Environmental Metrics

The Main Opportunity from ICT for Industrial Ecology

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There is a growing interest in the use of information and communication technologies (ICT) for environmental sustainability, including from academia, industry, and governance. There are still concerns about ICTs' direct environmental impact, such as energy use and e-waste. The positive effects of using ICT for sustainability, however, are argued to be bigger (Climate Group 2008; Tomlinson 2010), and the corpus of research in this area is growing fast (DiSalvo et al. 2010). We have identified some of the most prominent trends in this research and organized them into three clusters where ICT has a positive impact on environmental problems: optimization, dematerialization, and behavioral change. Metrics, the measurement and accounting of data, are presented as the common ground for all three and therefore a main opportunity that arises from ICT for industrial ecology.

With ICT it is possible to have accurate "metabolism accounting" in real time. . . . Measuring the environmental impacts in a fast and accurate way provides instant feedback to enable improvements in the flow of energy and materials within the systems.

Optimization

ICT provides numerous opportunities for increasing efficiency and decreasing resource use in existing systems. One reason for this is that sensors are getting smaller and cheaper and are more common in many applications, from buildings to personal electronics and mobile phones. Many data from physical flows can be sensed: geographic position, local temperature, soil nutrient level, atmospheric pollution, speed, user heartbeat, sunlight intensity, or livestock position, for example. Sensors enable accounting of invisible environmental variables, with great granularity and in real time. Being aware of these variables, intelligent systems can optimize the use of many processes currently under manual control. Examples of ICT optimization include smart grids, office climate, crop irrigation and fertilization, window shadowing, and logistic systems. As computer technology becomes more pervasive in the physical world, the potential for optimization in other contexts will increase. There is a risk, however, of rebound effects, whereby unexpected usage and changes in behavior can cancel out the gained efficiency (Hilty et al. 2006).[1] Researchers need to design and measure interventions to verify the total benefit and avoid unwanted negative effects.

Dematerialization

From an industrial ecology perspective, dematerialization is usually seen as the optimization of materials used in production. In the ICT

Supplementary material is available on the *JIE* Web site

DOI: 10.1111/j.1530-9290.2010.00272.x

Volume 00, Number 00

context, dematerialization is a more radical transformation, focusing on the move from physical products and services toward virtual ones. Two main assets have been the subjects of ICT dematerialization:

- Knowledge and cultural products: music, films, books, news, and statistics, for example.
- Presence: videoconferences, virtual presence, e-learning, services such as e-banking, e-government, and tele-medicine, for example.

From a sustainability point of view, these changes provide huge opportunities. The energy use and its connected environmental impact (i.e., creating and moving bits) are usually smaller than the impacts of transforming and moving material or people. This positive impact has been studied and established for several cases focusing on energy and climate change impact—for instance,

- reading newspapers or books on an e-reader rather than on paper
- using e-banking services, such as electronic instead of paper invoices
- videoconferencing instead of traveling to provide services in rural areas

Even if the environmental performance is improved, there are still risks of unexpected rebound effects due to unpredicted behavioral changes. Some classical examples of failed dematerialization are the increase in paper consumption with the introduction of the computer (instead of the promised paperless office) and the increase in traveled distance by teleworkers (Fuchs 2006).

Behavioral Change

Computer technologies are increasingly being used with persuasive intent. They can support behavior change when the willingness to change exists but the actions to be taken are difficult. Most existing interventions focus on health behaviors, such as exercising more frequently, stopping smoking, or eating healthier.[2] A growing number of projects work on applying these techniques to inform and change environmental behavior (DiSalvo et al. 2010). Examples of existing efforts include the following:

- PEIR[3] at the University of California, Los Angeles, which calculates the environmental impact of personal transportation using global positioning systems (GPS) and mobile phone sensors
- Eco-Island[4] at Waseda University, which helps lower household energy consumption through a game interface using competition and cooperation
- Good Guide,[5] which provides consumers with environmental information at the moment of purchase

These applications use different strategies, such as self-monitoring, praise, competition, social proof, and goal setting. Those strategies have been proven successful in other areas, such as health. Their actual impact and long-term effect in sustainability, however, are still mostly unverified.

Environmental Metrics

There is a growing interest in the proactive use of ICT as a tool for mitigating environmental problems—as a tool for industrial ecology. Optimization, dematerialization, and behavioral change can be seen as clusters of the existing developments and trends. We argue that metrics—the measuring and accounting of data—are the most important concept underlying all three opportunities and the common opportunity arising from the current state of the art.

As computers become more pervasive, metrics are getting more accurate, more extensive, and more important in the way the world is viewed and decisions are made. Pedometers in our shoes measure the distance and speed when we run and share the information on the Internet to persuade us to exercise more. Detailed Web analytics telling how many people have accessed a site, from where, and for how long are key in the way online businesses are managed. Mashups of global statistics, such as Gapminder,[6] help people understand the world's developments. We use ICT to measure and work with quantitative data in a growing number of contexts. Sustainability is not an exception, and all three identified clusters are based on or in need of metrics:

- Optimization is clearly data-centric. Efficiency applications, such as smart grids or smart buildings, are based on the measuring and analysis of quantitative data. Metrics are also a key in the evaluation of such interventions, verifying their results and identifying rebound effects.
- Dematerialization does not use environmental data in the same central way as do optimization or behavioral change. We see a need for metrics, however, to avoid the kind of rebound effects that have altered environmental gains in the past. Researchers need to measure and control the effects of such interventions to verify the actual reduction.
- Many behavioral change applications, such as PEIR or Good Guide, are based on the collection, analysis, and communication of environmental data. Metrics are used to inform the user, as a basis for providing actions, and for evaluation of the results.

The power of measurement is highly relevant to the concept of industrial ecology. In the analogy of industrial metabolism,[7] the accounting of energy and material flows is fundamental. With ICT it is possible to have accurate "metabolism accounting" in real time. Compared with static data, the use of sensors and information technologies allows a real-time gathering of bottom-up data, which facilitates a more dynamic approach to industrial ecology. Measuring the environmental impacts in a fast and accurate way provides instant feedback to enable improvements in the flow of energy and materials within the systems. This may be possible not only for industrial and mechanical processes but also for personal, household, or even city metabolisms.

ICTs have great possibilities as tools in industrial ecology. Measurement and accounting of environmental data can be seen as the basis of those possibilities, and they can help in decision making, consequently optimizing, leading to behavior change, and avoiding rebound effects. Our prognosis is that this kind of ICT-enabled environmental metrics will gain a relevant position in the practical work of industrial ecology.

Notes

1. Editor's note: For a series of articles assessing the direct and indirect effect of information technology on environmental outcomes, see the special issue of this journal on e-commerce, the Internet, and the environment (volume 6, number 2).
2. For more information about persuasive technology, see http://captology.stanford.edu.
3. http://peir.cens.ucla.edu/
4. http://www.dcl.info.waseda.ac.jp/ami/ecoisland
5. http://www.goodguide.com/
6. http://www.gapminder.org/
7. *Industrial metabolism* refers to the system of processes and flows by which resources are converted into products and wastes in an industrial or socio-technological system.

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Supplementary Material

Additional Supplementary Material may be found in the online version of this article:

Supplement S1: An appendix containing additional references related to information and communication technology (ICT) and the environment, including publications on optimization, dematerialization, and behavioral change.

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