Industrial Ecology and Eco-Efficiency

An introduction to the concepts

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Abstract.
This paper gives a brief presentation of the Industrial Ecology study- and research programs at the Norwegian University of Science and Technology, NTNU. These programs have been running for a few years, and they have recently been evaluated. The revised program will be presented. A central topic within the framework of industrial ecology is eco-efficiency. Eco-efficiency should be a tool for measuring internal progress as well as a tool for communicating level of economic and environmental performance. Some of the research projects in the NTNU-program are dealing with this concept. It is put effort in clarifying the terminology of eco-efficiency, the definitions and the methodologies for selecting eco-efficiency indicators, and how they can be used for reporting purposes and as a tool for improvement measures. The paper will present examples of the use of indicators for eco-efficiency measures both for production sites and for products and value chains. The paper will further give an overview of coming international requirements to environmental reporting in the context of industrial ecology. Here we find different types of reporting initiatives, e.g. are eco-efficiency reports informing about economic performance in addition to the environmental performance while sustainability reporting encompasses both social, economic and environmental aspects, the "triple bottom line". Today we see a move from traditional environmental reporting against eco-efficiency reporting and sustainability reporting. For products we see an international standardisation effort of environmental product declarations (EPDs), and the research within the industrial ecology program at NTNU, try to find eco-efficiency indicators that are possible to be harmonised with the product declaration standards. The paper will in addition give a few examples of eco-efficiency indicators for different branches, and at last some thoughts on appropriate indicators for groups of companies within a selected region.
Introduction
The concept of Industrial Ecology (IE) is based on an analogy between industrial systems and ecological systems. In nature, an ecologically sustainable system is a complex web of organisms, where materials and waste build cycles. A society that is organised according to the principles of IE will be similarly characterized by industry and industrial products forming value chains, where energy and materials enter loops that are kept as closed as possible. These products evolve through design, production, distribution and consumption. When they are disposed of, their energy and material can be used in new products and processes. By placing extended focus on the entire material and energy cycles, IE involves subjects within disciplines that range from humanities, the social sciences to the natural sciences and technology.

IE is also seen as a strategy complementary to Cleaner Production (CP). While CP focuses on individual companies, the strategy of IE focuses on a group or cluster of companies (e.g. industrial parks).

Industrial Ecology at the Norwegian University of Science and Technology
The Industrial Ecology Programme is a multidisciplinary programme at the Norwegian University of Science and Technology (NTNU). It is responsible for the coordination of NTNU's activities in education, research and communication in the area of IE. The program was started after an initiative from Norsk Hydro, and soon involved other industrial companies as well as the Norwegian Ministry of the Environment. It receives significant funding from the Norwegian Research Council, but also relies on business and industry partners for its activities. Industrial cases are important parts in the under-graduate education, and of mutual benefit to business, industry, researchers, doctoral and master students in their work.

Present business and industry partners include furniture companies, oil companies, packaging companies and suppliers for the car-industry all over the world. The governmental agencies like the Ministry of the Environment and the Pollution Control Authority (EPA) are supporting the program. In addition a number of other industrial companies are involved in the case projects within the research programme Productivity 2005 - P2005.

The Industrial Ecology Study Programme stands out as the most important long-term activity within its areas of responsibility. It was started in 1999, and is offered to students in engineering, natural sciences, social sciences and the humanities from their third year of study.

Students specialise in IE not instead of but in addition to a discipline. Students in chemical engineering still become chemical engineers, and political science students still become political scientists. The Study Programme gives students an alternative way of understanding and acting in the world; this enables them to perform their profession in a more sustainable fashion. In this sense, IE also becomes a basis for communication and cooperation among students, researchers and practitioners from a host of different disciplines.

In the Study Programme curriculum, the focus is upon local, regional and global use and flow of materials and energy in products, processes, industrial sectors and economies. The role of industry in reducing the environmental burden and minimize resource needs of products in a life cycle perspective is investigated. Students are to acquire skills in evaluating opportunities of improvements in products, production systems and technical infrastructure as well as changes in societal and political conditions necessary for the promotion of sustainable production and consumption.

The Study Programme consists of eight courses, six of them being compulsory core courses, and two of them being optional among six alternatives. The core courses construct a mental staircase of progressing sophistication of thought, and introduce students to the application of theories and methods
of central reference to the field. The two optional courses give students the possibility to widen their special field or concentrate on certain aspects of IE.

The six courses constituting the compulsory core part of the Study Programme are:

- Industrial Ecology and Systems Analysis
- Environmental Science and Occupational Hygiene
- Environmental and Resource Economy
- Environmental Systems Analysis and LCA
- Systems for Recycling and Closed Material Loops
- Strategies, Innovation and Change

In addition to the compulsory core courses, the students choose two out of six courses:

- Eco-Toxicology and Environmental Resources
- Geo-Resources
- Energy and Environmental Consequences
- Ecological Design
- Environment and Safety Management in Public Administration and Industry
- Environmental Politics

After having completed the Study Programme, students can choose an IE angle for their master thesis. The Industrial Ecology Programme will assist in supervising students in addition to tutoring offered to them by their home department (IndEcol 2002).

**Eco-efficiency – the concept and the use of eco-efficiency in reporting.**

Around 12 years ago the United Nations Environmental Programme (UNEP) developed the CP-strategy. CP was mainly developed on the background of some waste minimization efforts in USA and later Pollution Prevention defined by the Pollution Prevention Act. Basically the concepts Waste Minimization, Pollution Prevention and CP are for practical reasons identical. Later on the Organisation for Economic Co-operation and Development (OECD) in cooperation with World Business Council for Sustainable Development (WBSCD) developed the concept Eco-Efficiency in order to accommodate the CP concept and make it more familiar to the philosophy of the business community. Eco-efficiency is a central topic within the framework of industrial ecology. Schmidheiny first introduced the term in the book *Changing Course* (Schmidheiny 1992) that was a product of the Business Council for Sustainable Development and presented at the Rio Earth Summit in 1992. The purpose with eco-efficiency is very simple – to maximise value creation and minimise environmental burdens. There exist several definitions on eco-efficiency. World Business Council for Sustainable Development (WBCSD) defines eco-efficiency as “the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impact and resource intensity throughout the life cycle, to a level at least in line with the earth’s estimated carrying capacity” (DeSimone and Popoff 1997). OECD defines eco-efficiency as “the efficiency with which environmental resources are used to meet human needs” (OECD 1998).

The most important difference between these two definitions is that WDCSD include the carrying capacity in their definitions, while OECD look upon eco-efficiency more as a straightforward measure on the exploitation ratio of the resources that are introduced to the economy.

Eco-efficiency is also viewed as a tool to promote improvements of environmental performance. As a tool it has a wide range of use. The two most important is probably as a
tool for measuring internal progress and for communicating level of economic and
environmental performance. The combination of economic and environmental information
makes the results easy to understand and to interpret, and it also take into account fluctuations
in production volume and related changes in environmental performance.

The most used formula for operationalising eco-efficiency is (e.g. Verfaillie and Bidwell 2000):

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Eco - \text{efficiency} = \frac{\text{Product or service value}}{\text{Environmental influence}}
\]

As this formula shows, the consideration of the carrying capacity is not included when eco-
efficiency is operationalised and hence at the time being not a part of what actually is
measured. Eco-efficiency can thus be improved through increased value creation and/or
reduced environmental influence. Using this formula, improved eco-efficiency will result in
an increased indicator value. Graphic interpretations will give upward arrows and are thus
familiar for business where upward arrows indicate a desirable development.

To measure eco-efficiency, both product or service value and environmental influence must
be quantified. Product or service value can be measured in different terms; as quantity of
produced goods, as a monetary value or as the fulfilment of a need or function. Verfaillie and
Bidwell (2000) are recommending two indicators for product or service value that they claim
to be applicable for all kinds of companies:

- quantity of goods or services produced or provided to customers
- net sales

Similar, they are recommending five generally applicable indicators for measuring
environmental influence:

- energy consumption
- materials consumption
- water consumption
- greenhouse gas emissions
- ozone depleting substance emissions

These indicators must however not be regarded as a complete list. Different companies must
identify what environmental aspects that are most important for their activities and used this
to develop environmental performance indicators (EPIs) through a bottom-up approach.
Based on national political goals EPIs can also be developed through a top-down approach.

In addition it is appropriate to diverge between functional eco-efficiency and technical eco-
efficiency. Functional eco-efficiency gives a measure on how well a system performs in
relation to a defined target. Technical eco-efficiency on the other hand, gives a measure on
how well a specified system utilises the resources put into the system. The last one is the most
used in environmental reporting today and can be measured as

\[
Eco - \text{efficiency} = \frac{\text{quantity of produced goods}}{\text{environmental influence}} = \frac{\text{net sales}}{\text{environmental influence}}
\]

Environmental influence is equivalent with the environmental performance within a specific
impact category, and expressed by EPIs. (e.g. energy consumption or emission of greenhouse
gasses).
Reporting:
The intention with environmental reporting is to inform on the environmental aspects of a company, on the environmental achievements and on the goals for environmental improvements in the future. There are different types of reporting. Eco-efficiency reports inform about economic performance in addition to the environmental performance while sustainability reporting encompasses social, economic and environmental aspects, the "triple bottom line". Today we see a move from traditional environmental reporting against eco-efficiency reporting and sustainability reporting.

Indicators are frequently used to report the environmental performance. Figure 1 shows the three pillars in sustainable development as the corners in the triangle, and indicates reporting at different levels. In environmental reporting EPIs are commonly used. In eco-efficiency reporting we see that eco-efficiency indicators are the tools to be used to communicate the performance. In sustainability reporting different indicators can be used. As shown in Figure 1, socio-economic indicators and socio-ecological indicators are useful tools in addition to already mentioned indicators. Sustainability reporting is to be used at company level, but will also most probably be a useful information tool for groups of companies or within a region where IE is defined as a common strategy towards sustainable development.

Figure 1: Sustainable development encompasses ecological, economic and social aspects; sustainability reporting is the most comprehensive reporting.

Organisations like UNEP, WBCSD and OECD have a strong influence on the requirements set to such reporting. One of the initiatives by UNEP is the Global Reporting Initiative (GRI). GRI was established in 1997 with the mission of developing globally applicable guidelines for reporting on economic, environmental, and social performance. The GRI's Sustainable Reporting Guidelines (GRI 2000) represent the first global framework for comprehensive sustainability reporting. They give guidance to reporters on selecting generally applicable and
organisation specific indicators, as well as integrated sustainability indicators. Ahead-looking indicators like strategy, management indicators, trend information, and targets for future years are also included. Today, at least 2,000 companies around the world voluntarily report information on their economic, environmental, and social policies, practises, and performance.

In addition WBCSD (see e.g. DeSimone and Popoff 1997 and Lehni 2000) has developed seven guidelines that can help companies improve eco-efficiency. Improvements along these will lead to improved eco-efficiency:

- minimise the material intensity of goods and services
- minimise the energy intensity of goods and services
- minimise toxic dispersion
- enhance material recyclability
- maximise the use of renewable resources
- extend product durability
- increase the service intensity of goods and services

According to DeSimone and Popoff (1997) indicators should be developed to cover all these.

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Figure 2 shows examples of eco-efficiency indicators, sales in proportions to emissions of climatic gases (here, CO₂) and acidic components (NOₓ and SO₂). The eco-efficiency indicator for emissions of climatic gases shows a positive development over the past four years. For acidic components, the result shows an improvement for last year.

So far eco-efficiency is also only used for single production sites or processes (see e.g. Keffer et al. 2000). This leads to a danger of sub-optimisation. Some of the research at NTNU is thus directed to develop methods to use the concept and indicators also at a supply chain level.
Environmental Product Declarations
The most common is to use eco-efficiency to inform about an organisation's performance. However, more and more attention is put to the products that are spread all over the world. Different environmental labels are introduced for products, among other the Nordic Swan, the German “Blauen Engel”, and the EU eco-label scheme (the "Flower"). In addition ISO-standards on environmental product declaration are developed through the ISO 14020-series. Declarations aimed at consumers are recommended to include a third party certification, a common format within each product group, a full life cycle approach (in compliance with ISO 14040 series of standards on LCA) and interested party input. Environmental Labels Type I (ISO 14024), Environmental Claims Type II (ISO 14021) and Environmental Declarations Type III (ISO 14025), also called EPDs, should not be merged together. However the use of other labels or claims separately is not excluded. Type III Environmental Declarations and non-confidential information shall be made publicly available.

Some of the research activities in the IE research program at NTNU are focusing on building up models for how to calculate and present the eco-efficiency of different products. The research is based on the models developed by BASF in Germany (BASF 2002) similarly to eco-efficiency for processes there are research activities at NTNU focusing on the development of eco-efficiency for products. In this model the environmental impact is described based on five categories:
- Raw materials consumption
- Energy consumption
- Air and water emissions and disposal methods
- Potential toxicity
- Potential risks

Combining these individual data gives the total environmental impact of a product. Economic data are also compiled. All the various costs incurred in manufacturing or using a product is included in the calculation. The economic analysis and the overall environmental impact are used to make eco-efficiency comparisons. Economic and ecological data are plotted on an x/y graph. The costs are shown on the horizontal axis and the environmental impact is shown on the vertical axis. The graph reveals the eco-efficiency of a product compared to other products. And it allows looking into the future, since eco-efficiency analysis is utilized in making strategic decisions within IE. It also helps detect and exploit potential ecological and economic improvements. Figure 3 shows an example of how products with similar function can be placed in an eco-efficiency model. The model ranges the products from having low eco-efficiency in the left lowest corner to the ones with best eco-efficiency in the right upper corner.
There are still some efforts to do in finding appropriate eco-efficiency indicators to be harmonised with the requirement set in the environmental product declarations in accordance with the ISO 14020-series.

**Summary and further challenges**

WBCSD focuses on the development of eco-efficiency indicators and systemised ways of measuring eco-efficiency. Accurate measurements can help managers make decisions and assess whether their objectives can be met or not. The objective is not to develop one single approach to measuring and reporting eco-efficiency. Rather, it is to establish a general, voluntary framework that is flexible enough to be widely used, broadly accepted and easily interpreted in different sectors. The concept identifies two categories of indicators: commonly used; ‘generic core indicators’ and ‘business specific supplemental indicators’. WBCSD has proposed five elements of this voluntary framework (Verfaillie, H. A. and Bidwell, R. 2000):

1. Agreed definitions and terminology for environmental and value related indicators.
2. A recommended set of core-indicators following a widely agreed measurement methodology.
3. A process for developing “supplemental” indicators relevant to specific businesses.
4. A mean by which the eco-efficiency indicators, can be quantified.
5. Recommended ways for companies to communicate eco-efficiency measurements.

The UNEP’s GRI seeks to make sustainability reporting as routine and credible as financial reporting in terms of comparability, and verifiability. Specifically, the GRI's goals are to develop a generally accepted sustainability-reporting framework leading to simplification of the reporting process for organisations in all regions and countries, reliable benchmarking, and more effective linkage between sustainable practises and financial performance. The *OECD Environmental Outlook* suggests a range of policy options to address the main environmental concerns. The OECD Environmental Strategy (OECD 2001) identifies five interlinked objectives for enhancing cost-effective and operational environmental policies in the context of sustainable development:

1. Maintaining the integrity of ecosystems through the efficient management of natural resources;
2. De-coupling environmental pressures from economic growth;
3. Improving information for decision making: Measuring progress through indicators;
4. The social and environmental interface: Enhancing the quality of life; and
5. Global environmental interdependence: Improving governance and cooperation.

These objectives are in line with the IE strategy where one of the goals is sustainable products and production systems. One challenge is to agree on common rules of system description and
evaluation techniques to ensure that the eco-efficiency can be compared and benchmarked. Another challenge is to use eco-efficiency indicators for communication purposes among companies and other interested parties within an industrial network. This requires knowledge and understanding on a similar level among the involved persons. To implement the use of eco-efficiency as a tool for communications and improvement within e.g. a region, only a few indicators on environmental an economic performance should be selected in the beginning to test out both the availability of data and the understanding of the concept. The most obvious way is to start with eco-efficiency measures on company level, then on value chains and at last on a network within a smaller community.

References:
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ISO 14021: *Environmental labels and declarations – self-declared environmental claims* (Type II environmental labelling)
ISO 14024: *Environmental labels and declarations – Type I environmental labelling – principles and procedures*
ISO TR 14025: *Environmental labels and declarations – Type III environmental declarations*