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INDUSTRIAL ECOLOGY: SHEDDING MORE LIGHT ON ITS PERSPECTIVE OF UNDERSTANDING NATURE AS MODEL

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Industrial ecology represents an emerging interdisciplinary field of studying industrial systems in combination with their fundamental linkage with nature. An eye-catching characteristic at the basis of industrial ecology's scientific profile is its refreshingly unorthodox perspective of understanding nature as model, compared with other disciplines of understanding nature, e.g. in terms of 'sack of resources' or 'biophysical limit' as opposed to industrial systems. The idea of industrial ecology's appealing perspective is to balance the development of industrial systems with the constraints of natural ecosystems, analogous to an 'industrial symbiosis'. On the basis of initial efforts to conceptualize industrial ecology's underlying assumptions concerning nature, a philosophically focused approach of its characteristic perspective of understanding nature as model is presented. The contribution may provide industrial ecologists as well as other economists, engineers, scientists and policy-makers involved in the field of sustainability with an opportunity for accessible philosophical reflection, perhaps bringing to the surface their tacit frames regarding nature. Consequently, the goal is to gain greater conceptual clarity and to contribute to laying a solid foundation for industrial ecology's stimulating role when initiating change towards sustainability at large. Copyright © 2003 John Wiley & Sons, Ltd and ERP Environment.

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INTRODUCTION

As a summary, industrial ecology is announced as the 'science of sustainability' (Allenby, 1999a, xi; IEEE, 2000). An eye-catching characteristic at the basis of industrial ecology's scientific profile is its refreshingly unorthodox perspective of understanding nature as model. This different

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perspective is typically introduced in the phrasing of a natural ecosystem metaphor and further based on a proclaimed 'straightforward' (Frosch, 1992, p. 800), 'compelling' (Ayres, 1994, p. 23) or 'direct' (German *unmittelbar*) (Strebel, 1998, p. 2) analogy between natural ecosystems – seen as a mature cyclical economy on the one hand – and industrial systems – where, on the other hand, it is understood as a living systems approach. Industrial ecologists very often appreciate nature as being an ideal model in order to gain fruitful insights for theory and to learn to deal with natural resources and services in practice.

At first glance, industrial ecology's characteristic understanding of nature as model – although not actually new – draws our interest and attention. Moreover, it is intuitively appealing because it springs from humanity's inherent wish to balance industrial systems and natural ecosystems. However, within major parts of the scientific community, industrial ecology's interpretation sometimes causes surprise, doubt and criticism (Keitsch, 2000; Roundtable Discussion on *Industrial Ecology*, 2001). The reason for the partly quite unenthusiastic feedback lies primarily – among other things as critics may say – in a one-sided rather romantic view of understanding nature in general, especially in the probably overemphasized or inadequate use of the natural ecosystem metaphor and biological analogy. As a result, industrial ecologists are challenged to conceptualize their specific perspective on nature. To avoid present and future misunderstandings, industrial ecology's underlying assumptions concerning nature and its appealing use of metaphor and analogy need to be made more transparent. Thus, the major goal of this contribution is to shed more light on industrial ecology's 'hidden philosophy' of nature. Such an attempt also requires some clarification of the proper epistemological role of metaphor and analogy within science and research.

According to the above-mentioned goal and scope, basic but essential philosophical aspects are the main focus of this article. In the first introductory part, industrial ecology's scientific profile is described by a rough framework highlighting its disciplinary contours of understanding nature. Based on this, the major second part deals with industrial ecology's ambitious understanding of nature as model in a more detailed fashion. Therefore, its 'hidden philosophy' of nature is uncovered by reviewing current industrial ecology literature. Further, to avoid probably raised misunderstandings when referring to, talking about and employing nature as model, a general but tangible proposal on how to use metaphor and analogy appropriately is presented. Since industrial ecology's refreshingly different approach of perceiving nature is essential for shaping its disciplinary contours, it indicates a really fundamental change compared with other disciplines' traditional perspectives. This significant change can be described as a development away from using nature as a mere store of material and energy towards learning from nature by selectively applying nature's smart solutions, evolutionary strategies and ecological principles. Such a groundbreaking change of interpreting nature constituting the basis of industrial ecology is seen as a paradigmatic shift within science. In short, a set of philosophical arguments is provided, bearing in mind how to make progress to clarify industrial ecology's understanding of nature as model, and, as a larger goal, contributing to sharpening its scientific profile.

NATURE IN INDUSTRIAL ECOLOGY

Scientists have often employed metaphors for their needs, e.g. for educational, pedagogical, didactical and other 'eye-opening' purposes (Lagueux, 1999; Ortony, 1998). Surely, economists and engineers have frequently drawn heavily from biological analogies, in particular from organism analogy, evolution analogy, fractal firm analogy, brain analogy and bionics analogy in order to illustrate socio-economic phenomena (Hodgson, 1993; Mirowski, 1994). However, without an associated conceptual framework and without a broader philosophical clarification, industrial ecology's perspective of understanding nature as model probably remains solely speculative. As Socolow (1994, pp. 4–5) notes self-critically, 'Any claim to "new thinking" deserves to be treated with scepticism. Is there something new here, or just a repackaging of common sense?' Hence, it seems helpful to strengthen industrial ecology's basis for two main reasons: firstly, to *protect* the powerful idea of nature as model against quite loose efforts in using it as a merely rhetoric or picturesque note in environmental management literature, just like a nice accessory or degraded into a literal ornament (see, e.g., Apitz and Gege, 1991; Liesegang, 1993; Seidel, 1994; Zahn and Schmid, 1992). That approach would lead to *preventing* employing nature as model as a fruitful metaphor, if this is done without any associated substantial essence or underlying conceptual framework. Management consultants seem to be particularly at fault here (see, e.g., Baumgartner-Wehrli, 2001; Fuchs, 1995; Gouillart and Kelly, 1995; McKinsey, 1994; Moore, 1994). Vincent (2000, p. 139) reviewed two smart sounding textbooks related to the field of industrial ecology: 'Tell someone that an idea comes from nature and you're halfway toward selling it'. The second reason is to *critically examine* one-sided reasoning on nature as ethical measure or undisputed master, because of the danger of romanticizing nature in the sense of a 'holy world of harmony', 'biological community', 'familiar co-operation', 'ideal cyclical economy' and other probably inherent fallacies (see, e.g., Benyus, 1997; Commoner, 1973; Gottwald, 1997; Kreikebaum, 1996; Lovelock, 1982; Pauli, 1999; Shrivastava, 1994). Summed up, little theoretical progress can be made on the subject of understanding nature on fairly unquestioned grounds. Thus, underlying assumptions about nature in which industrial ecology is to exist should be brought to the surface. To borrow from Luks (1998, p. 146), being philosophically aware can *help shaping a critical industrial ecology*.

FIVE CHARACTERISTICS OF INDUSTRIAL ECOLOGY

In a recent editorial, D. Allen (2001, p. 1) – co-editor of the *Journal of Industrial Ecology* – emphasizes the need for shaping industrial ecology's disciplinary contours. It thus seems to be obvious that uncovering industrial ecology's up to now latent assumptions concerning nature represents an integral component within these processes addressed. Moreover, such a clarification will play a critically important and probably catalyzing role for sharpening industrial ecology's scientific profile. According to the pioneering effort of uncovering and elucidating industrial ecology's 'hidden philosophy' of nature, it appears useful to describe its disciplinary contours in a basic framework. This framework rests on five characteristics, perhaps illustrated by a simple network. This network-like framework includes industrial ecology's core idea, its fundamental perspective of understanding nature, its basic goal of research, a suitable working definition and main objects researched by industrial ecology (Figure 1).

The framework should be regarded as schematic, not photo-realistic. However, it is useful to highlight substantial differences

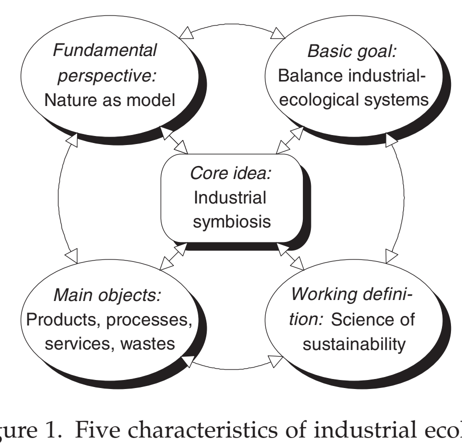

Figure 1. Five characteristics of industrial ecology

between industrial ecology's characteristic perspective of understanding nature as model in contrast to other disciplines. For example, on the one hand, in a neoclassical environmental and resource economics perspective nature is degraded to merely an object in the sense of a 'sack of resources' (Hampicke, 1977, p. 622) utilized for producing goods and services. On the other hand, Boulding's approach (1970, 1992) of a so-called 'spaceship economy' focuses on limits to supplies of natural resources and to the capacity for assimilating waste, i.e. scarce resources (input), finite sinks (output) and fragile self-organized cycles (throughput).

In an overview paper, Erkman (1997, p. 1) defines industrial ecology as a new *perspective* on the industrial system taken as a whole. He specifies this perspective by a *core idea* that 'is . . . to understand how the industrial system works, how it is regulated, and its interaction with the biosphere; then . . . to determine how it could be restructured to make it compatible with the way natural ecosystems function'. Graedel follows very closely (1994, p. 23): 'In industrial ecology, economic systems are viewed not in isolation from their surrounding systems, but in concert with them'. Similarly, Graedel and Allenby (1995, p. xviii) state 'Industrial ecology . . . is a very new way of thinking about economy–environment interactions'. Whatever definition of industrial ecology is drawn on, it is influenced by the assumption that industrial systems and ecological systems are intertwined (Graedel and Allenby, 1995, p. 9), perhaps expressed by the term 'industrial symbiosis' (Erkman, 1997, p. 2). According to Cleveland (1999, p. 148), it is characteristic for industrial ecology 'to look to the natural world for models of highly efficient use of resources, energy and byproducts'. Furthermore, Erkman (1997, p. 1) points out that 'the industrial system can be seen as a certain kind of ecosystem . . . described as a particular distribution of materials, energy, and information flows'. Also Manahan (1999, preface) states that a keynote of industrial ecology is 'to treat the industrial systems in a manner analogous to ecological systems in nature'. He stresses 'Industrial ecology views an industrial system as an artificial ecosystem'.

Industrial ecology's as yet abstract core idea and fundamental perspective of understanding nature become more concrete by highlighting its *basic goal*, i.e. to balance the development of industrial systems with the constraints of natural ecosystems (Tibbs, 1992, p. 4; Wernick and Ausubel, 1997, p. 25). As Manahan (1999, p. 2) points out, industrial ecology aims to provide 'a basis for a much more sustainable global industrial system than the one that now exists'. In the famous words of Frosch and Gallopoulos (1989, p. 94), industrial ecology's goal is 'to develop a more closed industrial ecosystem, one that is more sustainable'. Consequently, circular use of natural resources, cascade-like use of energy and so-called closed-loops are focused on instead of a linear economy with a simple throughput. As a consequence, all flows of materials and energy – representing an industrial metabolism (Ayres and Simonis, 1994) – are included.

In order to reach industrial ecology's ambitious goal, it is necessary to shift from traditional end-of-pipe strategies for manufacturing to alternative integrated and systemic strategies, e.g. by increasing resource productivity and absolute or relative dematerialization. In the terminology of Graedel (1994, pp. 24–26; also Graedel and Allenby, 1995, pp. 93–96; Richards *et al.*, 1994, pp. 6–8), this means developing industrial systems from 'type I' systems, characterized by predominantly linear material flows, unlimited resources and unlimited wastes, towards 'type III' systems, which stand for cyclical flows and closed loops, whereas the only linear flow coming in is solar energy.

Although there is no general accepted standard definition yet, industrial ecology can be specified by three key attributes that may constitute a suitable *working definition* (Erkman, 1997, p. 2; Manahan, 1999, p. 23; Keitsch, 2000). First, industrial ecology is based on a systemic and integrated view of all material and energetic components of industrial economy, including its relations with the biosphere (Richards *et al.*, 1994, p. 3; Wernick and Ausubel, 1997, p. 25; Allenby, 1999a, p. 12). Second, the biophysical substratum of industrial activities representing all flows of material and energy is explicitly emphasized. Third, technological progress is seen as a crucial but not an exclusive element towards sustainability. More precisely, technological progress is in concert with social change and cultural aspects, similar to the 'trefoil of development' proposed by Müller-Merbach (2000, pp. 172–173). He argues that a comprehensive understanding of any socio-economic development is rooted in continuous interdependence between technological progress, economic growth and social change. All of these developing forces influence each other. Industrial ecology is called 'an operational approach of sustainable development', which 'represents precisely one of the paths that could provide real solutions' (Erkman, 1997, p. 2).

The *main objects* of industrial ecology can be illustrated by an emerging field of research that develops along two dimensions. One relates to different aggregation levels of material and energy flows, containing local, regional and global scales (Allenby, 1999b, p. 78; Graedel and Allenby, 1995, p. 33). On every level, all the material and energy flows are analysed. The other dimension includes various research objects, i.e. design of products, processes, services and wastes (Graedel and Allenby, 1995, p. 183; Frosch, 1992, p. 801). The combination of different aggregation levels and various objects constitutes an emerging field researched by industrial ecology. In total, this comprehensive field of research may be called 'earth systems engineering' (Allenby, 1999b, 75 and passim), highlighting the broader, integrative, long-term and systemic perspective in comparison with traditional 'environmental engineering' such as cleaner production and pollution prevention (Ehrenfeld, 1997, p. 94), which are primarily focused – among other characteristics – on conventional regulatory bounds of single media, on short term, technology-driven and local problems.

UNCOVERING INDUSTRIAL ECOLOGY'S HIDDEN PHILOSOPHY OF NATURE

Despite its smart sound, industrial ecology's perspective remains largely uncommunicated with its usually 'hidden philosophy' of nature. Sure enough, industrial ecology's philosophy of nature (understood as an essential set of beliefs, attitudes and assumptions, including a certain interest in nature as meta-theoretical aspects, a specific comprehension of nature as theoretical aspects and a characteristic way of treating nature as practical aspects) has not been completely neglected, but it is still hidden, i.e. usually implicit, largely uncommunicated, in most cases relatively unquestioned and not made sufficiently clear. Due to the challenge to uncover their underlying pre-understanding, industrial ecologists have made some first efforts to strengthen their shared assumptions concerning nature, contributing to underline their apparently problematic employment of nature as model. In particular, there are several industrial ecology contributions illustrating the beneficial employment of natural ecosystem metaphor and biological analogy (e.g. Allenby and Cooper, 1994; Sagar and Frosch, 1997; Côte, 2000; Levine, 2000; Bey, 2001). However, despite varying degrees of usefulness of these contributions, from a philosophical point of view industrial ecology's perspective of understanding nature as model represents an ambitious effort still requiring an in-depth analysis. In order to uncover its hidden philosophy of nature, 20 current approaches of industrial ecology literature have been surveyed (Table 1).

Table 1. Survey of industrial ecologists' reference to nature as model

Author	Reference to nature understood as model
Frosch and Gallopoulos (1989, p. 94)	Industrial ecology 'would function as an *analogue* of biological systems'
Tibbs (1992, p. 2)	Industrial ecology 'takes the pattern of the natural environment as a *model*'
Simonis (1993, p. 131)	'*Learning* from nature' means to take private lessons in ecology
Graedel (1994, p. 24)	'The *ideal* anthropogenic use of . . . materials . . . would be one similar to the biological *model*'
Socolow (1994, p. 4)	'Nature is the *measure* of man'; nature 'as the principal *shaper* of global human activity'
Andrews *et al.* (1994, p. 471)	Nature is '*instructive* to explore in some detail what an industrial ecosystem could involve'
Richards *et al.* (1994, p. 3)	'A *mature* natural ecological community *operates* as waste minimizing system'
Allenby and Cooper (1994, p. 343)	'Sustainable economic structure will resemble a *mature* biological community'
Ring (1994, p. 92; 1997, p. 243)	'*Orienting* economic activities towards ecological principles of system organization'
Graedel and Allenby (1995, p. 10)	Nature understood as *master* of recycling
Erkman (1997, p. 1)	The 'industrial system can be seen as a certain kind of ecosystem'
Wernick and Ausubel (1997, p. 7)	Industrial ecology 'implies that *models* of non-human biological systems . . . are *instructive* for industrial systems'
Ausubel (1998, p. 1)	'Industrial ecology asks whether Nature can *teach* industry ways . . . in minimizing waste and in maximizing the economical use of waste'
Manahan (1999, preface)	Nature as cyclical *economy* without waste
Cleveland (1999, p. 148)	It is characteristic for industrial ecology 'to look to the natural world for *models* of . . . efficient use of resources'
Allenby (1991, p. 43)	'The concept of industrial ecology . . . [is] based here on the *biological analogy*'
Ehrenfeld (2000, p. 237)	'Natural ecosystems . . . offer the only . . . *example* . . . of long-lived, robust, resilient living systems'
Journal of Industrial Ecology (2000, p. 1)	'Industrial ecology . . . looks to the natural world for *models* of highly efficient use of resources, energy and byproducts'
Korhonen (2001, p. 57)	'Ecosystems are '*masters* of recycling' . . . the ecosystem metaphor provides a *sustainable model* of sustainable development for industrial systems'
NTNU (2000)	Industrial ecology means to understand 'nature as a *teacher*' and '*learning* from nature'

It suffices just to look at the table above to see that industrial ecologists are used to drawing heavily on the natural ecosystem metaphor and biological analogy. On the basis of these findings, it may be possible to state a first provisional result: *in industrial ecology nature is employed as model explicitly or at least implicitly, often phrased in terms of a natural ecosystem metaphor and frequently based on a proclaimed persuasive analogy between industrial systems and natural ecosystems*. Beyond different linguistic expressions, nature is understood as model and appreciated as being ideal in parts to gain fruitful insights for theory as well as to learn to deal with natural resources and services in practice.

However, it should be clear that referring to, talking about and employing nature as model covers a really serious philosophically-laden question (Honnefelder, 1992a; Zwierlein and Isenmann, 1995; 1996; Zwierlein, 1997). Obviously, there are several different ways to deal with nature in theory, e.g. philosophically based approaches, theological inspired approaches, quite a few evolutionary theories etc., theories distinguishing between nature and human beings and theories proclaiming nature embraces all that happens, even including 'environmental pollution' and so-called 'not natural' things and processes. Despite such definitional diversity and various ways of perceiving nature, however, it should be evident that it is just *impossible* and we are *unable* to read the 'book of nature' *directly*, in a *straightforward way* or just *immediately* in the sense of a blueprint or a template ready for copying one-to-one. Mere imitation as the term 'biomimicry' implies is not likely to be productive. 'Nature' does not automatically or clearly speak to us. Consequently, when trying to learn from nature, we are in the role of a 'negotiator', i.e. we have to 'translate' nature by our language and into our language. This translation necessitates of course some simplification. According to the preliminary stage of industrial ecology's discussion it seems reasonable to start understanding nature as a bio-cybernetic life support system. Following this provisional understanding, 'nature' may be *hypothetically* employed by industrial ecologists. However, this employment requires knowing *previously* what they are looking for and what the solution they are researching may look like at least in a schematic manner.

USING THE NATURAL ECOSYSTEM METAPHOR AND BIOLOGICAL ANALOGY APPROPRIATELY

To avoid probably raised misunderstandings on the one hand, and, no less importantly, in pursuing progress for clarification on the other, it seems useful to point out the proper epistemological role of using the natural ecosystem metaphor and biological analogy. Therefore, three essential contexts are proposed for describing characteristic processes of research, i.e.: context of discovery, context of justification and context of application (context of discovery and justification, Reichenbach, 1983, p. 3, 1977, p. 340, 1966, pp. 6–7, 381–382; Popper, 1994, pp. 6–7, pp. 60–76, pp. 256–258; context of application, Meyer-Abich, 1988, p. 136). These contexts merely indicate a rough framework. Nevertheless, it serves as a convenient scheme for examining epistemological issues in the actual network of research processes right from discovering new insights via justifying the validity of discovered insights towards applying already justified insights. This threefold scheme offers a suitable means for underlining relevant epistemological aspects.

The *context of discovery* refers to the underlying conceptual framework aiming at the question 'how do researchers discover, gain, explore, obtain etc. fruitful insights?' This context is influenced e.g. by different schools of thinking, behavioural traditions, personal beliefs, spiritual credos, societal circumstances, economic interests and cultural background. These key drivers are called pre-scientific because a researcher's individual point of view is not taken up merely as a scientific position. Thus, the criterion for the context of discovery is adequacy; that means the methods taken should be suitable to the purpose for solving underlying research problems. The *context of justification* deals with logical proof, rigour and plausibility of the underlying conceptual framework, typically asking 'what are the constraints of discovered insights, how well grounded are proclaimed conclusions and what are prerequisites to generalize findings for establishing a generally acceptable theory?' The context of justification takes care of scientific validity concerning logical consistence, methods of proof and empirical confirmation. For the context of justification the criterion is truth, which means substance, contents and usefulness for pursued research problems. The *context of application* indicates the area where insights, results, findings etc. may be used and, probably, put into practice. This leads to the specific question 'what are the consequences and what should be the effects resulting from new insights both for theory and for practice?' Here, several interrelations between science and the *Lebenswelt*, i.e. the melting pot we are living in, are explicitly considered. The criteria for the context of application are relevance and responsibility: the importance of solving our underlying problems by a responsible manner, more precisely, of contributing to reach the goal of sustainability while simultaneously considering a set of three essential verifications concerning human, social and environmental acceptability (Isenmann, 2001a).

In order to ensure scientific quality standards, for different contexts certain methodologies such as typology, induction, deduction, hermeneutics etc. are seen as 'appropriate' and 'legitimate'. Thus, here it becomes clear that to use methodologies properly must be at the centre of any scientist's or practitioner's efforts. Using them inappropriately may lead into possibly grave errors such as the 'genetic fallacy' – i.e. illegitimate substitution of validity merely by describing conditions of genesis, the 'naturalistic fallacy' – i.e. illegitimate substitution of the meaning 'good' by any functional equivalent, the 'normativistic fallacy' – i.e. impossibility to derive practical guidance just by pure norms, the 'teleological fallacy' – i.e. illegitimate substitution of validity just by describing its usefulness and fruitful application – and the 'is–ought-fallacy' – i.e. impossibility to conclude from facts to norms (Krohn, 1981, p. 33; Höffe, 1981, p. 16).

Indeed, there are substantial interrelations between the context of discovery, the context of justification and the context of application. For example, a certain well defined research problem may influence criteria of importance, relevance and the underlying set of guiding research principles. A specific understanding of importance, relevance and a certain underlying set of guiding research principles again may affect the pool of 'legitimate' ends of research. Nonetheless, despite some criticism against a sharp line of demarcation or a dogmatic separation (e.g. Habermas, 1997, 1977), the contexts are not simply substitutable with one another. In particular, in our case there is a considerable distinction between the context of discovery and the context of justification. This notable distinction goes back to Reichenbach (1983, p. 3, 1977, p. 340, 1966, pp. 6–7, pp. 381–382), a German physicist and epistemological thinker. He introduced the terms 'context of discovery' (German *Entdeckungszusammenhang*) and 'context of justification' (German *Rechtfertigungszusammenhang*) in order to distinguish between social and psychological circumstances of discovering on the one hand, and the claim of validity for scientific insights on the other. Similarly, Popper (1994, p. 257) emphasized in *The Logic of Scientific Discovery* making a distinction between the 'procedure of finding' (German *Auffindungsverfahren*) and the 'procedure of justifying' (German *Rechtfertigungsverfahren*). However, the idea itself is much older. It represents a matured topic of philosophy of science, known long before by classical epistemology and frequently phrased by the difference between 'genesis' and 'validity'. In other words, the origin of insights – representing the context of discovery asking how researchers gain fruitful insights – is rather different from the validity of insights – representing the context of justification, pursuing the constraints of discovered insights and asking how well grounded are proclaimed conclusions. Summed up, there is a remarkable difference between conditions of discovering on the one hand and logical proof on the other.

As a result, these common epistemological standards may imply consequences for industrial ecology. In the sense of Aristotle (*Poetik* 1457b; *Rhetorik* 1405a) – who introduced a metaphor as giving a thing a name that belongs to something else and an analogy as comparison between two domains pointing out a range of different similarities – using metaphor and analogy may primarily be assigned to the context of discovery. Hence, for illustrative, educational, didactical and pedagogical purposes they are seen as actually valuable instruments. Surely, use of natural ecosystem metaphor and biological analogy provide constructive insights as 'eye-openers' (Korhonen, 2001, p. 66), e.g. to encourage creativity, to initiate brainstorming and to gain inspiration (Huber, 2000, p. 282). Certainly, use of metaphor and analogy also lead to new facets of interpreting nature that help to forge a sustainable future. Moreover, as Allen *et al*. (2001) recently illustrate by a multitude of examples, metaphor and analogy are excellent instruments to recognize and communicate environmentally focused developments. Metaphor and analogy are also expedient to make industrial ecology's ambitious goal more accessible as it can seem too large, and too overwhelming to deal with. No less importantly, metaphor and analogy serve as powerful tools to initiate change and deliver new perceptions towards sustainability. Perhaps, when transformed into a guiding principle within a research program, 'nature as model' can offer a useful heuristic for learning in order to derive ecological innovations (Isenmann, 2000, 2001b). This area seems to be the genuine realm that made industrial ecology so appealing to economists and environmentalists as well as to engineers, policy-makers and other scientists.

However, metaphor and analogy are problematic and rather speculative if used for the context of justification. This in mind, Daly (1993, p. 250) emphasizes the vast difference between analogy and logical proof. Also, Hodgson (1993, p. 393) notes 'Metaphors are no royal road to truth: they may lead or mislead'. To be a little more precise, according to common epistemological standards, use of metaphor and analogy become more or less provocative and, probably, misleading when used inappropriately for the context of justification, maybe as a means for logical proof. Concerning the proper use of metaphor and analogy, it is helpful to remember the words of Marshall (1966, p. 314): 'It is well to know when to introduce them, it is even better to know when to stop them off'. In his survey on use and application of the natural ecosystem metaphor in current industrial ecology research, Bey (2001, p. 41) concludes 'Much is to be gained from understanding better the metaphor of the natural ecosystem', but he adds 'much is to be lost by using it inappropriately'. Providing a second provisional result, on the one hand, *it is a scientific task to protect the great value using metaphor and analogy against obvious shortcomings*; on the other, *it represents also a task to prevent users for overemphasizing them without being aware of both proper use and limits of productive employment*. Industrial ecologists will surely progress in their thinking by creating ideas of an area in the unknown by using metaphor and analogy drawn from an area of the known. However, we should be aware that in reasoning by metaphor and analogy there are pitfalls, shortcomings and fallacies to be avoided, i.e. use of metaphor and analogy are proper and legitimate and probably highly helpful, as long as what is involved is primarily the elucidation in the sense of a given proposition; but if we try to use them for proving a proposition or even to establish a presumption in its favour, we will be lead into potentially grave errors.

CHANGING THE PERSPECTIVE: FROM USING NATURE TOWARDS LEARNING FROM NATURE

In its scientific sense, industrial ecology's characteristic understanding of nature as model indicates a groundbreaking change of interpreting nature. This change represents a specific development from interpreting nature merely as an object in the sense of a 'sack of resources' towards understanding nature as model appreciated as being ideal in parts to learn from. For example, in comparison with other disciplinary developments within environmental economics schools, this change can be shown by the following classification framework, representing an extract of a comprehensive typology (Table 2). This classification framework is represented as a matrix containing three columns and four rows. It is a convenient scheme for surveying the different relevance of nature and its underlying conceptual basics in general. In particular, industrial ecology's characteristic interpretation of nature as model can be outlined in a broader sense.

The columns point to three different disciplinary perspectives of understanding nature, whereas the rows include three crucial indicators used to build the classification. Perspective 1 represents neoclassical environmental and resource economics representing mainstream economics, perspective 2 indicates the field of so-called 'spaceship economics' and perspective 3 defines the domain of industrial ecology. The classification is based on an underlying philosophically focused framework defined by three crucial indicators presented in rows, more or less following from concrete to abstract (Honnefelder, 1992b, p. 23), i.e. comprehension of nature, way of treating nature and epistemological interest in nature.

The *comprehension of nature* relates to theoretical aspects describing how nature is under-

Table 2. Classification framework on understanding nature

	Perspective 1		Perspective 2	Perspective 3
Different schools of economic thought	Neoclassical environmental and resource economics		Spaceship economics	*Industrial Ecology*
Comprehension of nature (theory)	Nature as object		Nature as limit	Nature as *model*
Treating nature (practice)	Utilizing nature	Taking care of nature	Avoiding use of nature	*Learning* from nature
Epistemological interest in nature meta-theory)	Intervene in nature	Preserve nature	Respect for nature	*Orientation* by nature

stood, perceived or defined in the 'light' of a certain scientific methodology. In other words, the comprehension is a certain (techno-economical) 'theory of nature' influenced by a set of assumptions, knowledge and attitudes in particular concerning human, nature and relationship between human and nature. Ultimately they govern whether to understand nature primarily as an object, a limit or a model. The theoretical aspects of how nature is understood are reflected by practical aspects indicating the role of humanity and its behaviour concerning nature and influencing the manner in which humans are dealing with nature in practice. Thus, a certain comprehension of nature correlates with a corresponding *way of treating* nature. A certain way of treating nature can be described by the kind of operating, using or manipulating nature, perhaps defining the predominantly way to handle natural resources and services. Four ways of treating nature are distinguished: use of nature, care of nature, avoiding use of nature and learning from nature. Every individual comprehension and every treatment is influenced by a specific *epistemological interest in nature*. Such an epistemological interest represents the underlying human motivation shaping the perspective from which the relationship between human and nature is seen. In the sense of Habermas (1977), an epistemological interest indicates a guiding purpose or main reason of understanding something. Thus, a certain epistemological interest in nature points to meta-theoretical aspects of understanding nature. Four types of epistemological interest in nature are distinguished: intervention in nature, conservation of nature, respect for nature and orientation by nature.

Based on the above-mentioned crucial indicators, the conceptual framework is grounded on the fact that a certain comprehension of nature corresponds to a specific way of treating nature. As Popper said, theory governs practice. Further, theory and practice concerning nature can be explained by the plausible connection between understanding nature and treating nature on the one hand and a characteristic epistemological interest in nature on the other, representing an underlying guiding desire for e.g. using nature, taking care of it, avoiding using nature or learning from nature. In other words, both the comprehension of nature representing theoretical aspects and the corresponding way of treating nature representing practical aspects are influenced by an equivalent epistemological interest in nature. Conversely, there is a logical connection and also some significant empirical evidence between a certain epistemological interest in nature, e.g. whether to intervene in nature, to keep nature as it is or to look at nature for a model in order to gain orientation, and the resulting conclusion drawn about e.g. utilizing nature, preserving it or learning from nature (Diekmann and Franzen, 1996; Ruijgrok *et al.*, 1999). In total, the three crucial indicators constitute a characteristic perspective of understanding nature including meta-theoretical aspects (epistemological interest in nature), theoretical aspects (comprehension of nature) and practical aspects (treatment of nature).

Perspective 1 – representing the position of neoclassical environmental and resource economics – indicates considering nature as an object: either focusing on the utilization of natural resources and services or on the care for nature for which humans may feel responsible. The position of a care for nature probably emerges when nature's welfare generating effects decrease, perhaps because of scarce resources (input), finite sinks (output) and fragile self-organized cycles (throughput). The underlying epistemological interest concerning the use of nature can be explained philosophically by humanity's will to take control of nature and to seize power over nature, i.e. to intervene in nature in the sense of a ruler or dominator (see, e.g., Hösle, 1991; Merchant, 1994). Otherwise, the responsible care for natural resources and services is predominantly motivated from conserving nature taken as a whole as it is. In short, nature as object exemplifies understanding nature analogous to a mechanistic figure of a complex machine, still influencing the mainstream of environmental economics. As such, nature is more or less degraded to mere material and energy.

Perspective 2 – representing 'spaceship economics' perhaps in the sense of Boulding (1970, 1992), Georgescu-Roegen (1987) and Meadows *et al.* (1972) – indicates understanding nature as a limit requiring respect to its inherent scarce resources, its restrictions regarding carrying capacity and its biophysical limits concerning fragile natural ecosystems' services. For example, there are limits to biophysical throughput of resources from nature's ecosystems, through the industrial system and back to nature's ecosystems as wastes. This perspective reminds us to respect the constraints of natural ecosystems, and to avoid using nature as a mere resource for three reasons: First, natural resource stocks are declining world-wide and may be exhausted; second, environmental pollution appears to approach or even exceed the absorption capacity of natural sinks, and third, as a long-term danger the fragile self-organizing cycles of natural ecosystems may be destroyed. Thus, according to spaceship economics, utilization of natural resources is limited to the natural rate that reproduction permits. Further, it also implies inflicting no more damage than natural resilience allows for. In total, spaceship economics' perspective on nature strongly recommends on not surpassing nature's inherent biophysical limits and ecosystems' implicit carrying capacity.

Within various developing disciplines, industrial ecology's perspective 3 of understanding nature as model remains still unorthodox, refreshingly different, but nonetheless scientifically plausible, and probably useful. It appears substantially different, because industrial ecology's perspective transcends the traditional ones. For industrial ecologists nature is much more than just a 'sack of resources'. It seems scientifically plausible (at least potentially), because of its interdisciplinary basis including insights of philosophy of nature, ethics, economics, ecology, biophysics and natural sciences. Further, it is useful, because it provides a powerful heuristic in order to derive ecological innovations e.g. when converted into guidelines towards sustainable companies (Isenmann, 2000), or employed as a paradigm for industrial ecology (Ehrenfeld, 1997, 2000; Gladwin *et al.*, 1995; Isenmann, 2001c). The core of industrial ecology's characteristic perspective indicates a fundamental shift away from interpreting nature degraded to a mere material and energy base representing an object, or a limit towards a (hypothetical) model appropriate for deriving ecological innovations. In a broader sense, such a model can serve as a blueprint in parts suitable to be explored by employing measured analogy. Thus, nature is appreciated as serving a proper heuristic to adapt, apply or learn from its implicit functionality, strategies and principles for balancing industrial systems and natural ecosystems. When accepted by industrial ecology's (scientific) community, it may provide a paradigm. As such, a paradigm can be interpreted as the epistemological counterpart of a model. In the words of Simonis (1993), the essence of industrial ecology's perspective of understanding nature as model is to learn from the 'wisdom of nature' in order to develop industrial systems according to the constraints of natural ecosystems. Thereby, basic ecological principles can be used as a rough but fundamental framework that should be regarded as a minimum requirement on the way towards sustainability.

CONCLUSIONS

Industrial ecology is characterized by the refreshingly unorthodox use of nature as model appreciated as an expedient ideal in order to gain valuable insights for theory and to learn to deal with natural resources and services in practice. In contrast to its intuitive appeal, though, industrial ecology's interpretation of nature remains fairly unquestioned, still containing a hidden philosophy. Hence, there is urgent need for research on industrial ecology's underlying assumptions concerning human, nature and the relationship between human and nature. In pursuing to gain greater conceptual clarity and to uncover up to now rather unspoken assumptions, a philosophically focused approach of nature as model has been presented.

First, industrial ecology's scientific profile was illustrated by a rough framework of five basic characteristics – including its core idea, fundamental perspective of understanding nature, basic goal of research, suitable working definition and main objects researched by industrial ecology – highlighting its disciplinary contours of understanding nature as model. Then, industrial ecology's ambitious understanding of nature as model was analysed in more detail. Therefore, its hidden philosophy of nature was uncovered by reviewing 20 current approaches of industrial ecology literature. As a result, in industrial ecology nature is employed as model explicitly or at least implicitly, often phrased in terms of a natural ecosystem metaphor and frequently based on a proclaimed persuasive analogy between industrial systems and natural ecosystems. Further, to avoid probably raised misunderstandings when industrial ecologists may refer to, talk about and employ nature as model, a general proposal on how to use metaphor and analogy appropriately was presented. It was argued that the great value of using metaphor and analogy should be shielded against obvious shortcomings, but it was also emphasized that scientists and practitioners should be restrained from overemphasizing them without being aware of both proper use and limits of productive employment. The fundamental point, it was argued, is to be aware that in reasoning by metaphor and analogy there are pitfalls, shortcomings and fallacies that need to be avoided. Use of metaphor and analogy are seen as proper and legitimate and probably highly fruitful for discovering new insights for the context of discovery and then for communicating these insights within the context of application. However, using metaphor and analogy may become provocative and probably misleading when they are employed inappropriately without any associated conceptual framework and without any philosophical foundation for the context of justification, maybe as a means for logical proof.

Bearing in mind these basic common epistemological standards, such a clarification of industrial ecology's perspective of understanding nature will surely play a critically important and probably catalyzing role for sharpening industrial ecology's scientific profile. Moreover, since it is essential for its disciplinary contours, it indicates a really fundamental change compared with other disciplines' traditional perspectives away from interpreting nature degraded to mere material and energy in the sense of a 'sack of resources' towards learning from nature by selectively applying nature's smart solutions, evolutionary strategies and ecological principles. Such a groundbreaking change of essential categories situated at the basis of its scientific profile represents a really paradigmatic shift. Considering that nature as model is more than fashionable rhetoric and smart theoretical idea, industrial ecology research should be advanced and turned into practice.

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