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Revisiting the relationship between Sustainable Development and Industrial Ecology

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Abstract
The concept of industrial ecology (IE) follows the ideal of environmental balanced industrial complexes and perceives an industrial system not apart from its surrounding systems but in interaction with them. The methodological consequence of this assertion is to investigate the flows of materials and energy in industrial cycles and consumer activities, the effects of these flows on the environment and how they are influenced by economic, political, regulatory and social factors, in order to evaluate and, finally, to optimize these flows.
Industrial ecology has been developed by engineers and thus the claim for scientific objectivity is strong. Considering political and social factors implies, however, to reflect about changes of operations *and* attitudes. Therefore one might ask about a methodological connection of engineering skills with political and ethical reasoning. This paper has the objective to argue for such a connection in some domains of industrial ecology. The presumption for the value of this endeavour is that IE has a normative potential for the design of a possible sustainable world, which stands next to its advanced technological features. In order to argue for a methodological connection between analytical and argumentative skills, section two and three of this paper will examine sustainable development as a framework for IE and discuss the theoretical basis of the IE concept. Section four and five analyse industrial metabolism as a core principle of IE and discuss IE tools and applications. The sixth section associates empirical and normative elements in IE with help of two domains and three different application levels and exemplifies the possibility for interdisciplinary cooperation within the field. The goal of this association is to make clear that the question today is no longer: Is IE is an objective science or not, but rather: how to assemble methods from the "two cultures" in the most beneficial manner?

Keywords: *Sustainable development characteristics, industrial ecology concept, elements, tools, domains of actions, interdisciplinary cooperation.*

1 Introduction
Since the mid of the 20th century increasing damages of ecosystems, physical sufferings, public discontent with traditional industrial and social processes and the awareness, that human actions can cause a global disaster have created an obligation to change attitudes as well as actions towards the environment. The inherent task of this obligation - finding an appropriate balance between the development of industrial cultures and the conditions of natural surroundings - led to many approaches that aim to improve industrial systems in technological

civilizations. Sustainable development (SD) obtains a major position within these efforts. SD provides the conceptual framework for industrial ecology (IE). IE investigates connections between humans and nature, placing human activity in the larger context of the biophysical environment from which we obtain resources and into which we put our wastes (Powers and Chertow, 1997, 24). The overall goal of IE is the ability to keep up, or even increase the production of artefacts and at the same time reducing the material and energy resources being used in the production.

2 Sustainable development

The notion "sustainable development" was introduced through the Brundtland-report, which defines it as:

> "…development that meets the needs of the present without compromising the ability of further generations to meet their own needs." (Our Common Future, 1987, 46)

In the following decades SD became not only a topic of a broad academic interest but a cliché as well, as Lélé points out:

> " Sustainable development is a ´metafix` that will unite everybody from the profit-minded industrialist and risk-minimizing farmer to the equity-seeking social worker, the pollution-concerned or wild-loving First Worlder, the growth-maximizing policy maker, the goal-oriented bureaucrat, and therefore, the vote counting politician."(Lélé, 1991, 613)

Dealing with an indefinite notion such as SD, it seems appropriate to recapitulate some of its characteristics. SD connotes "development" mainly with the principle to guarantee human needs (not explicitly the needs of other species). It demands intra- and intergenerational responsibility for other human beings i.e. equity among living and the consideration of the needs of future generations. "Sustainable" can be described as the ability to maintain a certain situation in a durable way.
A model of SD explicates, that economical, social and ecological development should be realized as connected and dependent on each other.

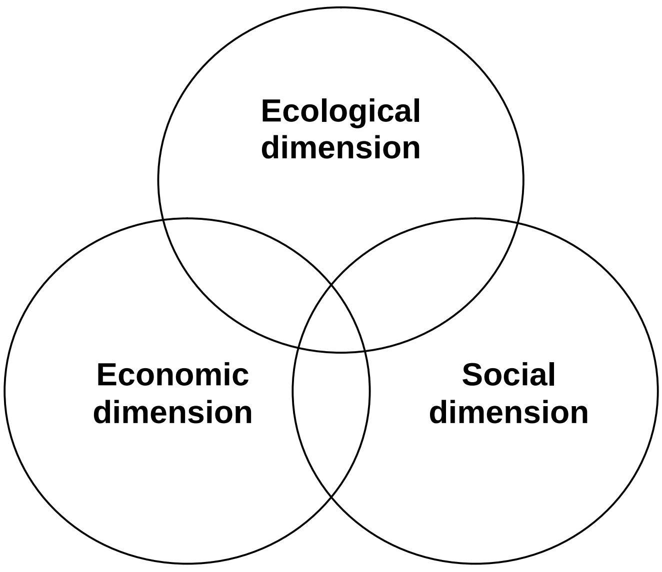

Figure 1: Dimensions of Sustainable Development

Besides requiring economic sustainability, SD includes two normative claims related to the social and ecological dimension (Tidsdell 1991):

1. The guarantee of social values
2. The guarantee of durability.

Ad 1. Humans have expectations towards their surroundings and one of these is the anticipation to be satisfied. We do not only expect the world as purposeful but as willing to reply to our wishes. Otherwise we would have no ambition to live as humans. Self-preservation is the foremost aim of a living being - but for a cultural being (zoon politikon) ontology ("to live") is inherently tied with ethics ("how to live"). This relates for example to values such as fairness, justice, equal opportunities aso. SD has realized that neglecting those values may lead to social distress which can cause as worse ecological consequences as an unlimited economic growth. The intention is therefore to co-ordinate the livability of ecological systems with societies´ values on one hand and to establish a balance between different national economies on the other hand.

Ad 2. The fact humans take an active part in transforming the environment and are able to design adequate living spaces is connected in SD with the fact that nature provides the means for design.

The natural surroundings offer a source of essential materials for human well being. Therefore, SD asserts that the sustainability and the flourishing of humans is connected with the sustainability of other living beings and of the ecosphere. This interdependency is not merely perceived as instrumental but rather seen as a combination of material and non-material values. It is reflected in the claim of guaranteed durability which refers to the preservation of the natural capacity or the total natural capital stock at or above the current level.

> *"Natural capital stock… is equivalent to the stock of all environmental and natural resource assets from the oil in the ground to the quality of the soil and groundwater, from the stock of fish in the oceans to the capacity of the globe to recycle and absorb carbon and other waste materials." (Majer 1995,12)*

However, Majer understands the natural capital stock not only in quantitative terms but he also indicates the durability of different functions within the natural environment. Disturbing these functions would mean to spoil human activity in general and economic activity in particular. Majer is referring to functions such as:

1. To supply: regenerative and non regenerative resources that nature provide as input for production purposes. The use and reduction of renewable resources may not overstep their rate of natural regenerabilty connected with the maxim to support the flourishing endurance of ecosystems.
2. To bear: assimilation of the outputs from industrial processes in form of waste, emissions, toxic substances, radiation danger ans.
3. to survive: uphold of dynamically substance-flow balance within the global natural "oikos"(Greek: household) e.g. water- and carbon flows, climate stability
4. To recreate: grant landscapes and bioregions for well-being, health, relaxation and aesthetic experiences.

Many SD concepts recognize the necessity to correlate the three dimensions. The epistemological and practical challenge for researchers is, however, to assemble methods from the natural sciences and engineering with methods from humanities and social sciences effectively into integrative approaches and strategies to realize SD.

3 Industrial ecology

The former section characterized roughly the framework of SD in which industrial ecology (IE) is operating. IE has rapidly gained ground, after being introduced through a series of articles in 1992 by the US National Academy of Engineers. It grew out of the earlier developed conceptualization of the 'industrial metabolism' that analyses the environmental impact of the flows of material and energy in industrial societies. The field's growing reputation is partly understandable by its ability to concretize industrial solutions to sustainable development (Opoku and Keitsch, 2006, 141).

Gradually, IE also got the reputation of being a multidisciplinary field bridging the gap between the natural sciences, social sciences and the humanities. The literature on this issue can be categorized in two broad branches: A positivistic scientific branch and a normative, perspective, design branch (Ehrenfeld, 1998, 2000). Ehrenfeld´s article: "Industrial Ecology: Paradigm Shift or Normal Science?" in *American Behavioral Scientist* (Ehrenfeld, 2000), stimulated a valuable debate on IE. This debate is on whether IE is a mere framework to analyze materials and energy flows of industrial systems or whether the concept provides not only measurements, tools and instruments but also includes new normative themes or new social paradigms for a possibly sustainable world and sustainable culture. Ehrenfeld contrasts IE´s capability as a descriptive "normal science" of sustainability with its paradigmatic, normative and prescriptive "culture shaping" potential.

As the concept has matured, the debate about IE´s features moved from an ontological to an epistemological level. Today we might ask: How to proceed from IE as a science of sustainability to IE as a science? As a science, IE would be able, to a certain degree, to analyze the socio-political structure of its applications.

As a field of study IE includes the investigation of flows of materials and energy in industrial and consumer activities, the effects of these flows on the environment and the influences of economic, political, regulatory and social factors on the flow, use and transformation of resources. Thereby it follows the ideal of "environmental balanced industrial complexes" and employs methodically maxims such as evaluating the impact and resource use in different phases as extraction, production, consumption, disposal, recycling in order to integrate them in the analysis. Industrial Ecologists apply systems science to industrial systems, defining their boundaries and seeking to optimize them via the following strategies (Lowe, 2001, 3):

- Balance inputs and outputs to natural ecosystem capacities
- Close loops through reuse and recycling.
- Maximize efficiency of materials and energy use.
- Minimize waste generation.
- Define all wastes as potential products and seek markets for them.
- Do more with less (technically called dematerialization).
- Align policy with a long-term perspective of industrial system evolution.

4 The industrial metabolism

The industrial metabolism is the core principle of IE. It means basically to match up production processes to ecological processes. The industrial metabolism is build on the idea that human history cannot provide descriptions for sustainable ways of living as it is a succession of states generally built on the last one, but that nature can lead to such metaphors (e.g. in Rorty,1994). The premise for this idea is the assumption that ecological systems and their functional courses have already proved their sufficiency in case of sustainability. For that reason they are appropriate models and reference systems for sustainable industrial actions as e.g. Fet (1997, 45) points out:

> *"Natural systems are those who came into being by natural processes. These exhibit a high degree of order and equilibrium; the material flows are cyclic. Man-made systems are those developed by human beings. All man-made systems produce entropy (the creation of more orderly states from less orderly states) and consume energy. All man-made systems are embedded into the natural world and important interfaces exist between man-made systems and natural systems …industrial ecology involves designing industrial infrastructures as if they were series of interlocking man-made ecosystems interfacing with the natural global ecosystem. Industrial ecology takes the pattern of the natural environment as a model for solving environmental problems".*

A practical principle of the ecological metaphor is the "industrial metabolism" (Ayres and Simonis, 1994, 5), which emphasizes the connection between micro, meso and macro levels of industrial processes. "Metabolism" comes from Greek "metabole" and means "modification". In the ecological dimension it relates to the assimilation processes of living organisms. It covers the complete system and the interaction of all biological functions that serve the endurable conservation of the organism. The motions of single metabolic sequences occur via principles of autopoetic[1] organization and via cybernetic control (Greek "kybernesis – steering, navigation"). Autopoesis means that a system or organism keeps up its existence by using energy and resources from the environment and produces waste. While in biology the single living organism appears as the object of investigation the single industrial organization is the analogy in IE. A superordinated system of steering is e.g. the market competition with its mechanisms of supply and demand.
The industrial metabolism applied to single industrial processes includes among others to strive for the best circulation of material flows in the economical system. This implicates likewise ecological responsibility within the companies that matters all production activities even the pre- and post-production processes – as it were from cradle to grave. Structural improvement relates to the establishment of metabolistic producer- consumer- waste-manager networks. The possibilities for the waste-managers are almost neglected in conventional industrial systems. Yet, for industrial companies the chance to complete the chain is available by focusing company purposes and goals consequently towards an economical flow that connects functions of recycling and decomposition of different forms of waste. Regarding the "translation" of ecological principles for industrial systems an adequate process methodology for the single branches is, however, still lacking in industrial ecology and the routines in the particular companies are rather arbitrary.
In IE, the insight that industrial systems should observe nature and learn from the structure and dynamics of natural ecosystems leads to the application of systems science to industrial systems. The conceptual idea is to transfer the principles of the natural ecological system into an industrial context. In the industrial context, as Frosh formulates it, we then may think of this as use of products and waste products (Gallopoulos, 2006, 11).

> *"…metabolism… does not fully describe the analogue required for the ultimate improvement of the industrial system. Our preferred approach is to view the industrial network as an industrial ecosystem, analogous in its function to a community of biological organisms and their environment. Some of the organisms use sunlight, water, and minerals to grow, while others consume the first, alive or dead, along with minerals and gases, and produce wastes of their own. These wastes are in turn food for other organisms, … Similarly, in the industrial ecosystem, each process and network of processes must be viewed as a dependent and interrelated part of a larger whole."*

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[1] Greek „αυτο – auto-self" and „ποιεσις – poiesis – to do, to create is a procedure that the organism directs for the purpose of self-preservation, reference and development. It implicates co evolutional growth with other forms of life and surroundings where the organism participates. The organisms organise their environment autopoetical means: although they are in an exchange with their environments they follow their own autonomous guidelines. See Maturana and Varela 1973.

From an IE perspective, unit processes and industries are regarded as interacting systems rather than isolated components. The dynamic, systems-based origin lays also descriptions of the system boundaries and asks for the optimization of the particular system. Applying systems science and the principle of industrial metabolism, IE provides as a fundament for designing and operating industrial systems as living systems interdependent with natural systems.

The most important principles for IE systems design are:

• Industry operates within the limits of global, regional, and local carrying capacity, maintaining a cautious margin for error

• Industry should reflect ecological and biological principles in the design and operation of its activities, from the shop floor to the executive suite

• Materials have to be cycled through the economy to an optimal degree, approaching a closed-loop system

• Use of renewable materials in balance with their production and non-renewable materials are important

• Efficiency and productivity are to bring in dynamic balance with resiliency, ensuring continued natural capacity

• Societies may attempt the transition to this state while maintaining the economical viability of systems for extraction, production, distribution, transportation, and services. The transition supports development of more viable communities, with improved quality of life around the planet is desirable.

5 Industrial ecology tools and practice

IE is applied on three levels: micro meso and macro level. On the micro and meso level it aims at the improvement of present types of industry and technology. IE indicates here alternatives and seeks to order and optimize operations in specific sectors with help of tools such as material flow analysis, life cycle assessment, product design, product use, cleaner production, aso. On the macro level IE is operating on a network level with tools such as by-product exchange and eco-industrial network design.

IE planning usually includes the following applications:

- An inventory of the area's ecological conditions and constraints (ecological footprint);
- A survey of the flows of materials and energy in human systems (MFA, LCA);
- Means of assessing alternative strategies (LCA, DFE, dynamic input-output modeling).
- Methods for improving industrial, commercial and household use of energy (energy efficiency) and materials (pollution prevention and recycling)
- Integration of these IE methods with urban planning, economic and community development, education, and citizen input (BPX, EIN).

Material and Substance Flow Analysis (MFA)

Understanding the structure and environmental effects of industrial systems requires knowledge of their anatomy and physiology. Materials flow studies reveal structure, and webs of economic and material relationships among actors, in the industrial system as they map the flow of natural resources into processing and manufacturing industries and the fate of products and wastes exiting them. The object for study can be the mass of individual chemical elements, compounds, or entire classes of materials. The framework for such studies includes individual facilities, whole industrial sectors, and geographic regions (Allenby, 1995, 111 ff).

Life Cycle Assessment: (LCA)
A number of different terms are used to describe these processes. Recently two terms have come to largely replace life cycle analysis: Life Cycle Inventory (LCI) and Life Cycle Assessment (LCA, since these refer to the different stages of the process. LCA has been defined as a way to "evaluate the environmental effects associated with any given industrial activity from the initial gathering of raw materials from the earth until the point at which all residuals are returned to the earth." (Wernick and Ausubel, 1997) The Life Cycle Initiative divides the LCA process according to the ISO series 14040 into four distinct components:

1. Goal and Scope Definition, the product(s) or service(s) to be assessed are defined, a functional basis for comparison is chosen and the required level of detail is defined;
2. Inventory Analysis of extractions and emissions, the energy and raw materials used, and emissions to the atmosphere, water and land, are quantified for each process, then combined in the process flow chart and related to the functional basis;
3. Impact Assessment, the effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance;
4. Interpretation, the results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.

Design for Environment (DFE)
DFE has evolved out of concurrent engineering and product life-cycle analysis (LCA). DFE developers apply this approach to all potential environmental implications of a product or process being designed—energy and materials used; manufacture and packaging; transportation; consumer use, reuse or recycling; and disposal. DFE tools enable consideration of these implications at every step of the production process from chemical design, process engineering, procurement practices, and end-product specification to post-use disposal. DFE also enables designers to consider traditional design issues of cost, quality, manufacturing process, and efficiency as part of the same decision system. (Allenby, 1999, 71).

By-Product Exchange (BPX) and Eco-industrial Networks (EIN)
On the macro level the example of industrial ecology in practice (Ehrenfeld 1997) is the design of eco-parks. An eco-park is an industrial ecosystem consisting of different actors partly located in the same area, which attempt to achieve better eco-economical performances by cooperation e.g. via cascading, waste exchange, by-product exchange, transport, employee facilities etc. The most successful example is Kalundborg (Ehrenfeld and Gertler 1997), where companies exchange energy, by-products and wastes, even if it was not planned as eco-park when it emerged some decades ago. BPX and EIN include the following steps:

- Characterize the flows of energy, water and materials in the target region (IE Systems analysis).
- Highlight and map existing exchanges of by-products.
- Identify potential barriers (Risk analysis).
- Enable business transactions for by-product utilization (Cascading of material, energy and water).
- Provide training, tools and support to the managers and employers (Maintenance).

6 Interdisciplinary cooperation in industrial ecology

Agreeing on sustainable development as a concern for the future implies to connect *instrumental discourses* (what is possible to achieve and how) with *normative discourses* (what is worth to achieve and why). The first argument for this connection in industrial ecology as a sub-field of sus-

tainble development can be illustrated by sketching out to two domains: The first domain “ecological modernization” (Prittwitz, 1988, 114) attempts to work out operations for environmental friendly production through technical innovations. It does not only focus on the invention and the application of entirely new products or procedures but indicates and definitely requires the enforcement of such alternatives, that can be done with current technological prospects but have not come into practice yet. The objectives concentrate on the micro and meso level and relate to engineering methods and practice (e.g. Life Cycle Assessment, Material Flow Analysis, Design for Environment, etc.).
The second domain “structural ecologisation” supplements “ecological modernization” and relates to human attitudes and decision-making. It includes aspects of sanitation, conservation and formation and acts upon a macro level within fields like ethics, economy, politics and education, employing methods from e.g. social sciences, humanities and management sciences. It bases on the idea to modify perceptions and interpretations of the environment in general.

Ecological Modernization	**Structural Ecologisation**
Design of environmentally friendly cars or vehicles (concerning weight, emission, construction of parts, like motors, batteries aso.)	Modifies the ideas of “prosperity” and “life-quality”. Changes consumers’ behavior: “rent instead of buy”; “common share instead of single possessions”. Shifts producers aims from the sale of merely physical products towards functional criteria
Waste- recycling techniques, cleaner production, low waste production	Education to establish distinct views and customs towards consumption and conservation to avoid waste. Introduction of producers’ responsibility-concepts in firms. Formation of laws; agreement policies

Figure 2: Ecological Modernization and Structural ecologisation in car production

The second argument for an interdisciplinary cooperation within the IE community can be related to validity claims in communication. Habermas distinguishes tree types of discourses as fundaments for decision making:

1. Claim to truth provable via empirical facts, concerning the sum of existing state of affairs. (e.g. reduction of emissions, waste, energy consumption)
2. Claim to correctness discussible via pro and contra arguments, concerning situations and interactions within the social world. (Networking activities, eco-industrial cooperation, extended producer responsibility)
3. Claim to truthfulness explainable via subjective decision making, concerning individual experiences and attitudes.

In order to vote for an argument, one might give certified empirical facts or good reasons in discourse 1 and 2. In discourse 3, one cannot confirm a statement just through arguments but has to prove it with corresponding behavior. If one asserts for instance to be vegetarian, eating beefsteak contradicts this commitment. It is realistic to assume that IE as a research curriculum field includes at least the first and second discourse type.

7 Conclusion

Industrial ecology consists of a self-reliant philosophy and provides operations that correspond with societal goals towards a sustainble development, and hence, it delivers necessary identification patterns to anchor environmental sound technology in culture. However, the task for organisations remains, to use the concept as a guideline for their particular purposes. An in-depth evalua-

tion of practical experiences in implementing industrial ecology in companies or branches would show possibilities and deficiencies, but is not available, yet.
If we agree on sustainability as a concern for the future, it seems further necessary to investigate common views and values on the environment created within and through the society and to proof whether they are still sufficient for contemporary questions and demands.
Industrial ecology can and shall deliver means not purposes for a sustainable development. However, technology as a mean and technology as a medium are hardly to distinguish (Postman, 1985, 94). Industrial processes also have an important influence on ecological environments and take part to shape social surroundings. From my point of view, industrial ecology as a field of education and research should strive to reflect these relationships methodologically. As a concept, industrial ecology should not only develop its tools but become more conscious about its own hidden values and "ideologies" too (Opoku, Keitsch, 2006, p.144,145).

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