EnviroInfo 2008 (Lüneburg)
Environmental Informatics and Industrial Ecology
 ISBN: 978-3-8322-7313-2

Environmental Informatics and Industrial Ecology – Scientific Profiles of Two Emerging Fields Striving for Sustainability

Ralf Isenmann[1]

Abstract

This paper provides an approach that could be used to compare the fields of research of Environmental Informatics and Industrial Ecology. Based on supposed overlapping areas, this approach further facilitates the linkage between their associated communities. From a theoretical perspective, the approach makes clear whether the fields of research may have common objects, similar tools, and shared principles, values, and value judgements. No less important, the approach is also helpful from a practical point of view as it helps to identify issues for fruitful institutional co-operation and joint projects. It is argued here that a proper method for a comparison between Environmental Informatics and Industrial Ecology would be an epistemological point of view. Such an "out of the box" perspective finally helps to describe the emerging bodies of theory and clarifies contours of their certain scientific profiles. The proposed approach is illustrated in the form of a pyramid, structured in layers like an architecture, and built with the help of tools of philosophy. It has its methodological basis in a generic framework used in epistemology. This generic framework is further conceptualised through document analyses identifying certain issues that are prototypical for the current communities and literature both, for Environmental Informatics and Industrial Ecology.

Keywords

Body of theory, Environmental Informatics, epistemology, Industrial Ecology, scientific profile, sustainability

1. Introduction

Environmental Informatics and Industrial Ecology are two emerging fields of research striving for sustainability. The object of Environmental Informatics is to analyse information processing, support information management, and develop information systems related to the environment in its broadest sense while using methods, techniques, and tools of computer science, thereby – it is hoped – contributing to environmental protection (Page et al. 1990a, 1990b; Page and Hilty 1995; Rautenstrauch and Patig 2001) and finally to a more sustainable future (Hilty and Gilgen 2001; Dompke et al. 2004; Hilty et al. 2005; Isenmann 2008a). The object of Industrial Ecology is to study industrial systems and their fundamental linkage with natural ecosystems, with the aim to contribute to a more sustainable future (Isenmann und von Hauff 2007a). According to White (1994) the focus of Industrial Ecology is „the study of the flows of materials and energy in industrial and consumer activities, of the effects of this flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use and transformation of resources".

More than two decades ago, Environmental Informatics (Pillmann et al. 2006) and Industrial Ecology (Erkmann 2007) were launched. In the early 1980s, the fields have started single attempts, and they have become a somewhat fuzzy movement, first: Environmental Informatics as a part in applied informatics

[1] Fraunhofer Institute for Systems and Innovation Research (ISI), Germany, email: ralf.isenmann@isi.fraunhofer.de

(Page and Hilty 1995), while Industrial Ecology has its early focus in an engineering/technological- and resource/industry-focused bipolar view (Ayres and Ayres 1996).

Despite differences in history and early movements in detail, the number of similarities is obvious: Both fields share the same goal, and both have reached a level of academic culture so that they are promising branches within "sustainability sciences". The two fields have their intellectual heritage today in professional international societies. Further, both provide numerous tools, studies, publications, resources and other characteristics that may make them a "discipline", and hence the disciplinary contours and constitutive characteristics may share common features. An indicator that there are actually overlapping areas is the current re-launch in 2007: The technical committee "Environmental Informatics" has formally broadened its scope, moving away from a solely environmental focus now also addressing sustainable development and risk management in its community headline. This development is mirrored in the new term of the expert group as "Environmental Informatics – Informatics for Environmental Protection, Sustainable Development and Risk Management" (http://www.iai.fzk.de/Fachgruppe/GI/index.html).

2. What is unique for Environmental Informatics? What makes Industrial Ecology distinctive? The need to develop a unifying scientific profile

Nowadays, Environmental Informatics and Industrial Ecology have reached a certain degree of institutionalisation. As an intellectual area, the communities with their academic culture have a growing impact on governmental agendas, business applications in industry, and higher education programs. Hence, it may be the right time to describe the contours and constitutive characteristics for better clarification what is distinctive for the fields and where they differ. A comparison between Environmental Informatics and Industrial Ecology is embedded in a long term-process of setting the boundaries, developing a unifying profile, and establishing a widely shared self-image (Pillmann et al. 2006; Isenmann et al. 2008). These issues seem particular essential for further movements in each field as well as for finding overlapping areas for fruitful co-operation and joint endeavours like projects across societies and other activities like conferences etc.

Considering the fields' intellectual heritage, tracing back scientific roots, and outlining future developments are becoming topics of increasing importance. Among other factors of influence, these issues are of relevance for distribution, institutional growth, and – no less important – for educational issues as well as for funding projects and other institutional and public affairs. For example, in a recent editorial of the Journal of Industrial Ecology (JIE), Lifset (2007) – who is the current Editor in Chief of the JIE – made the point: "Perhaps the greatest challenge for the field of industrial ecology is the expansion of its boundaries." Further, he added that "the key question is how to expand the boundaries of industrial ecology productively without having the field lose its identity." This is also the case and may be true for Environmental Informatics, especially since the EnviroInfo Conference series is developing from a German meeting to a truly international European event.

The early stages in both fields have served their purpose well in ensuing years because they helped to facilitate community engagement and stimulated a wide range of projects. Too rigid or prescriptive a definition could have stifled interested members in science, government, business, and education from their development path. As the fields moved forward, however, establishing Environmental Informatics and Industrial Ecology will require greater clarity in communication if it is to maintain any substantial meaning in contrast to other fields like:

- Bioinformatics, Computational Biology, Chemical Informatics, Geoinformatics, and Environmental Engineering regarding Environmental Informatics, and
- Ecological Economics, Sustainability Management, Cleaner Production and similar approaches to Environmental Management – among others – concerning Industrial Ecology.

In the last couple of years, the discussion about what is essential and what makes the certain fields distinctive and unique has become a topic of increasing importance, not just inside the Environmental Informatics and Industrial Ecology communities, but also from an outside perspective. For example, in Environmental Informatics a number of contributions with mind-propelling ideas have been presented:

- Probably in the first textbook of the field, Page and Hilty (1995) figured out methodological issues of Environmental Informatics. This seminal chapter provides an outline of the foci of Environmental Informatics, its domains of applications, and the toolbox prototypical for the field, so far.
- Rautenstrauch and Patig (2001) presented an update to the field. The comprehensive volume reports the dynamics and progression of the field. For example, certain projects were carried out, research programmes were initiated, and capacity building in Environmental Informatics was launched.
- Möller and Bornemann (2005) made a contribution to the self-image of Environmental Informatics. They argued that the interdisciplinary nature and goal of sustainability are powerful drivers influencing the field. Hence, these drivers may have a strong impact to the range of issues to be researched, but more importantly for the self-image of Environmental Informatics and its relationships to other environmental sciences.
- Pillmann, Geiger, and Voigt (2006) provided a broad survey of Environmental Informatics in Europe. They described the history and early efforts of the field. Further, they offered a concise overview of its institutional developments, including current research projects, successful implementations, and case studies in Environmental Informatics.
- A new stimulus came from Naumann (2007). He initiated discussions to the future development of the field, presenting an article to "Sustainability Informatics" (Nachhaltigkeitsinformatik). He described this new field as a subset of applied informatics while broadening the scope from a narrow environmental focus to the holistic goal of sustainability.
- Hüttmann (2007) also contributed to the future of the German Environmental Informatics. He questioned the current focus of the field, particularly mainstream-thinking of the German Society for Informatics (GI) and its supposed instrumental orientation. In contrast, he argues to realign the field with environmental protection. From his perspective, the goal should be to prevent the loss of biodiversity.
- Isenmann (2008b, 2008c; Isenmann and von Hauff 2007b) opened the window to epistemological issues. He shed light on the disciplinary contours of the fields, particularly how Industrial Ecology could be described in a unifying structure. He proposed a generic framework based in tools of philosophy to describe the scientific profiles of any field of research. Applying this framework to Industrial Ecology, suggestions are made to what is distinctive for this field and how its body of theory could be arranged.

Contributions that are fuelling internal and external discussions could be identified in Environmental Informatics and in Industrial Ecology, too. This ongoing process of setting the boundaries seem quite similar and may run in parallel (for details in Industrial Ecology e.g. Isenmann et al. 2008, for links to Environmental Informatics e.g. Isenmann 2008a). Regardless to which field the contributions may belong, all these comments and suggestions could be seen as indicators that the communities are alive and vital and perhaps in the process of a transition. More importantly, they make clear that discussing "out of the box" issues actually becomes of relevance. Clearer definition how Environmental Informatics and Industrial Ecology may look like and where to develop – also in a long-term perspective – becomes crucial. One reason is that more scientific communities position themselves as disciplines focused on sustainability and claim to provide relevance for approaching this ambitious goal. As the fields mature, features of identity, differentiation, intellectual heritage, and uniqueness are regarded as more important: This is particular the case for any emerging field, either for Environmental Informatics or for Industrial Ecology.

3. Epistemological framework – method to illustrate scientific profiles

The discourse on what makes a field distinctive and what are proper issues for a comparison usually require the consideration of various crucial topics, e.g. methodological basis, common language, definitions and goals, concepts, tools for applications, and no less important, aspects of institutionalisation and historical development. Further, setting the boundaries is essential to any research field. This is true for well-established entities like physics and biology, but in particular for emerging entities evolving from diverse intellectual roots like for Environmental Informatics and Industrial Ecology. Except for some early efforts in Environmental Informatics (Page et al. 1990; Page and Hilty 1995; Hilty 1997) and few recent contributions in Industrial Ecology (Isenmann 2008b, 2008c) rather little has been done to expose the emerging bodies of theory and compare the scientific profiles of these fields.

A comparison between Environmental Informatics and Industrial Ecology is not as simple a process as it may appear at first glance. In both communities there is no generally accepted definition or a clear picture on how to describe the certain fields, yet: Some see Environmental Informatics and Industrial Ecology as fields of research, some term them academic branches, others prefer just schools of thought. Some others again announce them scientific communities highlighting institutional developments and social structures, while some call them "umbrella approaches" indicating that they might merely cover and/or provide a certain toolbox, but without any intellectual features of uniqueness and certain self-image. The different perspectives to the fields are often accompanied by attributes like "multidisciplinary", "interdisciplinary", "transdisciplinary", or even "metadisciplinary". All terms and labels are a sign that Environmental Informatics and Industrial Ecology have several scientific roots and make use of various intellectual resources.

Resulting from this status nascendi, a sound methodology for a comparison is required. It is argued here that a proper method for a comparison between Environmental Informatics and Industrial Ecology would be an epistemological perspective. Such an "out of the box" approach could finally helps to illustrate the emerging bodies of theory. This approach is illustrated in the form of a pyramid and built with the help of tools of philosophy. It has its methodological basis in a generic framework used in epistemology. This framework is further conceptualised through document analyses identifying certain issues that are prototypical for the communities and literature in Environmental Informatics and Industrial Ecology.

Usually all research fields share a common "perspective", no matter of certain roots or specific origins. Put differently, any form of intellectual arrangement could be characterised through a specific "view". In terms of epistemology, such a "perspective/view" is understood as a specific way to treat and deal with "problems". These problems are phenomena that are regarded as being of relevance. For the clarification of Environmental Informatics' and Industrial Ecology's theoretical foundation with the help of tools of philosophy, here a generic framework is used. This framework is represented in the form of a pyramid and structured in layers. It serves as a rough "architecture" for examining epistemological issues when portraying the contours of a scientific profile along four basic layers (I-IV) or contexts respectively (fig. 1).

- Layer I: A statement or a system of statements, that covers insights, information, expertise and knowledge, usually documented in articles, textbooks, journal publications etc. (*context of statements*);
- layer II: Different phenomena that could be considered, treated, or observed, an object or a class of objects are regarded as relevant (*context of phenomena*);
- layer III: Methods, instruments, calculations etc. that make the toolbox and which are used for research and hence regarded as proper and legitimate for a certain way of dealing and treating with phenomena in layer II (*context of instruments*);
- layer IV: Basic ideas, theories, principles, and axioms, particularly the underlying assumptions of understanding: human, nature, relationship human-nature, and the role economy and technology should take. These assumptions represent the fundamentals that are underlying any conceptualisation in a scientific sense (*context of basics*).

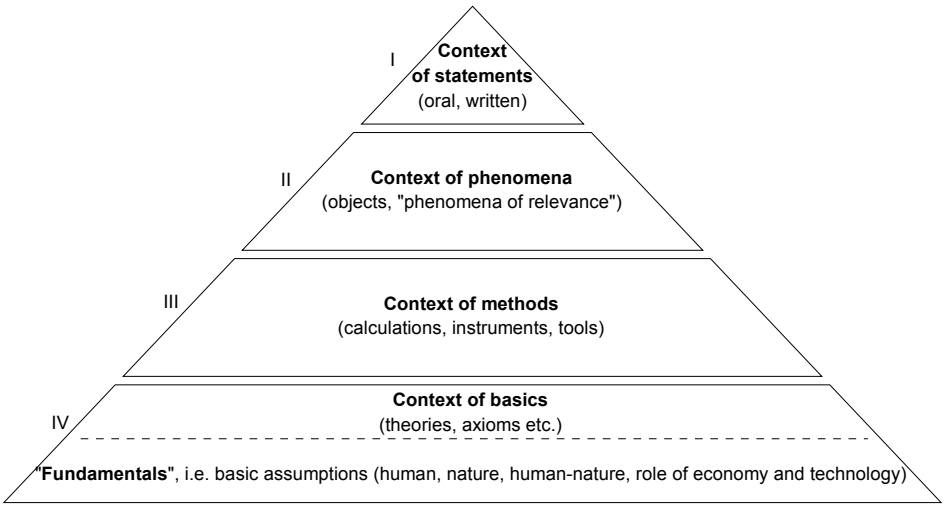

Fig. 1: Epistemological framework – method to illustrate scientific profiles in a basic structure

The framework described here has its methodological basis in the philosophy of science (Zwierlein 1994), sociology of science (Krüger 1987), and history of science (Kuhn 2006). It is especially useful to illustrate the "inter-disciplinary" common ground of various disciplines, analyse different fields of research, and compare diverse schools of thought.

The distinction between the layers/contexts in the framework above could be traced back even to earlier works in philosophy (Rickert 1986[1926]) and economics (Amonn 1927): Amonn (1927) introduced the terms "object of experience" (German "Erfahrungsobjekt") and "object of cognition" (German "Erkenntnisobjekt") to distinguish between on the one hand a phenomenon that is considered, observed, or treated as an object of research, and on the other, the distinct method of consideration, observation, or treatment as the manner of providing insights. According to Amonn, a field is defined through a combination of certain objects of research and specific objects of cognition for which a set of methods, instruments, and tools could be employed. It is this approach proposed by Amonn that serves as the basic method primary used in modern economics as well as in engineering and management sciences in order to define what to research and thus determine how to prepare or manipulate certain research objects.

The scientific profile above (fig. 1) merely indicates a "blank architecture" (German "Leerstellengerüst"): The particular fields of research are delivering the certain contents. With these contents, the layers/contexts could be filled. Further, the architecture is schematic: For example, layer III includes several contexts such as the context of discovery, description, explanation, justification and application (Bey and Isenmann 2005; Isenmann 2003a). Moreover, a set of basic assumptions is situated typically at the bottom of layer IV, carrying at least an understanding on humanity, nature, and the relationship human-nature (Isenmann 2003a, 2003b). The viewpoint from which humans interpret nature notably depends on underlying presuppositions which indicate the human observer's subjective perception employed for explaining and making sense of all that is happening on the Earth. As the assumptions necessarily contain experiences, final interests, and usually (implicit) valuations and value judgements, they constitute a normative compass.

In the sense of the example above, the epistemological framework comprises (I) a statement about (II) something that is (III) represented, interpreted or manipulated by something (IV) in the light of something.

3.1 Scientific profile of Environmental Informatics

Applying the framework (fig. 1) to Environmental Informatics, the characteristics of this field come to the surface and can be arranged in terms of the four contexts (fig. 2).

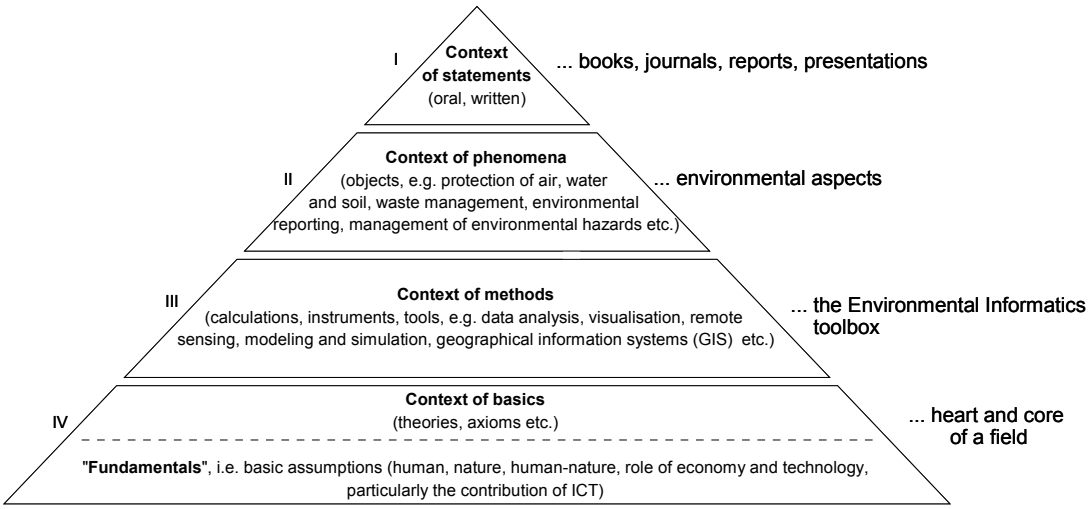

Fig. 2: Scientific profile of Environmental Informatics, illustrated in a basic architecture

The architecture for Environmental Informatics (fig. 2) has been conceptualised through certain issues that are widely discussed in the community, so far. Hence, these issues can be taken as prototypical for the current state of the field. For example, data analysis, visualisation, geographic information systems, environmental databases, modelling and simulation, and knowledge management are some of the methods that call the community its own and thus make the Environmental Informatics toolbox, among others (Page et al 1990b; Page and Hilty 1995; Rautenstrauch and Patig 2001). The issues (in fig. 2) used to conceptualise the epistemological architecture have been identified from a document analysis of the EnviroInfo Conferences, from online resources of the Technical Committee (TC) 4.6.1 "Computer Science in Environmental Protection", and the current literature. The short list of issues again has been clustered in terms of the four layers (in fig. 1).

3.2 Scientific profile of Industrial Ecology

The framework (in fig. 1) has also been conceptualised for Industrial Ecology (fig. 3): For example, materials flow analysis (MFA), life cycle analysis (LCA), and design for environment (DfE) are some of the methods that comprise the Industrial Ecology toolbox (Lifset 2007). The contents that have been filled into the generic framework (fig. 1) are resulting from a document analysis, covering all oral and poster presentations along the workshops that were held during the international Industrial Ecology conferences, including the inaugural conference "The Science and Culture of Industrial Ecology" in Leiden (The Netherlands) 2001, the 2nd conference "Industrial Ecology for a Sustainable Future" in Ann Arbour 2003 (USA), and the 3rd conference "Industrial Ecology for a Sustainable Future" in Stockholm 2005 (Sweden). Then, the issues along the conference workshops have been arranged in terms of the four layers above (i.e. statements, phenomena, methods, and basics). Next, all issues identified have been registered in a table: In

order to prioritise the most important issues of Industrial Ecology, a simple rule has been applied: An issue was regarded as a primary one when there was a workshop dedicated to this issue at least more than once.

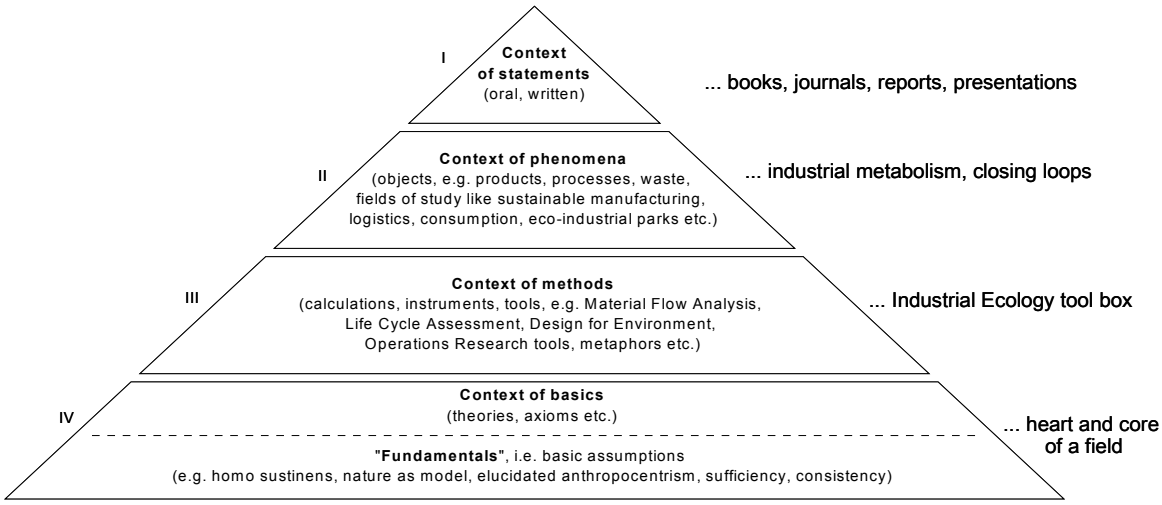

Fig. 3: Scientific profile of Industrial Ecology, illustrated in a basic architecture

A comparison of the scientific profiles highlights that Environmental Informatics and Industrial Ecology share some overlapping areas. For example, these areas include layer II (context of phenomena) and particularly layer III (context of methods): Data analysis, visualization, geographic information systems, environmental databases, and modelling and simulation are some of the methods that call Environmental Informatics its own. Aside, these tools are also common for Industrial Ecology. Further, in both communities discussions on each field itself have started, reflecting on setting the boundaries, defining principles, research methods, topics, and instruments etc. that are particular for Environmental Informatics respectively for Industrial Ecology. The most recent effort is the International Conference "EnviroInfo 2008". It takes place at the Leuphana University of Lueneburg (Germany), and it is explicitly announced under an converging banner (http://www.enviroinfo2008.org/): "Environmental Informatics and Industrial Ecology".

4. Conclusions

The aim of this paper was to stimulate the ongoing discussion in Environmental Informatics and Industrial Ecology, fuel the dialogue what is key for these new but fast emerging fields, finally contributing to find out overlapping areas: When considering these aspects, scholars in the fields will necessarily come across epistemological issues, which are of relevance for theory building but in particular for education and communication, too. The fields of Environmental Informatics and Industrial Ecology consist of assumptions, concepts, tools and applications. While some aspects of these emerging fields may have attained a well-defined status, other issues still seem to be in a status nascendi. This interim status is not viewed as a weakness in principle, but rather as an opportunity for fruitful development. For that purpose, an epistemological perspective is proposed, highlighting the contours of the scientific profiles. The scientific profiles of Environmental Informatics and Industrial Ecology were developed through a two step procedure: First, a generic and structured framework drawn from philosophy was used. Then, this basic structure was filled and made specific through issues that are prototypical for the fields, yet.

Despite the usefulness and value of all previous proposals in the fields above, however, what the epistemological framework with its unifying and structured architecture makes essential is its sound methodology, clear structure, and ease of visualisation. Hence, the scientific profiles of the fields resulting from such a sound methodology will surely support further conceptual developments and promote theory building. Further, based on the scientific profiles, discussions on theoretical dimensions, inside and outside the communities, could be made clearer. In addition, discussions on emerging issues like objectivity, normativity, epistemological standards, values, and value judgements could be brought to the surface and explained in a transparent manner. No less important, the profiles in particular help to find overlapping areas to start institutional co-operation, e.g. to the LCA community (SETAC) as some shared features could be identified.

The limitations of the epistemological framework lie in its rather static nature. It only offers a snapshot with insights for a certain period of time. As the fields are evolving over time, however, the process of capturing what is prototypical for the fields needs to be updated on a regular basis, e.g. every two years. Doing so, dynamics, developments, and evolution could be registered and mapped. Another limitation refers to the document analyses used in this context. It needs to be broadened and made representative: Journals articles, books, further publications, and other relevant incarnations of the fields might be taken into account. Hence, a more detailed and perhaps refined picture could be drawn.

All in all, the emerging interest in matters of identity, differentiation, and uniqueness is a sign for intellectual dynamics and institutional growth of the communities, picking up these "out of the box" issues as a critical theme and considering the implications as important. It is seen that matters of clear argument, proper vocabulary, and fair communication are relevant for the fields both, in terms of the intellectual heritage of its proponents and the development of the certain communities as a whole. Although some may deem these issues as useless in comparison to more practical like software development, design of ICT applications, or empirical research, such discussions are crucial for recognising that these issues have practical consequences: They shape concepts, instruments, and vocabularies that are used to approach research problems. For this reason, if no other, the fields' scientific profiles need to be examined.

References

Amonn, A. (1927): *Objekt und Grundbegriffe der theoretischen Nationalökonomie*. Leipzig, Wien: 2nd ed. Franz Deuticke.

Ayres, R.U.; Ayres, L.W. (1996): *Industrial ecology. Towards closing the material cycle*. Cheltenham, Brookfield : Edward Elgar.

Bey, C.; Isenmann, R. (2005): Human systems in terms of natural systems? *International Journal of Sustainable Development* 8(3): 189-206.

Dompke, M.; Geibler, J. von; Göhring, W.; Herget, M.; Hilty, L.M.; Isenmann, R.; Kuhndt, M.; Naumann, S.,; Quack, D.; Seifert, E.K. (Eds) (2004): *Memorandum Nachhaltige Informationsgesellschaft*. Stuttgart: Fraunhofer IRB. <http://www.giani-memorandum.de>, access 2005-01-24.

Erkmann, S. (2007): Historischer Überblick zur Industrial Ecology. In: Isenmann, R.; Hauff, M. von (Eds). *Industrial Ecology. Mit Ökologie nachhaltig wirtschaften*. München: Elsevier. 31-47.

Hilty, L.M. (1997): *Umweltbezogene Informationsverarbeitung. Beiträge der Informatik zu einer nachhaltigen Entwicklung*. Habilitationsschrift. Universität Hamburg: Fachbereich Informatik.

Hilty, L.M.; Gilgen, P.W. (Eds) (2001): *Sustainability in the information society. 15th International Symposium Informatics for Environmental Protection*. Zurich 2001. Part 1 and Part 2. Marburg: Metropolis.

Hilty, L.M.; Seifert, E.K.; Treibert, R. (Eds) (2005): *Information systems for sustainable development*. Hershey et al.: Idea Group Publishing.

Hüttmann, F. (2007): Deutsche Umwelt-Informatik vs. Naturschutz, GBIF, Rio, Statistik und Nachhaltigkeit. Ist das Pferd das wir retten bereits tot? *Rundbrief Umweltinformatik* 41: 11-14.

Isenmann, R. (2003a): Further efforts to clarify industrial ecology' hidden philosophy of nature. *Journal of Industrial Ecology* 6(3/4): 27-48.

Isenmann, R. (2003b). Industrial ecology: Shedding more light on its perspective of understanding nature as model. *Sustainable Development* 11(3): 143-158.

Isenmann, R. (2008a): Sustainable information society. In: M. Quigley (Ed.). *Encyclopedia of information ethics and security*. Hershey: IGI Global, 622-630.

Isenmann, R. (2008b): Setting the boundaries and highlighting the scientific profile of Industrial Ecology. *Information Technologies in Environmental Engineering*, Special Issue January 1(1): 32-39, online: <http://www.iteejournal.com/Volume1/index.htm>.

Isenmann, R. (2008c): Industrial Ecology auf dem Weg zur Wissenschaft der Nachhaltigkeit? In: A. von Gleich, S. Gößling-Reisemann (Eds). *Industrial Ecology – Nachhaltige industrielle Systeme gestalten*. Stuttgart: Teubner, 304-315.

Isenmann, R.; Bey, C.; Keitsch, M. (2008): Beyond a sack of resources. Nature as a model – core feature of Industrial Ecology. In: M. Ruth; B. Davidsdottir (Eds). *Changing stocks, flows and behaviors in industrial ecosystems*. Cheltenham, Northampton: Edward Elgar, 157-181.

Isenmann, R.; Hauff, M. von (2007): Einführung in die Industrial Ecology. In: R. Isenmann; M. von Hauff (Eds). *Industrial Ecology. Mit Ökologie nachhaltig wirtschaften*. München: Elsevier, 1-15.

Isenmann, R.; Hauff, M. von (Eds) (2007): *Industrial Ecology. Mit Ökologie nachhaltig wirtschaften*. München: Elsevier.

Krüger, L. (1987): Einheit der Welt – Vielheit der Wissenschaften. In: J. Kocka (Ed). *Interdisziplinarität: Praxis – Herausforderung – Ideologie*. Frankfurt am Main: Suhrkamp, 106-125.

Kuhn, T.S. (2006): *Die Struktur wissenschaftlicher Revolutionen*. Zweite revidierte und um das Postskriptum von 1969 ergänzte Auflage. Frankfurt am Main: Suhrkamp.

Lifset, R. (2007): Reaching out but staying connected. *Journal of Industrial Ecology* 11(1): 1-3.

Möller, A.; Bornemann, B. (2005): Kyoto ist anderswo. Zwischen Interdisziplinarität und Nachhaltigkeit. *Informatik Spektrum* 28(1): 15-23.

Naumann, S. (2007): Nachhaltigkeitsinformatik. Ein neues Teilgebiet der angewandten Informatik? *Rundbrief Umweltinformatik* 40: 9-12.

Page, B.; Hilty, L.M. (1995): Umweltinformatik als Teilgebiet der Angewandten Informatik. In: B. Page, L.M. Hilty (Eds): *Umweltinformatik. Informatikmethoden für Umweltschutz und Umweltforschung*. München, Wien: 2. ed. Oldenburg, 15-31.

Page, B.; Jaeschke, A.; Pillmann, W. (1990a): Angewandte Informatik im Umweltschutz. Teil 1. *Informatik Spektrum* 13: 6-16.

Page, B.; Jaeschke, A.; Pillmann, W. (1990b): Angewandte Informatik im Umweltschutz. Teil 2. *Informatik Spektrum* 13: 86-97.

Pillmann, W.; Geiger, W.; Voigt, K. (2006): Survey of environmental informatics in Europe. *Environmental Modeling & Software* 21(11): 1519-1527.

Rautenstrauch, C.; Patig, S. (Eds) (2001): *Environmental information Systems in Industry and administration*. Hershey: Idea Group Publishing.

Rickert, H. (1986): *Kulturwissenschaft und Naturwissenschaft*. Stuttgart: Reclam [first published: Tübingen 1926].

White, R. (1994): Preface. In: B.R. Allenby; D.J. Richards (Eds). *The Greening of industrial ecosystems*. Washington: National Academy Press.

Zwierlein E (1994): The paradigm of self-organization and its philosophical foundations. In: R.K. Mishra, D. Maaß, E. Zwierlein (Eds.). *On self-organization. An interdisciplinary search for a unifying principle*. Berlin et al.: Springer, 288-298.