

# Industrial ecosystems as a social network

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## **Abstract**

With solid theoretical support from industrial ecology, an increasing number of industrial ecosystems (including eco-industrial parks and industrial symbiosis) have been created all over the world. There is no doubt that the Kalundborg symbiosis, which has steadily operates for thirty years, is our successful exemplar, although some problems also occurred in its history. However, we must realize that the Kalundborg symbiosis is not directly replicable elsewhere due to its special location and social surrounding. Indeed, designed EIPs (especially in the US in the 1990s) have often resulted in failures, and most identifiable EIPs are still at a very early stage or transformation to an industrial ecosystem. The study of critical factors of EIPs is therefore important. One question is how to use typical IE tools, like MFA and LCA in EIPs. Recently, attention has been given to indentify and promote “uncovering” industrial symbiosis from the social perspective. Since an industrial ecosystem is a regional community with waste or byproduct links, cooperation and coordination among firms plays an important role. Researchers investigate this issue from multi-disciplines knowledge, such as social network approach, complex systems science, and system engineering to simulate the development, to evaluate an industrial ecosystem, or to help transformation of a traditional industrial system toward an EIP. Along this line, we should always reflect on to what extent IES could achieve resource recovery and sustainability. Uncertainty factors and reasons of failed IES should be further examined. Metrics or standards of successful industrial systems should be further clarified. This presentation will sketch some of these newer developments.

## **Keywords**

*Industrial ecosystems, social network, complex systems science, system engineering.*

### **1. Introduction- a glance of the implementation of industrial ecosystems**

Nowadays, with the rapid economic development worldwide, the contradiction between humans and nature has become increasingly significant. Industrial Ecology (IE), which is supposed to carry us to a sustainable society, has been in our horizon for more than twenty years. One of its offsprings has been a large number of industrial ecosystems (IES) in the form of eco-industrial parks (EIPs) or industrial symbiosis (IS), where companies are interconnected via integrated use of by-product/waste material or energy, thus forming a synergistic industrial network. Up to now, some successful IES have been identified. For example the Guigang EIPs (Qinghua Zhu et al.,2007) in China, centered around a sugar factory, has generated new revenues and reduced environmental emissions and disposal costs, while simultaneously improving the quality of sugar via firstly invested in developing its own collection of downstream companies to utilize nearly all by-products of sugar production . And likewise the regional synergy developments in Kwinana and Gladstone (Dick van Beers et al.,2007) compare favorably with well-regarded international examples, for example Kalundborg (Denmark) and Rotterdam (The Netherlands).

However, the overall results so far don't live up to our expectations. In the Netherlands (Janet A.M. Eilering et al., 2004), yet only a limited number of local projects are actually designed to bring about symbiosis and utility sharing. Even iconic Kalundborg symbiosis has potential problems (James Scott Baldwin et al., 2004) brought by new evolutions of technical change, renovation or external pressure (e.g. law and public, new energy and raw materials) which may result in collapse as to whole symbiosis. The Macheon Industrial Park (MIP) (Heungsoon Kim, 2007) in South Korea unsuccessfully deals with the needs of the stakeholders because of technical, economic and social obstacles, while support from the public sector for the project seems quite inadequate. It is said there are 27 EIPs demonstration sites in China till December,2008(SEPA,2009), but to what extent they accord with sustainability criteria needs further investigations. It is not surprising that a new concept's progress is usually accompanied with challenging problems, and so it is with IES.

### **2 Exploration of the reasons of failures**

Why did many efforts of IES implementation in fact fail? We firstly examine this from a structural perspective. IES are special systems that have been created or designed and that are managed by human beings with a purpose of decoupling environmental issues from

economic growth. As a system, they own all the usual systemic attributes (such as resilience, evolution, and self-organization). What we can do only is to promote it to evolve towards a healthy functioning system with positive systemic characteristics. Donella H. Meadows (2008) said, "Once we see the relationship between structure and behavior, we begin to understand how system work, what makes them produce poor results and how to shift them into better behavior patterns". Liang Chen et al. (2010) proposed Structural Analysis Method for Industrial Ecosystems (SAMIE) according to two valuation indices, species index and rigidity and concluded that "it is the species with the highest system rigidity that dominates the stable level of whole industrial ecosystem, because the system rigidity is a synthetic indicator under the consideration of the absolute rigidity and source relative rigidity to the dominant nodal point species". In SAMIE, a set of indicators is developed to evaluate the industrial system, in order to explore the problems of structural complexity, identify the limiting factors of industrial ecosystem evolution, and strengthen the capacity of adaptation and self-organization.

Secondly, deficiencies or open questions still exist in theoretically research. Structure is always connected with a network, and IES, as complex systems, need multi-disciplinary knowledge. It seems that it is difficult to analyze and get a clear result: many of the indicators characterizing the network interactions of material and energy are variable and changing over time and space. In IE, amongst others SFA, MFA, E-IOA, and LCA are used to trace and measure the physical flows of materials and energy in various levels of the network. For example, LCA is often applied in environmental impact in IES and can be applied in different sectors at various scales, which proves it the knowledge basis and the common driving approach and methodology (see Fulvio Ardente et al., 2009). Sangwon Suh (2004) also conducted combined analysis of LCA, IOA and MFA to push forward IE theoretical research. Davis, Nikolic, and Dijkema (2009) created a method to combine LCA with agent-based modeling, to help participating actors make decisions using environmental information. However, none of these tools have been applied to the specific conceptual features of IES (Matti Melanen et al., 2007). Finally, dynamic energy and materials flows analyzes (Matthias Ruth et al., 2009), although still useful, may become challenging due to data/scale issues and many other factors. Therefore, how to further promote the application of these IE tools in the design and analysis of IES rather than staying theoretically is a new task in front of us. It is time to combine them with some social analytical tools.

Thirdly, we should put more attention on the social side or the social network of IES. The performance of IES doesn't proceed in proportion with theoretical maturity, as "Empirical accounts points to numerous non-technical reasons for the failure of industrial symbiosis efforts, including failures of communication, co-ordination, trust and reciprocity" (Heeres et al. 2004; Gibbs, 2005). All such issues are rooted in social interactions, like the operational, financial, and behavioral issues within organizations (Chertow 2000; Chertow 2003; Gibbs 2003; Mirata 2004). As a consequence, we should shift our gaze to "uncovering" symbiosis rather than planning from scratch. Further, we should put more attention to the technical models when applying the principles of IES in a social environment rather than only emphasizing the implementation issues themselves. Models of IES become politically meaningful only when they are carefully contextualized and linked to localized needs (Olli Salmi et al, 2007). Researchers investigate such aspects from different angles of social side, such as social network approach, complex systems science, and system engineering and so on. The following is a short review of this in recent years.

### **3 A short review of recent research from social analytical tools**

#### **3.1 Social network approach**

When referring to IES as a social network, cooperation or interplay among member companies for trust and cooperation are clearly key factors influencing networks and interchanges (Gibbs, 2003; Terry Tudor et al. 2006). This is especially so when significant relationship-specific investments are made (Michael Hiete et al., 2010). How to quantify this relation? Weslyne Ashton (2008) used social network analysis (SNA) to analyze the relation of connectivity among actors and the observed linkages in Barceloneta, Puerto Rico, with quantifying patterns of relationships among companies, among managers, and the correlations between both types of network ties and IS. She argued that SNA can be used by concentrating on the interactions among actors and relating observed behavior to their relationships and that it can be used to compare IS with different inter-firm relations in a defined system. Further, it could help to explore the evolution of IES for in "repeated studies [that] can be used to create time series data to examine how a system changes". Baas and Boons (2004) provided a social science analytical framework for investigating regional IES considering the system boundaries and dynamic issues, and argued that we should "centre on production of collective competitive goods for it links our work to regional economics and general processes of cluster development". They also argue to pay attention to its governance mechanism, and the learning process of the system. In the dynamic issue, they focused on institutionalization with the actors in the life cycle in a community or network (formal or informal), considering that the evolution of collective good producing organizations

and community development are predecessors of sustainable development and three stages (regional efficiency; regional learning and sustainable district) of IE initiatives evolves.

An important method to map the complexity of industrial symbiosis is stakeholder analysis . It helps to identify the involved actors as well as their interest and objectives, and especially their interactions (Mitchell et al, 1997). Heungsoon Kim (2007) investigated the actual development of an eco-industrial park (EIP) in South Korea with case study on the Macheon Industrial Park and reviews the stakeholders' understanding of EIPs with interviews. He found that it is self-interested, that the need for EIPs is quite different from its original intention and that the project unsuccessfully deals with the needs of the stakeholders because of technical, economic, and social obstacles. In addition, support from the public sector for the project seems quite inadequate. Finally, the Korean government needs to participate more actively in the project than it currently is doing. Anna Wolf et al. (2007) developed an approach for initiating development of a local industrial symbiosis network focusing on and identifying actors from local perspective. They stress the importance of a genuine insight of the system and close contact with the actors, since a simple analysis of energy and material flows is not sufficient to decide which solutions might be more advantageous. Meanwhile a flexible system boundary is needed, because it is important to look at the system "from different perspectives and at different levels to find the best uses for existing energy and material streams". However, the issue of scale and where to draw the boundary must be considered. Also, knowledge about legislation and existing subsidies and increasing awareness of integration advantages is important, as well as a strategy to profiling developing and recruiting new actors.

### **3.2 Complex systems theory**

The development of industrial systems has a strong characteristic of complex system; various types of industries and government sectors and consumers are independent and react against external environmental changes or stimuli. Ashton (2009) built a framework with industrial ecology and economic geography and complex systems theory to assess the structure, function, and evolution of a regional industrial ecosystem with comparing 12 ecological/regional economic/IES attributes in national context/ company/ regional IES levels. It highlights "the multilayered landscape of natural ecosystem functions, economic transactions, policy contexts, and social interactions in which inter-firm collaboration evolves".

Agent-based modeling or simulation is an important tool in complex systems science, through which more social science could be included in IE (Janssen, 2001) and is increasingly used in IE in recent years. Batten (2009) applied agent-based simulation to “identify those potential elements and simulate alternative future scenarios of an industrial ecosystem to seek how could they work together to achieve more eco-efficient outcomes” for it can explore various “what-if” scenarios under different eco-efficient goals. Then he argued that eco-industrial development is co-evolutionary learning systems to gain mutual economic and ecological benefits and this co-evolutionary learning process could be aided by participatory modeling for it can help build trust and reduce conflict among sharing resources. Cao et al. (2009) also used ABM to see the evolution of IES by simulating flows using the mechanism for determining the price of every product, calculating the inventory and profits of the factory (agent) and the mechanism for determining the demand. They designed some important interaction mechanisms between agents and studied the sustainability evolution with emergy theory and use “internal-flow emergy” to indicate the evolution direction of an IES. Andrews and DeVault (2009) introduced a multi-agent simulation framework for investigating the emergence of niche markets for environmentally innovative products. They investigated how consumer preferences, business strategy, and government policy interact during market development. The framework allows investigation of the effects of uncertainty and agents’ corresponding coping strategies. Instead of focusing on technological product innovation alone, their work illustrates that not only diffusion into the market but the very emergence of such a niche market is crucial for the success of any green product invention.

A related tool sometimes used in IES studies is game-theory. Lou et al (2004) developed an approach to “derive an economically and environmentally optimal status of an industrial ecosystem” using extended emergy analysis, and demonstrated the effectiveness of the approach by identifying the Nash Equilibrium for the profit payoff of member companies in a case study problem. Game theory is also used to analyze the stability of IES in some Chinese literature (Yu Hongwei et al., 2007; Shang Haiyang, 2006).

### **3.3 Systems engineering**

Systems engineering has emerged to manage complexity and risk in modern systems design ,the role of which would be in the enlargement of the range of problems it is applied and it is especially effective when bringing together stakeholders from diverse backgrounds and experts from multidisciplinary engineering and technical backgrounds to coordinate the creation of complex systems( Haskins, 2006;Haskins,2007). Haskins(2007) proposes a

systems engineering framework, iFACE, for the formation of eco-industrial parks. Sopha et al. (2010) used systems engineering to build a dynamic framework, based on multidiscipline knowledge of supply chain management, business strategy, and system theory and system dynamics.

#### **4 Discussion**

We should always reflect on to what extent industrial ecosystems can achieve resource recovery and sustainability. Seen from that perspective, quantifying the environmental and economic aspects of EIPs is still in an early period. David Gibbs et al.(2005) once said that “despite a growing interest in EIPs, there have been few empirically informed studies that seek to explore the potential contribution such EIPs may make to sustainable development”. In a similar vein, Murat Mirata (2004) argued that the IS programmes in the UK are still in their infancy. Although collaboration possibilities were identified, elaborated analyses to quantitatively evaluate the environmental and economic performances of functional synergies or projected networks are not performed as yet. Currently, only a few efforts appeared in literature. Chertow et al. (2005) quantitatively analyzed the potential cost and benefits of the Puerto Rico industrial symbiosis network ; Hodge (2007) attempted to identify opportunities where existing incentives to cooperate are greatest using LCA, GIS and decision analysis, taking the profit of stakeholders as the primary criteria. Brings Jacobsen (2008) did an in-depth quantitative analysis of the economic and environmental performances of the Kalundborg symbiosis using detailed economic and environmental data. Despite of this, a more mature systemic analytical framework to quantifying in IES is urgently needed which can also attract relevant stakeholders. Metrics or standards of successful industrial systems should be further clarified.

The initial enthusiasm regarding pilot IE projects has faded somewhat, and there has been a growing concern that EIPs are not stable in the situation where the members of the EIPs change (Lambert and Boons, 2002). From a complex systems perspective , sustainability in IES encompass the retention of creative and adaptive capacities which allows subsystems (companies, organizations) to innovate, grow, and interact in ways that enhance overall system health and function (Walker et al. 2004). Thus, we should pay attention to the stability of the IES in pursuing better environmental and economic performance. In some cases, spare capacity, reserve resource stocks and redundancy are sometimes critically important to stability, investments in what may seem counter to eco-efficiency can nonetheless be important for sustainability (Jouni Korhonen et al., 2008).

Appropriate policy interference is sometimes necessary. In 2001, the Dutch government adopted 'transition management' as the official government policy (VROM, 2001) to deal with persistent problems of non-sustainability (Derk Loorbach et al., 2009). Also, it is the initial strict environmental policies that appears to have promoted the formation of the Kalundborg symbiosis. Chertow et al (2005) argue that policy intervention can be a viable means of motivating more regular occurrences of resource exchanges among groups of firms in cases where benefits do not fall unevenly on participating organizations. However, the reason why Dutch EIPs are more successful than their US counterparts is that there is less government participation (Heeres et al., 2004). Public planning is unlikely to prove more efficient than private initiatives, and what the lessons from Kalundborg may be valuable in a flexible regulatory framework (Pierre Desrochers, 2002). Just like in ecology, it is the intermediate frequencies and intensities of disturbance that most benefits the natural ecosystems.

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