented in industries in recent years to reduce contamination are proven as inefficient, making the option of creating eco-industrial parks the favourite to solve such a problem.

The application in eco-industrial parks should be evaluated primarily on four areas: sustainability, technical, economic and social. For the sustainability, even though there is evidence that this approach has helped to lower the pollution, it has always done in small measure. Although we also face the added problem of delocalisation of pollution, my opinion is that the implementation of eco-industrial parks has been positive for sustainable development. Technically speaking, the approach is not as attractive to me. In an eco-industrial park where companies from different sectors are gathered, issues such as trust and transfer of information between them is very difficult to achieve,

being this a serious problem in finding synergies and commonalities, fundamental objectives for a correct operation of a park like this. So much so that most of eco-industrial parks projects are not carried out for this lack of sense of community among businesses. A proper management of an eco-industrial park is therefore essential. This technical complication derives also economically. Today, the creation of eco-industrial parks is an operation that involves a large economic risk, inasmuch as there is just a minority of cases that have resulted in successful parks. The entry of a company in an eco-industrial park requires a strong initial investment and then a very high maintenance cost. The option of joining an eco-industrial park is so unattractive that local governments through laws or grants end up for legally forcing or funding their entry. For these local governments, the success that eco-industrial parks can achieve really entails many advantages not only from the point of view of economic development of the province, but also sustainable character (in global terms) and social. From my perspective, economically eco-industrial parks are a ruin. The social aspect is probably the one that benefit more from the creation of such parks. Although there are always groups of people (minority, but in no case negligible) initially opposed to eco-industrial parks stating an increase of pollution in their closer area, the reality is that their creation involves a great the number of new jobs and economic competitiveness in the province. In my opinion, the introduction of eco-industrial parks is very beneficial socially.

To conclude, I carry out an assessment of eco-industrial parks from two main perspectives: (1) the company, (2) the people and local governments. From the point of view of a company that thinks of joining an eco-industrial park, I personally would not advise their entry. After analysing several case studies, there are very few cases that have resulted in successful parks. In addition, it is always advised that in the early years only simple synergies be made, making the profit to be in a park like this small. The economic risk is too high for economic gain that could be achieved, and this gain only begin to be significant several years after their entry. Personally I would advise to wait for future approaches more efficient than eco-industrial parks. However, in front of laws or attractive subsidies by governments, the economic outlook could always end up being different. From the point of view of the population, I would advise its creation. Although it may lead to greater pollution in the vicinity of the park and a considerable expenditure of public money in grants, advantages in terms of sustainable economic development of the region and the increase in jobs is reason to advise the establishment of eco-industrial parks. After this assessment in global terms, it is necessary to note that each eco-industrial park project is different and we always will need to evaluate particularly and in detail its feasibility.

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