better linking material flows, as in recycling, to this still static framework.

The linkage of natural science, social science, and normative analysis remains a fundamentally unresolved issue in industrial ecology. There are dangers of physical reductionism, on the one hand, and disregard for social causalities, on the other, with free will and more general autopoietic cultural mechanisms unduly squeezed by both.

Clearly, the visions differ in many respects and cannot be combined into one overarching view of the industrial ecology cathedral. Quite some work is still to be done, at all levels of analysis.

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Social Metabolism and Hybrid Structures

Marina Fischer-Kowalski and Julia K. Steinberger

What are the most promising (or necessary) directions for an integrated socio-environmental science capable of facing the challenges of sustainability? Our research findings at the Institute of Social Ecology in Vienna suggest there is a need for a new epistemological paradigm that allows the re-connection of the fields that have become separated by the "great divide" (Snow 1959) in the course of the evolution of academic disciplines. This new paradigm can be outlined by the following general principles.

1. Respect the qualitative differences between biophysical realities and the cultural/social/economic realm of meaning, the latter dominated by communicative interconnectedness, rather than causal relationships. Simply merging the two realms currently situated on different sides of the divide leads to a reductionism that will be rejected by both intellectual traditions. Separation implies mutual non-substitutability; blindly applying ideas from ecology or other natural sciences to social systems inevitably leads to fatal oversimplifications, the most famous example perhaps being Hardin's Tragedy of the Commons. Conversely, the social domain is often tempted to borrow ideas from natural sciences as metaphors, which too often only serves to creatively obscure reality. A truly integrated social and environmental science requires openness and a healthy dose of skepticism: ideas and concepts should be tested, contrasted, pitted against each other, so that new, better ideas and paradigms can emerge. Complexity should be acknowledged without being fetishized.
2. Maintain a thorough understanding of the global biogeochemical cycles and the various types of physical interdependencies they imply. We know that biogeochemical cycles are connected, though in no way substitutable. But this understanding needs to become foundational to our integrated science, to avoid simple mistakes with profound implications, such as the notion that biofuels can substitute fossil fuels, or that hectares are an appropriate way to measure carbon emissions. Taking stock of interdependency and non-substitutability requires moving beyond simple air-soil-water categorizations, to the ecosystem level, and also beyond individual sectors of the economy. Grand cycles remind us to transcend territorial boundaries, and include globalization and trade in our analysis. The

biogeochemical cycles and their anthropological perturbations are the evidence of an integrated earth, and it is imperative that our science rise to the task of explaining the interconnected social and cultural activities which have such global implications.

3. Respect the diversity of geographic locations and scales, while avoiding the pitfall of local studies which often equate social system boundaries with a certain area and fail to detect larger functional patterns. Recognize the decisive role of interconnectedness between regions, through trade, migration, communication, and, crucially, through history, as well as through the grand cycles mentioned above.
4. Respect the directionality of time and the system-specificity of time horizons. Deal with path dependencies and long-term effects in both directions (sustainability is a long-term issue—and has been in many earlier societies). Be prepared to learn from longer time horizons than the post WWII era, not just in terms of environmental challenges, but also of social upheavals.
5. Focus on hybrid structures (Latour 1993) that mediate between the two realms, and mediate between past and future across time. Hybrid structures are structures molded both physically and culturally, in which the rules of the two realms are somehow superimposed upon one another. Such hybrid structures include technologies, infrastructures, and physical stocks of social systems; in our view, these also encompass the human population. Traditional sciences, both natural science and the humanities, cannot appropriately deal with such hybrid structures: they perceive only one aspect but fail to recognize the others. These hybrid structures have to be reproduced culturally/socially/economically as well as physically. This is where the notion of social metabolism takes hold, as the system of socially governed physical flows that are required to reproduce society's hybrid structures. Future research lines should identify sustainable societal directions through their hybrid structures, but also explicitly deal with the legacy of current hybrid structures, which will continue to influence society and the environment far into the future.
6. Be aware of the autopoietic character of economic cycles: in the end, money will buy you physical objects (or set in motion physical work). And in the end, efficiency will not buy you physical resource savings, but instead drive growth (Ayres and Warr 2009; Polimeni et al. 2008).
7. Pay attention to the human population, its size, demographic structure, and wellbeing. This should be obvious, but is too often forgotten in favor of economically focused analyses. The economy's function is symbolic valuation and prioritization, and although it is not fully disconnected from human wellbeing, studying human wellbeing should be a separate, and possibly more important, focus of sustainability research. An integrated sustainability science should be informed by the fields of demography and public health, and grapple with the issue of defining a fulfilling, meaningful life, given the diversity of human experience and potential.

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Resource Efficiency

Five Governance Challenges Toward a Green Economy

Raimund Bleischwitz

The European Union (EU) has selected resource efficiency as one of the seven flagship initiatives for its 2020 strategy.[1] It aims to bring major economic opportunities, improve productivity, drive down costs, and boost competitiveness—while also supporting a low-carbon economy and sustainable growth. In a similar spirit, the Organisation for Economic Cooperation and Development (OECD) and the United Nations Environment Programme (UNEP) promote resource efficiency in their campaign for "green growth" and a "green economy." Research is needed to assess the merits of different strategies and to identify suitable policies and levers for action, especially to minimize risks. I argue that industrial ecology can indeed provide valuable insights. A probably even more important aspect is the need to strengthen research on innovation and transition management. This will require collaborative research that allows actors and institutions to be centrally addressed. The following sections explore key opportunities and risks associated with resource efficiency and draw conclusions on five central challenges. The definitions in this short article follow the OECD handbook on measuring resource productivity as well as related work by the Wuppertal Institute (Bringezu and Bleischwitz 2009).

Opportunities: Cost Reduction and Process Innovation in the Manufacturing Industry

Given that material purchasing costs are relevant for business, a number of studies have identified a remarkable potential to save these material costs using resource efficiency tools. Data on the relevance of material costs in industry exist but are not yet commonly available. A recent Eurobarometer survey shows that more than half of European companies in the manufacturing, construction, water, food services, and agricultural sectors spend at least 30% of their total costs on materials. Almost 90% of the enterprises surveyed expected prices to rise even further in the coming years. The resulting opportunities for innovation are just emerging. Around 45% of active eco-innovating companies were able to realize savings between 5% and 39%, whereas in a few cases material reductions of 40% or even 60% were achieved.

Our conclusion is that the evidence for such opportunities is robust but that there is a need for more research into "net material costs," as distinct from added labor costs of suppliers (de Bruyn et al. 2009, 27), information deficits, and other barriers to dissemination at the level of business, industries, and countries. Other opportunities, such as system innovation and long-term reduction of primary materials, require more in-depth research that captures patterns of change, technology pathways, and their socioeconomic levers.

Risks: What if Only Selected Business Opportunities Are Being Exploited?

A resource efficiency strategy has to be comprehensive, both from an environmental and from an innovation-oriented point of view. Because Europe and many other regions import large percentages of their resource requirements, there is a real risk of shifting environmental burdens abroad. International trade aggravates this risk through exports of used goods, such as cars and electronic devices, causing their end-of-life processing to occur in developing countries, where environmental standards tend to be lower than in the industrialized world. In an analysis of physical trade balances, Dittrich (2009) showed that between 1960 and 2005, the growth of traded goods increased about 3.5-fold (in terms of weight), whereas the *ecological rucksacks* (or hidden flows) of these traded goods increased by a factor of