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Methodological and Ideological Options

Socioeconomic metabolism as paradigm for studying the biophysical basis of human societies☆

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ABSTRACT

A wide spectrum of quantitative systems approaches such as life cycle assessment or integrated assessment models are available to assess sustainable development strategies. These methods describe certain aspects of the biophysical basis of society, which comprises in-use stocks and the processes and flows that maintain and operate these stocks. Despite this commonality, the methods are often developed and applied in isolation, which dampens scientific progress and complicates communication between scientists and decision makers. As research on socioecological systems matures, more structure and classification are needed. We argue that the concept of socioeconomic metabolism (SEM), which was developed in material flow analysis and material flow accounting, is a powerful boundary object that can serve as paradigm for studying the biophysical basis of human society. A common paradigm can facilitate model combination and integration, which can lead to more robust and comprehensive interdisciplinary assessments of sustainable development strategies. We refine the notion of SEM, clarify the relation between SEM and the economy, and provide a list of features that we believe qualifies SEM as research paradigm. We argue that SEM as paradigm can help to justify alternative economic concepts, suggest analogies that make the concept more accessible, and discuss its limitations.

1. Introduction

1.1. The Interdisciplinary Systems Approach to Increase Environmental Literacy

Human interference with global bio-geochemical cycles has grown to a level where human actions are likely to trigger epochal changes, like dangerous climatic change (IPCC, 2014; UNFCCC, 1992) and a state shift in the Earth's biosphere (Barnosky et al., 2012). A new age, the anthropocene, was ushered in (Steffen et al., 2011), during which humans not only cause but anticipate and respond to epochal changes by adapting to new environmental conditions and by mitigating negative human impacts on the natural environment. Mitigation and adaptation strategies include geoengineering, technology development and deployment, economic instruments like taxes and subsidies, regulation and standards, and changes in consumer choices and lifestyle. To design and successfully implement adaptation and mitigation strategies for the coming global socio-metabolic transition (Krausmann and Fischer-Kowalski, 2013; Krausmann et al., 2008), humans require 'environmental literacy', which is the "capability […] to appropriately read, utilize, and adapt to environmental information, resources, and system dynamics" (Scholz & Binder 2011). At present, human environmental literacy is higher than ever before, and a wide range of scientific methods is applied to further increase it.

The systems approach is the widely accepted epistemological basis of environmental literacy. Under this approach, human society is considered a complex autopoietic system (Deutz and Ioppolo, 2015; Forrester, 1968; Maturana and Varela, 1980; Meerow and Newell, 2015; Rammel et al., 2007; von Bertalanffy, 1968), that is a complex system that can reproduce and maintain its structures and so compensate for the inevitable losses due to the second law of thermodynamics with the help of external energy and material input (Ayres and Kneese, 1969; Georgescu-Roegen, 1971). Human societies form a hybrid of the material or biophysical realm and a symbolic or social realm (Fischer-Kowalski and Weisz, 1999), and together with their natural environment, they are commonly described as socio-ecological systems (SES) (Binder et al., 2013; Holling, 2001; Ostrom, 2007, 2009). SES contain many interlinked bio-physical and social aspects (Spash, 2012), nonlinearities, and feedback mechanisms, and they are non-deterministic because human agents use their environmental literacy to deliberately change the development of the system.

The complexity of SES poses major challenges to the scientific approach to increasing environmental literacy. First, researchers cannot reliably predict the development of complex systems even if they understand the underlying mechanisms. Research can, however, shine

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light on the role of different factors and illustrate potential outcomes. Second, and in the focus of this work, complexity challenges boundaries between established scientific disciplines. Inter- and trans-disciplinary collaboration of researchers from many fields can increase our environmental literacy (Baumgärtner et al., 2008). This type of research requires certain concepts about SES that are general enough to facilitate exchange among disciplines and between science and the public (Brand and Jax, 2007) and that are clearly specified and well described to be of practical use in the different fields. Concepts like 'resilience', 'industrial ecosystem', or 'metabolism' can enrich science and facilitate interdisciplinary research as metaphors (Ehrenfeld, 2004), boundary objects (Star and Griesemer, 1989), or even research paradigms (Kuhn, 1996). When properly communicated, their integrative power can facilitate the development of new research questions and data exchange and avoid re-labeling or 're-invention' of existing concepts under new names. Common concepts can also motivate people to stop thinking in silos of individual methods and frameworks and appreciate their work as part of a spectrum of similar or complementary efforts to increase environmental literacy.

1.2. Quantitative Systems Analysis of the Biophysical Basis of Society

Quantitative approaches to study the biophysical basis of human societies are a central component of the research on socioecological systems, and a variety of methods to study that basis has developed as part of distinct research traditions. In our opinion, these research traditions could benefit from the appreciation of common concepts in ways described above, and the elaboration of a suitable overarching concept for these methods is the scope of this work.

Descriptive research approaches include purely physical modeling approaches like material flow accounting (MFA) (Eurostat, 2001; Fischer-Kowalski et al., 2011), substance or material flow analysis (Baccini and Bader, 1996; Baccini and Brunner, 2012, 1991), or physical supply and use tables (SUT) (Miller and Blair, 2009; Pauliuk et al., 2015; Suh et al., 2010). Attributional or footprint-type methods include life cycle assessment (LCA) (Heijungs and Suh, 2002; ISO, 2006) and environmentally extended input/output analysis (EE-IO), especially multi-regional input/output analysis (Miller and Blair, 2009; Wiedmann et al., 2011). Prospective methods include the econometric, partial equilibrium, or system dynamics models of the energy system that come as standalone models (Cambridge Econometrics, 2014; Jebaraj and Iniyan, 2006; Pfenninger et al., 2014) or that are part of integrated assessment models (de Vries et al., 2001; Loulou et al., 2005; Richardson, 2013), computable general equilibrium models (CGE) (Burfisher, 2011), system dynamics approaches (Buongiorno, 1996; Pruyt, 2010; Sterman, 1994), and agent-based models (Axtell and Andrews, 2002; Sopha et al., 2011).

The different methods partly depend on each other. CGE models, for example, are built from Leontief IO models, which in turn are derived from SUTs. Moreover, many 'hybrid models' that combine features of different methods exist. Those include hybrid LCA, mixed-unit I/O, waste-I/O, combinations of LCA and CGE, extended dynamic MFA, scenario-based hybrid I/O, and consequential LCA (Dandres et al., 2012; Earles and Halog, 2011; Finnveden et al., 2009; Hawkins et al., 2007; Heijungs and Suh, 2002; Hertwich et al., 2015; Modaresi et al., 2014; Nakamura and Kondo, 2002; Nakamura et al., 2008; Suh et al., 2004).

The methods differ regarding the choice of system boundary, process resolution, the layer of analysis (physical or monetary), regional coverage, exogenous drivers, and the way they model the interaction between human society and nature. Despite these differences, the methods have one central commonality. They all describe certain aspects of the biophysical structures of society (Haberl et al., 2004), which includes human-controlled in-use stocks such as infrastructure, buildings, vehicles, machines and other fixed capital, consumer products, but also our own bodies, and of socioeconomic metabolism, which describes the industrial processes, market activities, commodity flows, and exchanges with nature to build, maintain, and operate the in-use stocks (Fischer-Kowalski and Haberl, 1998).

1.3. Socioeconomic Metabolism as Concept: Metaphor, Boundary Object, or Paradigm?

In a recent paper, Newell and Cousins (2014) ask the community to 'reinvigorate the urban metabolism metaphor' to overcome academic isolation between different fields including industrial ecology, Marxist ecologies, and urban ecology. We strongly agree with them regarding the unifying role of the metabolism concept in the study of socioecological systems from different angles. In a first step towards greater unification, socioeconomic metabolism (henceforth SEM) could be seen as boundary object of different methods that study the biophysical basis of society in different disciplines. A boundary object "is an analytic concept of those scientific objects which both inhabit several intersecting social worlds [including different scientific fields, S.P.] and satisfy the informational requirements of each of them" (Star and Griesemer, 1989). To accommodate the ontological differences across different fields and to create some common identity across fields the general notion of a boundary object needs to be rather vague (Hertz and Schlüter, 2015). The currently prevailing metaphorical use of the concept SEM probably meets this criterion.

We believe, however, that it is necessary to move beyond metaphorical use of the term 'metabolism', because socioeconomic metabolism is more and more often used without explicit reference to biological systems, and because the application of the metabolism concept as boundary object for socio-ecological systems requires a new scoping and redefinition of the term to facilitate analytical rigor in the fields that study SES (Fischer-Kowalski, 1998; Hertz and Schlüter, 2015).

The study of the socioeconomic metabolism as part of the biophysical basis of SES is subject to natural scientific principles, and hence, it follows an explicit or implicit paradigm. In the third edition of The Structure of Scientific Revolutions, Kuhn (1996) defines a scientific paradigm as a group of "universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of practitioners". A paradigm facilitates scientific progress, and ultimately, it helps to increase the relevance of science for society (Kuhn, 1996). Does SEM qualify as 'universally recognized scientific achievement', and hence as paradigm? That would have implications that go far beyond the use of SEM as metaphor or boundary object.

1.4. Research Gap, Goal and Scope of the Paper

Socioeconomic metabolism (SEM) has already been described as paradigm (ConAccount, 1998; Fischer-Kowalski and Hüttler, 1999; Fischer-Kowalski and Weisz, 1999; Fischer-Kowalski, 1998), but the foundations and implications of this assertion were not clearly stated. Moreover, the consequences of this assertion for the systematization of the different methods were not investigated.

This paper tries to fill that gap; it aims to complement the work on the historic development of SEM (Fischer-Kowalski and Hüttler, 1999; Fischer-Kowalski, 1998) by putting the concept into a broader context. We argue that the concept of socioeconomic metabolism, which was developed in material flow analysis and material flow accounting,

(i) is powerful and can be applied more broadly to a number of efforts that have not yet fully recognized that they do research on the same subject and that could benefit from more interaction.
(ii) can serve as paradigm for the study of the biophysical basis of human society, which has further implications that have not been fully recognized yet.

In Section 2 we further elaborate the notion of SEM and examine what might qualify SEM as paradigm for the study of the biophysical