Editorial II: The dimensions of industrial symbioses and their system boundaries

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Abstract: This editorial article of *Progress in Industrial Ecology* triple special issue 'System Boundaries of Industrial Symbioses' introduces the themes and objectives of the special issue and reflects on the 12 published international peer-reviewed article contributions. Our research objective is to identify what dimensions and questions are important and what further research is needed in the area of system boundary definition and practical application of industrial symbiosis. Our analysis of the international working process leading to this publication and our analysis of the 12 article contributions suggests that there are many other important dimensions and questions concerning industrial symbiosis system boundaries than the currently dominant spatial/geographical, administrative and organisational boundary definitions. We find that industrial symbiosis has spatial and geographical boundaries, organisational and administrative boundaries, temporal boundaries, intellectual boundaries, methodological boundaries, strategic versus operational boundaries, cultural boundaries and boundaries of the economics paradigm. The system boundary definition decides the sustainable development contribution of industrial symbiosis.

Keywords: industrial ecology; industrial symbiosis; system boundaries.

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1 Introduction

1.1 Background and objectives of the editorial article

The Finnish Environment Institute (SYKE) and Åbo Akademi University are carrying out (from 2007–2010) an Academy of Finland-funded research project, Industrial Symbiosis System Boundaries (ISSB) (code 216348). As part of the *13th Annual International Sustainable Development Research Conference* of the International Sustainable Development Research Society, held on 10–12 June 2007 in Västerås, Sweden, the project organised a workshop (Track 10 of the conference) entitled *How Can Industrial Ecology Contribute to Regional Sustainability?*

Altogether, 18 platform presentations were made at the workshop that was co-chaired by Jouni Korhonen and Matti Melanen, the leaders of the ISSB project. The contributions were debated during the workshop. The debate was intensive and lively. The authors received direct feedback from their international peers. After the workshop, the authors submitted full papers for consideration in a special issue, 'System Boundaries of Industrial Symbioses', for *Progress in Industrial Ecology*. The manuscripts were processed through the normal peer review process of the journal.

We are pleased to introduce the product of the working process. The final outcome of the initiative materialises in this triple special issue of PIE: Vol. 5, Nos. 5 and 6 as Part 1 and Vol. 6, No. 1 as Part 2. The triple special issue includes 12 peer-reviewed article contributions and this editorial article, which is a full research paper itself. We received papers from Europe, North America, Asia and Australia.

The purpose of this editorial article is to introduce the theme and objectives of the publication, as well as introduce the 12 contributions. The editorial article then uses the learning of the working process that led to this publication and the published article contributions and reflects on the theme of the system boundaries of industrial symbiosis. *Our research objective is to identify what dimensions and questions are important and what further research is needed in the area of system boundary definition and practical application of industrial symbiosis.*

2 Introducing the papers of the special issue

In the first article of Part 1, ‘The synergistic role of embeddedness and capabilities in industrial symbiosis: illustration based upon 12 years of experiences in the Rotterdam Harbour and Industry Complex’, Leo Baas and Don Huisingh discuss the interlinkages of the physical, environmental and social science dimensions based on ongoing developments in the Rotterdam Harbour and its large Industry Complex, initiated in 1994. The article reflects on the theories of embeddedness, capabilities and transition. The authors convincingly argue that previously, too much emphasis was placed upon the technical and mechanical dimensions of change and far too little emphasis on understanding and working with the nontechnical dimensions. Baas and Huisingh, therefore, claim that better success will be achieved with the integration of the economic, environmental and social dimensions into industrial ecology activities.

The paper of Gyula Zilahy and Simon Milton, ‘The environmental activities of industrial park organisations in Hungary’, offers an interesting comparison with the debate in the first article. In Hungary – which joined the European Union (EU) in 2004 – the transition process to a market economy started some 20 years ago, resulting in the current economic environment similar to that of the more developed states of the EU. Using a questionnaire survey and interviews, the authors analyse the environmental practices and motives of the country’s industrial park organisations and provide suggestions for their future development.

‘US feedlots and slaughterhouses: bounding industrial ecology with the extreme case’, by Van V. Miller, is a well-founded effort to address the boundaries of industrial ecosystems. As a case, Miller uses an agro-industrial ecosystem, the Kansas Cattle Feedlot-Slaughterhouse System, and interestingly asks what the ‘legitimate concerns’ of industrial ecology actually are. The case study here has implications for the larger picture of the science of industrial ecology and its contribution to global sustainable development. How is it possible to prioritise aspects of complex systems through the lens of a scientific discipline or through the larger societal call for a sustainable global society?

In his article, ‘Bringing interregional linkages back in: industrial symbiosis, international trade and the emergence of the synthetic dyes industry in the late 19th century’, Pierre Desrochers critically discusses some assumptions (“local production is preferable to long-distance trade”; “the use of renewable resources is preferable to the use of non-renewables”) that are often acknowledged as basic points of departure of industrial ecology. The author has written an impressive account of the contribution of the economist and geographer Erich Zimmermann to byproduct development. A case study on the substitution of natural dyes with synthetic dyes is presented to illustrate Zimmermann’s main points. Finally, some reflective conclusions are drawn: “… while valuable, the industrial symbiosis perspective should not frame the discussion of regional sustainability in a way that downplays the environmentally beneficial role of inter-regional trade and the larger division of labor in which human actions are embedded”. This contribution directly addresses the important question of the spatial and geographical boundary/border definition of industrial symbiosis networks. One is inclined to ask whether the criteria should, first and foremost, be those of global sustainable development rather than geographical, administrative and organisational boundaries when trying to advance industrial symbiosis.

'Building a framework for strategic architecture to foster the development of industrial ecology', by Brian H. Roberts, argues that industrial ecology has the potential to realise much greater economic, social and environmental benefits than it does at present. The paper examines the planning issues which affect the application and acceptance of industrial ecology. A planning framework comprising six strategic architecture elements to support the development and application of industrial ecology is presented. This article brings in an important experience from Australia that is important for making progress in the global science of industrial ecology. The author builds upon his 2004 contribution to the *Journal of Cleaner Production* triple special issue on 'Applications of Industrial Ecology'.

The next two articles deal with the measurement of the environmental benefits and sustainability performance of industrial symbioses. The article by Anna Wolf and Magnus Karlsson, 'Evaluating the environmental benefits of industrial symbiosis: discussion and demonstration of a new approach', aims to bring in a new understanding of the environmental assessments of industrial systems. A computer model, Method for analysis of INDustrial energy flows (MIND), is applied to an industrial symbiosis that comprises a pulp mill, a paper mill, a sawmill and a biofuel upgrading plant. The CO_2 emissions from the symbiosis system are compared to those from a system of stand-alone plants, *i.e.*, a system where the industrial ecosystem-type of symbiotic and cooperative relations between the involved actors and processes are missing. In all cases, with varying assumptions, the integrated system generated lower emissions than the stand-alone system. The authors, however, point out that there are still large uncertainties in the results, depending on the assumptions made.

In 'How can the sustainability of industrial symbioses be measured?', Sokka *et al.* propose a framework based on the guiding principles derived from The Natural Step (TNS) System Conditions and combined with quantitative tools developed within industrial ecology for the analysis of industrial symbioses. In the framework, the TNS System Conditions constitute a basis which – through a set of sustainability criteria and a series of questions based upon them – steers the analyses of the environmental performance and overall sustainability of the IS network at hand. The framework is applied to a case study symbiosis located in the Kymenlaakso region in Finland. It is important to note that the message is to complement, not substitute, the many existing approaches, tools and indicators that measure the environmental performance of production-consumption systems. The authors endorse the TNS logic in that all firm, process and product system boundaries should be assessed for their overall contribution to global sustainable development in the long term. This task is very ambitious and challenging. It is impossible to achieve a consensus between the many existing environmental performance analyses or environmental impact assessment teams on the numbers or detailed impact categories. Qualitative and flexible principles is the only way to generate a consensus. This consensus will then help direct and apply specific quantitative tools and analyses, such as Life Cycle Assessment (LCA) or applications of the input-output Material Flow Analysis (MFA). That is, quantitative and detailed accounts of environmental impacts are important, but should be conducted only when contributing to sustainable development. For example, time-consuming LCAs for an inherently unsustainable substance, *e.g.*, a certain heavy metal, are not necessarily required as from the sustainability point of view, such flows should eventually be phased out altogether.

We conclude Part 1 of this triple special issue with Arun Sahay's article, 'Perception of pollution and expectation from NTPC's Talcher Super Thermal Power Plant'. It is an illustrative example of the conditions of a developing country where modern technology is used. The case here, the Talcher plant, is the biggest power generation station in India with an installed capacity of 3000 MW. The local population considers the plant both a boon and a bane. In a note to the editors, Professor Sahay wrote: "The article should be seen from the Indian background and perspective where there is poverty; people in villages hardly know about the nuances of air, water or solid waste pollution. The women folk of referred villages are mostly illiterate …"

The first article of Part 2, 'The clean development mechanism and the principles of industrial ecology – exploring the interconnections and mutual opportunities', by Rikke Lybæk and Noel Brings Jacobsen, presents the results of a Clean Development Mechanism (CDM) feasibility study in Thailand. A local biomass-based combined heat and power system was designed, applying a few central industrial ecology principles. The authors claim that industrial ecology and CDM may cross-fertilise each other and that CO_2 credits would be generated by implementing the project concerned. It is interesting to consider whether local industrial ecosystems, *e.g.*, based on local renewable fuels and the combined production of heat and power, could actually become market players in the global economy through CO_2 emissions trading systems. We could envision a locally integrated electricity, industrial process steam, district heat and waste management system located in a small rural community in a developing country and producing a surplus of carbon-neutral energy for the global market economy. The symbiosis would build on local biomass flows such as industrial, agricultural, forestry or farm biomass wastes and generate energy to all of these local actors and sectors.

In the next article, 'Towards eco-efficiency: granulated nickel slag's transformation into a product', Leinonen *et al.* discuss the background, obstacles and opportunities for the utilisation of nickel slag, employing the Finnish Harjavalta eco-industrial park as an example. At present, three-quarters of the slag is dumped, but as the authors show, there are potential new ways to use the resources of slag as a raw material or a product instead of natural raw materials, thus supporting the eco-efficiency development of the Harjavalta industrial park. The case is important for the global mining sector. If industrial ecosystem principles can be more widely applied in the mining sector, significant reductions in environment impacts and energy use could be achieved.

'Environmental information for sustainable supply chains', by Elke Perl and Stefan Vorbach, addresses a timely and important topic of sustainability: the aspects and flows of information in interorganisational supply chains. An empirical survey of the Austrian production industry is used to illustrate the practical implications of the theoretical findings. The outcome is rather discouraging: the surveyed companies are not aware of the advantages of interorganisational cooperation in supply chains. Industrial ecology has mainly focused on the physical flows of materials and energy in production-consumption systems and observed that these matters are interorganisational. Less attention has been paid to the flows of information in interorganisational life cycles, supply chains, value chains or local symbiosis network systems. The information flows, of course, direct the physical flows of materials and the more diverse the system in question is, the more difficult the generation, coordination and management of the flows of information.

Teresa Doménech and Michael Davies' article, 'The social aspects of industrial symbiosis: the application of social network analysis to industrial symbiosis networks', explores the potential of applying social network analysis and network theory to industrial symbioses as a way to increase the understanding of the complexity of industrial symbiosis networks. The authors argue that the network approach can provide a comprehensive framework for understanding the social aspects behind material and energy exchanges. Thus, their contribution is a much-wanted response to the claims that Leo Baas and Don Huisingh make in the first article of Part 1 of the special issue. Also Perl and Vorbach's article in this issue that concentrates on information flows is fruitful in this context. Social sciences are currently at the margins of our field. What we need are well-argued cases demonstrating the need for social science methods and practical and transparent illustrations on how these methods can work in practical analyses and make progress in sustainable development through industrial ecology. Without such clear evidence, the argument of bridging industrial ecology and social sciences becomes more like a catchphrase or an argument which is empty in meaning and relevance.

3 Reflecting on the system boundaries of industrial symbiosis

The core of the scientific field of industrial ecology is the study of the physical flows of materials and energy in complex production and consumption systems and in natural ecosystems on which technological systems depend for their source and sink functions. Unlike nature, cultural systems and their production-consumption systems are defined, designed and operated through cultural perceptions or intentions and the resulting governance and management models. Natural boundaries are radically different from the boundaries decided in political systems and societal institutions. Human-induced materials and energy flows always exceed administrative and organisational boundaries or borders.

Industrial symbiosis has mainly been defined according to the geographical, spatial and administrative (organisational) boundaries of a certain local/regional system, *e.g.*, an industrial park. The process of this special issue and the results of the process now documented in the 12 international contributions show that there are many other dimensions we have to consider to understand and define the boundaries of industrial symbiosis. In the following subsections, we reflect upon this challenge to learn and understand the diverse aspects that need to be addressed when investigating where an industrial symbiosis system begins and where this network system ends.

3.1 Intellectual boundaries

There are intellectual boundaries. Industrial ecology, in general, and industrial symbiosis, in particular, are dominated by engineering and natural science-oriented materials and energy flow analyses. The most commonly used method in industrial ecology is LCA, which produces quantitative results on materials and energy flows and their potential impacts on the environment. Our learning during this working experience of the special issue demonstrates that the social science aspects are also important. Human behaviour and decision making in policies and organisations cannot be studied with materials flow analysis. Business studies, management and organisational studies as well as decision-making sciences provide important contributions when answering the question of how and why exactly an organisation or individual consumer changes. The contribution by Leo Baas and Don Huisingh in this special issue offers a fruitful perspective on these challenges.

3.2 Temporal boundaries

Note that innovations for industrial symbiosis are not that new, as commonly believed in the (institutionalised) industrial ecology literature, now some 20 years of age. The temporal boundaries of the insights and learning central to our discipline cover a much longer time period. Many firms in the past, since the beginning of the industrial revolution (and prior), have innovated towards more efficient materials and energy flow utilisation, including industrial waste and byproduct synergies. People have simply acted rationally and attempted to produce more from less. In addition, note that the definition of waste is temporally dependent. The definitions of waste, a byproduct, a material flow or a product have changed due to the modern environmental and waste management legislation and policy. The definition of waste was different some 200 years back. The article of Pierre Desrochers in this issue reflects on the history of waste.

Industrial ecosystems are complex systems. The debate is ongoing on whether industrial ecosystems can be intentionally planned or are they so self-organised that all that we can do is try and facilitate such self-organisation processes and evolutions. Regardless of what side of the debate one takes, all should agree that successful complex industrial ecosystems need a long time to develop and mature. Historical, evolutionary and time-series materials flow accounts are important for understanding the critical elements of system development. We need more case studies that focus on the birth, development and maturity, as well as the future projection, of a particular industrial symbiosis.

3.3 Spatial and geographical boundaries

In terms of spatial and geographical boundaries and borders, three points should be addressed. First, it is very difficult (if not impossible) to establish a locally closed industrial ecosystem in which the life cycles of the products and their production and consumption would take place within the local system. In the globalised market economy, all local systems are usually linked through trade, imports and exports to the global market economy. It would be hard to sustain a system without these linkages. Second, a local or industrial park-level symbiosis is not necessarily the best option for the sustainability of industrial symbiosis. Useful wastes and byproducts or the potential users for these flows can be found outside the immediate industrial park boundaries in the larger regional system. The article by Pierre Desrochers in this issue also addresses this question.

Third, problem shifting and problem displacement must be taken into account. As described in the paper by Sokka *et al.*, the forest industry of Finland has several fruitful examples of successful industrial symbiosis. Indeed, the forest industry parks that rely almost up to 100% on local wood waste-derived renewable and CO_2 neutral fuels and sell their surplus energy to the grid (CO_2 emissions become negative in such a case) are better examples of industrial ecosystem principles occurring in practice than the often-cited Kalundborg case. Kalundborg relies on two key actors: a coal-fired power plant and an oil refinery. The renewable biomass and carbon cycles of the very energy-intensive and globally significant Finnish forest industry sector are exceptionally good cases for the application and development of industrial symbiosis theories.

However, when we enlarge the system boundaries of the forest industry symbiosis, we observe the risk of problem shifting. Climate change and sustainable development are global phenomena. Imports of timber from Russia to Finland have increased during the last decades. It is commonly known that biodiversity protection is more advanced in Finland than in Russia. Furthermore, 90% of the paper produced in the forest industry is exported. The waste paper management problems at European landfills are well known.

3.4 Methodological boundaries

Methodological boundaries in sustainability science and sustainable development research are many. The number of different approaches, tools, instruments, metrics and indicators applied, *e.g.*, in industrial ecology, cleaner production or corporate environmental management, is rapidly increasing. The problem that results to the tool user, whether a policy decision maker or a business leader, is that the different tools and instruments are perceived as competing and each other's substitutes. All the individual tools have their own and specific system boundary definitions. For example, from the industrial symbiosis perspective, waste generation at an individual firm is viewed as beneficial, provided that the other firms in the local network can utilise this flow to substitute for virgin resources or fossil energies. For the Environmental Management System (EMS) of the firm and its performance measurement indicators, however, increasing waste generation is hardly desirable, *e.g.*, in terms of publishing the firm environmental or corporate social responsibility report to its shareholders and other societal stakeholders.

Furthermore, LCA measures the (potential) environmental impacts of a product in production-consumption systems from cradle to grave or, desirably, from cradle to cradle. The life cycle also covers interregional and intercontinental flows. Production and consumption are often geographically separated in the global market economy. Industrial symbiosis focuses on many organisations, processes and products, but within a local context. Interregional LCAs could benefit industrial symbiosis approaches. Naturally, it must be acknowledged that it can be an enormous task to complete a life cycle analysis for all the products affecting or affected by a certain local industrial park. Still, industrial symbiosis and LCA should be seen as complementary approaches and tools. To work strategically toward sustainability, the process of sustainable development needs to acknowledge that the many different tools and instruments are each other's complements and can be used in parallel to benefit from the specific strengths of the individual tools and correct their weaknesses.

In this special issue, Anna Wolf and Magnus Karlsson discuss the complexity of environmental assessment of industrial symbioses. When aiming to quantify the impacts of industrial symbiosis, they write, the challenge is to identify whether the environmental benefits are due to the industrial symbiosis or to other factors influencing the involved companies. Wolf and Karlsson point to important questions, such as what the reference system should be for calculating savings and the other benefits of an industrial symbiosis. They also emphasise the classical allocation problem of LCA; in the case of industrial ecosystems, how should the environmental pressure or environmental benefits be allocated between the participating entities?

3.5 Strategic versus operational boundaries

Most industrial ecology, cleaner production and sustainable development tools and methods focus on the currently known environmental impacts. Impacts are measured with detailed and quantitative approaches. Specific impact categories such as climate change and acidification are defined. Decisions are then undertaken regarding on what impacts to focus with the study. However, many negative impacts in nature caused by societal production and consumption systems are still unknown to modern science. Uncertainties prevail in the understanding of many species in ecosystems and their complex interactions. Moreover, it is very difficult to achieve a societal consensus between the diversity of the actors and the interests involved in complex sustainability questions and especially so if consensus is attempted on numbers and detailed impacts.

Unfortunately, industrial ecologists often exclude more strategic questions from their studies and remain on the operational level of observed impacts and practical actions to fix the problems resulting from these impacts. The strategic dimension would bring in the underlying mechanisms and root causes upstream of the negative environmental and social impacts that occur downstream in cause-and-effect chains. Instead of only quantitative and detailed impacts, the strategic industrial ecologist also concentrates on qualitative and general principles. This enables preventative environmental and sustainability management including currently unknown impacts.

The general mechanisms and root causes of environmental problems can be identified through existing scientific knowledge. We know that lithosphere-oriented materials can cause problems in the biosphere and we know that chemical compounds foreign to nature may cause harm, *etc.* Professor Karl Henrik Robért's research group and TNS are working to bridge the gap between the strategic and operational aspects of sustainable development. Sokka *et al.*, in this issue, apply Robért's sustainability principles to industrial symbiosis. The strategic dimension (underlining mechanisms and root causes) is also discussed by Van V. Miller in his article on the Kansas Cattle Feedlot-Slaughterhouse System – an "unusual, or counterintuitive, IE system", as Miller characterises his case.

3.6 Cultural boundaries

Cultural boundaries exist, too. This special issue includes contributions from four continents: North America, Europe, Asia and Australia. The application of industrial symbiosis is very different in varying local settings. Local situational factors and conditions (including ecological, economic, social and cultural) vary substantially when moving from North America to Asia. For example, in developing countries, the definition of waste is different from that in developed countries. In poor countries, waste can literally equal food.

In order to make progress in sustainable development through industrial ecology, cooperation between developed and developing countries' scientists is needed. This process has been launched. Industrial ecology was one of the main streams of the *14th Annual International Sustainable Development Research Conference* that took place in New Delhi, India, on 21–23 September 2008 with over 300 participants from some 50 countries. The main objective of the conference was to engage sustainability scientists from developing and developed countries in cooperation for the global challenge of sustainable development. PIE was one of the journals supporting the conference.

PIE is also one of the journals cooperating with the *International Sustainable Development Research Society* (ISDRS) that annually organises this conference. The links to Asia and the practical, visible and output-oriented cooperation projects with partners in Asia are critically important for the development and quality of the journal. In this special issue, the article of Rikke Lybæk and Noel Brings Jacobsen demonstrates that industrial ecology principles can be effectively applied in developing countries in their case for advancing CDM. The article by Arun Sahay also addresses the challenge of sustainability and technological transfer with an Indian case study.

3.7 Boundaries of the economics paradigm

Finally, we need to consider the boundaries and reach of the economics paradigm in the global society. Edward Lazear has used the term 'economic(s) imperialism' in a 2000 article in *The Quarterly Journal of Economics*. Economics science has gained ground in scientific disciplines and in societal sectors originally deemed outside its realm. Efficiency has always been part of the economics science message. Eco-efficiency, then, has evolved into a central concept of the science of industrial ecology, too. Both PIE and JIE have published special issues on eco-efficiency. Efficiency is a relative figure, a ratio of output to input. Economic and population growth are measured in absolute, total quantities. Environmental impacts increase if the absolute quantity of emissions, the total burden on nature increases, although the increase would result from production processes that are more efficient than earlier. Efficiency usually stimulates growth. So far, eco-efficiency has not been able to reverse the growth of resource use, waste and emission generation of the global economy.

Sustainable development has many dimensions that cannot be measured in quantitative terms. Qualitative analysis is required. Eco-efficiency is a very important tool and practical instrument because it integrates ecological and economic questions. But eco-efficiency should be used strategically for the overall goal of sustainability. This means that eco-efficiency is integrated to other perspectives and approaches in sustainability science, including those that address population and economic growth and the qualitative aspects of environmental impacts. Industrial ecology and industrial symbiosis can be fruitful approaches in the process to make progress in sustainable development. We invite you, the reader, to respond to this triple special issue and its 12 international peer-reviewed contributions. Critical responses and debate are encouraged for publication in the journal.

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