Self-organization and sustainability: The emergence of a regional industrial ecology

June 30, 2008 - Academic
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Abstract

Industrial ecology is a rapidly developing field of research and practice in which the sustainability of industrial systems is thought to be improved through closing of material and energy loops among firms. In this paper, I look at the developing practice around this concept from a self-organization perspective. A central question is the extent to which closing of material loops has to be planned and guided by governmental agencies. Based on a longitudinal case study of industrial ecology development in the Rotterdam harbor area (the Netherlands), the interplay between self-organization, external control, and vision development is analyzed.

Industrial ecology as a laboratory for self-organization

The field of Industrial Ecology developed from the notion that industrial systems can be fruitfully analyzed through the metaphor of biological ecosystems. Central in this application is the (somewhat mistaken) idea that in biological ecosystems, nothing goes to waste: each output of an animal or plant is used as food by another organism. The metaphor thus provides a normative goal for industrial systems that is thought to contribute to sustainable development: closing as much as possible the material and energy flows within the boundaries of the industrial system. In this, Industrial Ecology differs from the concept of business ecosystems (Peltoniemi, 2006), which does not share this normative dimension.

Although there were some antecedents (Erkman, 1997), the concept of Industrial Ecology was first presented by Frosch and Gallopoulos (1989). Since then, it has spread rapidly, both in academic terms (dedicated yearly conferences, two academic journals; see Cohen & Howard (2006) for a history of the institutionalization of the field) and in practice, especially at the regional level (Gibbs, 2003).

An important issue related to Industrial Ecology is the extent to which it requires external guidance/management in order to occur. Economic systems consist of complex chains of raw material extractors, producers of intermediate products, end producers, consumers, and waste treatment companies. Such economic systems self-organize to a great extent through the market mechanism within constraints set by legislation. The normative goal of Industrial ecology requires linkages that close material and energy loops to reduce ecological impact. Although such impact is partly the result of the quantity of by-products that are treated as waste, to a great extent it is their quality, in terms of toxicity or their contribution to specific problems (such as CO$_2$ contributing to global warming). Thus, for a producer to take the waste product from another company and make it into a marketable product is not necessarily contributing to this goal. In order to process the waste into a product, additional material and energy is needed, which increases ecological impact. Also, the new product may, when
it is discarded, pose more serious ecological problems than the original waste. Thus, linkages that are preferred under the definition of Industrial Ecology demand that additional criteria are met, such as not using a substance like chlorine. A major question is if this can be achieved through market coordination. Many proponents have argued that industrial ecology requires a vision on what linkages contribute to reducing ecological impact, and some form of regulation, as this quality is not taken into account in the prices on firm-to-firm markets (Graedel & Allenby, 1995).

In this paper, I address this issue from a self-organization perspective. More specifically, I will develop the argument that Industrial Ecology can emerge in an interaction between external control and self-organization, resulting in a multi-level system as described by Simon (1962). Industrial Ecology is in that sense a laboratory in which ideas about self-organization can be tested.

I first present the concept of self-organization. I then analyze a case study of an emerging regional industrial ecology in the Rotterdam harbour area (the Netherlands). In the concluding section, I build on the analysis of this case to show the relevance of the field of industrial ecology for studying complex systems.

**Self-organization and governance**

I will first present my conceptualization of self-organization, using it as a perspective to analyze complex systems. Then, I discuss the concept of governance, to develop a nuanced view on the role governments play in society. Based on this, a framework for analysis is presented.

**Self-organization in complex systems**

Self-organization is defined by De Wolf and Holvoet (2004) as “a dynamical and adaptive process where systems acquire and maintain structure themselves, without external control.” This structure, or organization, emerges as a result of local interactions between system elements. Organization implies increase in order as well as a function or goal, to which the order contributes (Heylighen, 2002).

Control of the organization is typically distributed over the whole of the system. System elements contribute to the resulting pattern of organization. The absence of external control does not exclude external inputs or selection pressures on the system (Correia, 2006); it requires that these external stimuli do not specify the order that results from self-organization. Self-organization is usually triggered by a change in the external situation, the **boundary conditions** of the system (Heylighen, 2002). Although there is a limited set of patterns into which it can organize, it is often impossible to predict which pattern will occur.

Heylighen (2002) discusses organization as closure of the system from its environment, producing a stable identity. This stability is dynamic, in the sense that it is produced through a set of interlocking positive and negative feedback loops, leading to non linear dynamics.

Self-organization necessarily produces a pattern that is adapted to the system environment; otherwise it would not occur. When boundary conditions change, the system may disorganize. A resilient system has the capacity to adapt to changing circumstances, which requires the ability to produce variety in activities, and a selection procedure for selecting from that variety the action that increases fit to new boundary conditions. “Whereas self-organization allows a system to develop autonomously, natural selection is responsible for its adaptation to a variable environment” (Heylighen, 2002: 4).

The adaptive process also explains why complex systems often have a nested structure. A collection of many
elements has a small probability of self-organizing directly to form a viable entity. If elements first self-organize into smaller viable sub-systems, or stable assemblies, then these can self-organize to form a more complex system (Simon, 1962). This evolutionary perspective on complex systems is useful because it states the processes through which system elements can self-organize to form stable assemblies, which can then connect in response to their selection environment to form nested systems.

Thus, a self-organizing system persists partly because of its inner dynamics which produce order, and partly as adaptation to the selection environment in which they emerge.

**Self-organization as perspective**

Gershenson and Heylighen (2003) argue that self-organization is a perspective rather than a quality of certain systems. When the increase of order that indicates self-organization is measured in terms of statistical entropy (the degree of uncertainty about the state of a system), it can be proven that whether a system is self-organizing or self-disorganizing depends on the system boundary drawn by the observer. Simply stated, uncertainty about the state of a system requires a definition of what variable is used to define that state, and depending on that choice, entropy may be seen to decrease or increase. This becomes only more apparent when we consider that self-organization is more than order; it is a structure that has a function or purpose. Again, qualifying a system as being organized depends on the function or goal that is observed, which hinges on the observer.

Although the mathematical proof is new, the insight is not. Several authors stress the implications of the boundary judgements of analysts in studying systems (Beer, 1966; Flood, 1999; Cilliers, 2005). Thus, as “any system can be said to be self organizing” (Gershenson & Heylighen, 2003), it becomes important to identify in what cases it is a fruitful perspective to take. It is not useful to analyze a person drinking a glass of water from the perspective of self-organization of the individual cells of her body; in that case, an intentional explanation (Elster, 1983) is more useful.

The problem of Industrial Ecology outlined above lends itself well to a self-organization perspective. Exactly because the question is about the necessity of external control in bringing about linkages between autonomous economic actors, it can provide fruitful insights.

**Governance**

The discussion on how to promote Industrial Ecology is often framed in terms of the dichotomy government versus market (Desrochers, 2002), leading to questions about the necessity and specific role of government intervention in regional economic systems. This distinction can easily be stated in terms of self-organization. Markets (in their arch-typical neo-classical conception) can be viewed as an example of self-organization in social systems (Heylighen, 2002). Government, as the external agent setting limits for the activities of citizens, can be seen as the external control that is absent in self-organization. However, the public administration literature suggests that this dichotomy is too simple.

Public administration science developed as the analysis of this unique role of public agencies in society. In the last decades, this position has been qualified based on the empirical analysis of processes of policy making, as well as an evolution in the way in which the boundary around public services is drawn. Although governmental agencies have unique characteristics, the idea of top-down control over activities of citizens is naïve. Instead, governments operate in networks in which other actors have the ability to influence goal attainment of public policies, or change their content. These insights have been fed back into governmental policy making, resulting in
in new ways of organizing governmental activities. As a result, a diverse set of governance patterns is now recognized (Stoker, 1998).

The concept of governance brings government closer to the perspective of self-organization. As Heylighen (2002: 9) notes, “Any explanation for organization that relies on some separate control, plan or blueprint must also explain where that control comes from, otherwise it is not really an explanation. The only way to avoid falling into the trap of an infinite regress is to uncover a mechanism of self-organization at some level.”

Elinor Ostrom has developed a distinct research program uncovering this process of emergent government. Her work focusses on the management of common pool resources, classic situations of the Tragedy of the Commons (Hardin, 1968). She finds that, contrary to game theoretical predictions, actors in real life situations are sometimes able to coordinate their activities in such a way as to prevent the resource from over-exploitation. This can involve communication, but in cases extends to monitoring and sanctioning schemes. Effectively, actors using the resource develop their own government, hence her label of self-governance (Ostrom et al., 1992).

While her cases are an example of emergent governance in absence of governmental agencies, there are also examples of self-governance in regulated environments. During the 1980s, a distinct approach developed in several European countries in which government abstained from legislation in exchange for the commitment of organized sectors to develop their own regulation. These cases of private interest government (Cawson, 1985; Boons et al., 2000) build on self-organizing initiatives of societal actors, who are induced by a government which provides specific incentives, and thus creates a selection environment in which self organization can thrive. Thus, governments can set decisive boundary conditions, or in evolutionary terms, provide selection pressure that induces self-organization. This is different from external control, as government does not specify the order and goal of the system, as it does in regulation.

Based on these insights, we can draw up the following categories of relationship between self-organization and external control by government:

1. Actors can self-organize through interaction (self-organization without governmental involvement);

2. Actors can self-organize and develop monitoring and sanctioning rules (self- organization leading to self-governance);

3. Actors can self-organize under pressure of governmental legislation (self-organization with government providing selection pressure);


Summary of the analytical framework

The normative goal of regional Industrial Ecology provides an explicit boundary judgement in my analysis. Thus, (self-)organization as analyzed in this paper consists of increased order consisting of linkages between economic actors in a geographically bounded area, with the goal of reducing ecological impact of the system as
a whole. This results in stable assemblies, of which the scope and goals of the system, membership, and the ability to maintain a boundary around the system can be described. The process through which these stable assemblies develop will be analyzed as an adaptive process to the environment. This process can be characterized according to the four categories presented above. Together, this will provide insight into occurring relationships of self-organization and external control by government.

**An emerging industrial ecology in the Rotterdam harbour**

The Rotterdam Harbour and Industry Complex (HIC) is one of the largest harbours in the world. It functions as a transit-point to Germany with many transport and storage facilities for energy-resources such as coal and crude oil, as well as other goods, which are being transported in-land by small ships, trains and trucks. Value-adding activities also take place, mainly based on crude oil (four refineries and many (petro-) chemical facilities).

Industrial activities in this area have for a long time been subject to environmental regulation, mostly in terms of a permitting framework regulating the emissions from individual production plants. From 1990 onwards, new initiatives were taken. This case is based on longitudinal research that was conducted during the period 1991-2004. Data were collected through document analysis, interviews, and at various stages of development, active participation. Data were brought together in a rich descriptive text which has been presented elsewhere (Baas & Boons, 2007).

1991-1994: An industry association mobilizes its members

Since the late 1960s, some seventy companies together formed an industry association, EBB, devoted to interest representation and organizing training courses for its members. Environmental issues were sometimes addressed by EBB, but they did not form a core concern. However, in 1989 the Dutch Environmental Ministry developed an approach of ‘internalization’ of environmental management. The idea was that firms should develop their own responsibility for environmental issues. One of the suggestions was that companies should implement their own environmental management system (EMS).

During the period 1991-1992, EBB took the initiative to promote EMS among its members, and facilitate knowledge exchange and training workshops. In separate meeting groups for six industry branches, companies shared information and experiences on the implementation of environmental management systems. In a coordinating group, experiences were exchanged among these groups. This structure was evaluated positively by the participating environmental coordinators of the firms.

In 1992, EBB asked Rotterdam University (EUR) and Delft University (TUD) to organise a workshop to discuss possibilities to build upon these positive collaborative experiences. Both universities suggested the then new concept of industrial ecology as a possible focal point for further activities. The core idea of developing energy and material linkages between firms to improve environmental performance was accepted by participants. Governmental agencies, happy with this signal of success of the internalization approach, supported this initiative through funding and by withholding to some extent further regulations to allow for experimentation.

**Analysis**

The actors in this phase all have their specific history, but at the beginning of the research period they are existing stable assemblies. Firms are collections of interacting individuals, and interest associations are a classic
example of a difficult to maintain stable assembly of firms (Streeck & Schmitter, 1985). The initial activities in this phase can be seen as successful attempts of existing assemblies to respond to selection pressures from the national government (category 3). The experience of these activities leads to further activities that go beyond this pressure (category 1). This leads to the inclusion of researchers of two universities into the system.

1994-1997: The INES-program

EBB coined its initiative the Industrial EcoSystem (INES) program, which started in 1994 with a workshop for environmental managers and local plant managers of member companies. The workshop introduced the concept of Industrial Ecology to firms. Later that year, environmental coordinators formulated the INES Declaration, a vision document expressing the willingness to develop from environmental management systems towards an approach that considers the life cycle of products as well as the need to look for possible exchanges within the region.

Following the workshop, the resources, products and waste streams of companies were assessed in order to define possible projects. In all, 15 projects were defined. Utility sharing was found to be a first possibility for developing linkages between firms. Three projects were selected for further development, based on their economic potential, environmental relevance, and company participation potential: joint systems for compressed air, waste water circulation, and a collective bio-sludge reduction system.

These projects did not lead to immediate results, but through exploration of these linkages, further awareness was raised for the Industrial Ecology perspective. One identified sub-project was commercialized. This concerned the flaring of natural gas that occurred as a by-product of oil drilling in the Rotterdam harbour. Through the INES-program, a contract for utilizing this natural gas was made with another company within one week.

Analysis

This phase of the development of the regional industrial ecology marks the shift from a governmentally induced dissemination of EMS to a self-organizing process in which representatives of a number of EBB-members develop the idea of linking their production processes. It must be stressed that this idea is radically different from what most companies, and indeed most legislation, strive for: the reduction of ecological impact within the bounds of an individual production facility. Thus, the space given by governmental agencies for experimentation was a necessary condition. At the same time, this space was given conditionally, in the sense that governmental agencies voiced their expectations that the experiments should result in reduction of emissions that were deemed relevant in their policy plans. In that sense, government influenced the selection process of projects (category 3).

Another major shift concerned the up till then valued structure of sectorally based working groups. In exploring linkages between firms, this was found to be not effective any more. Over time, this structure was replaced by emerging (and periodically dissolving) project groups in which specific linkages were explored. Thus, the organizational pattern within the system changed. Another indication of increased organization is the development of the vision document. At this time, it served as a commitment of company representatives to exploring linkages to reduce ecological impact.

The role of the EBB in this project can be best described as that of a broker and facilitator for communication. The willingness of firms and their knowledge provided the basis for formulating projects, and EBB monitored
projects from a distance, in line with its role of securing funding for INES (category 2).

1999-2004: INES Mainport and inclusion into Sustainable Rijnmond

After a period of relative silence, a follow up program, INES Mainport, was developed by the EBB. This program connected to the framework of the ROM-Rijnmond Covenant, which was signed by national and regional governments, as well as industry, to develop and implement a vision for 2010 on physical planning and environmental issues in the Rijnmond region in which the HIC is situated. In this program, the feasibility studies from INES were taken as a starting point.

In addition, a strategic platform was initiated in which EBB and managing representatives from major companies in the area were joined by representatives of the National Industry Association, the National Ministries of Economic Affairs (EZ), and Environment & Spatial Planning (VROM), regional and local authorities, the regional environmental organization MFZH) and Erasmus University Rotterdam. A major reason for the EBB (which by then had changed its name into Deltalinqs) to include representatives from national governmental agencies was to give them insight into the results of the experiments that were conducted. A second reason was that the regulations for which these agencies are responsible sometimes provided barriers to linking material and energy streams between firms.

Initially, the platform functioned mainly as a passive sounding board, but after an evaluation, it decided to write a sustainability vision for the region. Underneath this strategic process, project ideas generated in earlier years were further developed and in some instances implemented, such as a joint system for compressed air.

Environmental managers were unaware that the use of compressed air systems by companies in Rotterdam harbour had significant environmental consequences, and that the energy requirement for compressed air represented 7% to 15% of the total electricity use for those companies. After the identification of the opportunities in Phase I, a first attempt was made by a supplier and four companies, but this did not materialise due to lack of sufficient scale. Another compressed air supplier learned about this sub-project and started a new project building on the trust required for the exchange of knowledge with four other firms and by reducing the scale of the investment needed for the installation. Preliminary results showed 20% costs and energy savings, and CO2 saving of 4150 tons each year. In 2002, the delivery was extended to seven plants in total, and again increased to fourteen companies in 2003. Other successful projects included the coupling of rest industrial heat of Shell Pernis (and later of Esso/Exxon) to the Rotterdam city district heating system, and the reduction of waste water through a cascading approach. A large number of other ideas were explored as well, but did not yet materialize.

On 1 January 2003 the Industrial Ecology initiative became part of an even larger framework: Sustainable Rijnmond, a merger of three large initiatives in the Rijnmond region. Before the merger, the Industrial Ecology system developed separate from Energy 2010, an initiative which focussed on sustainable energy provision in the region, and Sustainable Rijnmond, a program which implemented a transition approach to sustainability. Before merging, there were only a few individuals which were part of more than one of these initiatives, but the Ministry of Economic Affairs took the initiative to combine them as it saw possibilities for synergy. In 2003, a 45 page vision document was presented, based on the concept of transitions, a then emerging theme on the national environmental policy agenda. The vision was summarized in the following statement:

A world striving towards lowering carbon-intensity of the economy provides an attractive perspective for industrial centres that are able to process carbon related streams in a highly efficient, clean, and sustainable way. Rotterdam harbour is ideally suited to be such a centre. It has
the ambition to be in 2020 the preferred location in Europe for the haulage and processing of carbon-related fuels and raw materials. It can only make this ambition a reality by being a trendsetter in economically feasible reductions of CO2-emissions related to these activities, and by acting as a field of experimentation for innovations on themes such as clean fossil fuels, clean energy carriers such as hydrogen, syngas, heat, electricity and biomass as a gateway to a carbon-extensive future.

The program runs for the period 2003-2010 and is facilitated by a small staff bureau of a strategic platform that involves representatives of the Ministries of Economics and Environment, the province of Zuid-Holland, the Development Board of Rotterdam, the Port Authority, the industry association Deltalinqs, a plant manager, the Sustainable Mobility Programme manager, representatives of the Universities of Delft and Rotterdam, and the representative of an environmental advocacy organization.

Analysis

During this period, the system first of all shows increasing internal organization, as more linkages between firms are actually established. In a way, the system boundary is redrawn through the development of the rest heat system, providing a linkage to the city of Rotterdam. Also, the new name of the EBB, Deltalinqs, hints at the identity shaping nature of the industrial ecology initiatives of its members (category 1).

Operating under the flag of the ROM Rijnmond Covenant provides a linkage of the total system to a previously established stable assembly. This results in the involvement of representatives of national governmental agencies in the strategic platform, which serves partially as a response to the selection pressure of the threat of regulation, but also as a way of influencing these agencies to give further space to the self-organizing capacity of the industrial ecology that is emerging (category 3).

The inclusion of the Industrial Ecology initiative in Sustainable Rijnmond is a governmentally designed combination (category 4). It marks the end of an evolutionary trajectory in which self-organization dominates. However, as the Industrial Ecology system has been experienced as a self sustaining initiative, generating more linkages, actors are motivated to maintain the boundary of what is now a sub-system, and use the linkage to other initiatives as potential for further activities within that boundary.

Conclusions and practical implications

The case study provides insight into the interaction of self-organization and external control by government shaping the evolution of industrial ecology. It is clear that organization within the system increases, both in terms of linkages that reduce ecological impact, as well as through coordination activities aiming at developing a vision which provides the basis on which further linkages can be developed.
Rather than being exclusively a process of self-organization or external control, organization within the collection of firms increases in an interplay between self-organization and (withholding) external control. Generally, the system self-organizes under selection pressures from government, combined with postponing or withholding external control. Importantly, the case shows that the development of a vision, often deemed necessary for industrial ecology, is possible within that context and does not require external control in the traditional sense. However, the case also indicates that without government providing selection pressure, self-organization would probably not have occurred.

The framework developed in this paper provides a tool for analyzing governance as the interplay between self-organization of societal actors and interventions from governmental agencies. The framework is new in the sense that it focusses on the process of self-organization and adaptation in response to selection pressures. This perspective will be useful in other instances of policy analysis.

References


