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Is there more in common than we think? Convergence of ecological footprinting, emergy analysis, life cycle assessment and other methods of environmental accounting

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ABSTRACT

Over the last four decades, Environmental Accounting tools have been developed to conceptualise and quantify the *direct* and *indirect* effects of human activity on the environment, to enable decision-makers to track and measure progress towards sustainability outcomes and goals. These environmental accounting methods range from ecological footprinting, carbon footprinting, energy analysis, emergy analysis, ecological pricing and life cycle assessment to environmental input-output analysis. Regrettably, the contemporaneous development of these tools has frequently occurred in isolation from each other, even though they often seek to serve common analytical and evaluative purposes, as well as serving similar communities of interest. It is the central argument of this paper that, in spite of this isolation, the environmental accounting methods have a number of common features – that is, they can be mathematically reduced to similar analytics, and they often confront the same methodological issues – e.g., joint production (co-products) problem, weighting, commensuration, double counting and boundary setting. In this regard the paper reviews how the various environmental accounting tools can 'learn' from each other – e.g., how the mathematics of ecological pricing can address the joint production problem in a number of the other environmental accounting methods; and how the insights from input-output analysis can be used in system boundary setting. The paper concludes by agreeing with previous authors, that a better understanding of any given environmental issue is likely to be achieved by using a mix of these environmental accounting tools, rather than relying on just one tool, one perspective or one criterion.

1. Introduction and context

Over the last century, the world population has quadrupled with associated increases in global resource consumption and waste emissions such that people now consume at a faster rate than the Earth can regenerate (Hoekstra, 2009; World Wildlife Fund, 2010). Such growth has occurred at the expense of the planet's ecosystem health and ability to sustain life (Nelson et al., 2006; Rockström et al., 2009). Sustainable development and management of the planet's ecological assets has thus become a central issue for decisions makers around the world (Best et al., 2008). In this context, there is a need to develop mechanisms, policies and strategies to address this issue, as well as to develop analytical tools to support these processes. Environmental accounting provides a 'family' of tools for assessing resource use, pollution and sustainability in a number of areas ranging from industrial production, green consumerism to areas such as nature conservation, biodiversity and ecosystem services (Patterson et al., 2011).

A range of environmental accounting[1] frameworks, tools and models have been developed, often in isolation from each other, to conceptualise, operationalise and measure the system-wide progress towards to sustainability outcomes and goals. However, sustainability assessment is not an easy or straightforward task, not

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[1] 'Environmental Accounting' is a broad term, crossing a number of different disciplines and perspectives. This paper is restricted to covering 'biophysical' methods of environmental accounting, which primarily use biophysical metrics. This paper does not cover 'environmental accounting' that seeks to integrate national accounts on macro-economic activity and the environment [e.g., United Nations (2014) SEEA system]. Nor does this paper cover environmental accounting that refers to the integration of environmental data into business and firm-level financial accounting and auditing systems (e.g., Gray et al., 1993).

least because of the various ways the concept of sustainability can be interpreted:

- *ecological interpretations* tend to emphasise the ideas of threshold, the steady state (although this is hotly disputed), carrying capacity, interdependence between ecological processes, and the idea that the socio-economic sub-system is embedded within the global biophysical system;
- *economic interpretations* tend to emphasise the idea of social welfare and the external environmental costs associated with economic activity, as well as the principle of intergenerational equity through the use of capital theory;
- *thermodynamic and ecological-economic interpretations* accept the essence of many of the ecological interpretations but go further by situating ecological sustainability in the context of the entropic nature of economic-environmental interactions;
- *public policy and planning* theory approaches to sustainability emphasise the social, institutional, economic and environmental aspects of sustainability within a framework that seeks to achieve a 'balance' or an 'integration' of these factors.

Across many of these interpretations of sustainability has been the perceived need for quantitative indicators to take account of the *system-wide effects* in addition to on-site environmental impacts. For example, a pesticide might have little or no effect at the site of application, but as it flows up the food chain it can concentrate through the process of bio-accumulation. These *indirect and cumulative effects* may become quite profound and more critical than the direct impacts.

Herendeen and Hirst (1972) provide an early example of determining the *indirect* energy use of automobiles. Their data showed that the 'true' energy cost of an automobile was 60% higher than the direct fuel cost, if all of the *indirect inputs* required to run an automobile are accounted for. For example, take 'tyres' as just one of many components of an automobile. There are many inputs required to make 'tyres': the inner, body ply, sidewall, bronze or brass, extruded tread and so forth – all of which require indirect energy to produce them. Furthermore, the automobiles require investment and roading infrastructure which also requires a substantive amount of energy, as does the process of refining oil to produce automobile fuels such as gasoline. When all of the energy inputs of all of the components required by a car are taken into account, it is not hard to see how 60% of the energy required to run a car is non-fuel.

Given the importance of taking account of these indirect effects, as well as the centrality of systems thinking in the sustainability literature, it is therefore not surprising that over the last four decades several Environmental Accounting tools have emerged to take account of *indirect (or system-wide)* environmental effects. The explicit purpose of these tools is, in one way or another, to make 'visible' the indirect environmental effects of human decisions and behaviour – this visibility is needed because, as Herendeen (1998) points out, "most humans tend to think of, deal with, matters that are of local immediate and relatively direct causation".

2. Characterisation of the environmental accounting methods

The main methods of Environmental Accounting methods for measuring and understanding 'indirect effects' in sustainability assessment are: (1) Energy Analysis (EA), (2) Emergy Analysis (EmA), (3) Environmental Input-Output Analysis (EIO), (4) Ecological Footprinting (EF), (5) Carbon Footprinting (CF), (6) Ecological Pricing (EP), and (7) Life Cycle Assessment (LCA). There are, of course, other methods that measure the indirect effects such as 'Material Input per Unit of Service'/MIPs (Schmidt-Bleek, 1994) and Environs Analysis (Patten, 1982) but they are outside the immediate realm of this paper as they are not widely used.

Table 1 evaluates these Environmental Accounting methods in terms of seven criteria: (1) the Method's Purpose, (2) History of the Method's Development, (3) Standardisation of the Method; (4) Analytical Methods Used for Measuring Indirect Effects; (5) Key Concepts, (6) Methodological Rigour of the method, versus the 'Resonance' of the method with both public and professional audiences. Each of the Environmental Accounting methods are evaluated using these and other criteria in the following sub-sections.

2.1. Energy analysis

Perhaps the earliest attempt to understand and quantify *indirect resource/environmental effects* was the growth of Energy Analysis in the early 1970s. Energy Analysis can be defined as "the process of determining the energy required to directly and indirectly produce a specified good or service" (IFIAS, 1974).

Early analysts were often concerned with the way most economists underplayed the role of energy in the economy (Peet and Baines, 1986), and therefore saw it as important to measure indirect and system-wide energy interactions. By adopting this approach over the early 1970s period, a large volume of research papers and articles were produced aimed at calculating the direct and indirect energy requirements of many products and activities, including: food production (Leach, 1976; Steinhart and Steinhart, 1974), packaging (Bousted, 1974), nuclear power stations (Chapman, 1975), automobiles (Hirst, 1972, 1974), polymers (Berry et al., 1975) and so forth.

The methodological development that arose from these early Energy Analysis studies was significant and generally not widely recognised in the contemporary literature. Firstly, the Energy Analysis literature provides the earliest examples of the main methods for calculating indirect environmental impacts including: (i) the *Process Method* requires determining the direct and indirect energy inputs, by diagramming each step in the production chain, and then assigning energy values to each step; (ii) *Input-Output Analysis* by using economic input-output tables to calculate, by matrix algebra, the direct and indirect energy inputs, (iii) the *Hybrid Method* that combines the process method (to quantify the main flows) and then utilises input-output analysis to determine other flows.

Secondly, the Energy Analysis literature successfully identified many of the methodological problems and issues that would then arise in the ensuing decades with the emergence of the other Environmental Accounting methods such as Life Cycle Assessment. These problems that were identified in this early Energy Analysis literature included the: (i) *Partitioning Problem*,[2] which referred to the problem of allocating one energy input to several (or multiple) outputs of a process or system; (ii) *Valuation Problem*. Energy inputs often have quite different qualities (different abilities to be converted to useful work), so therefore the energy inputs need to be commensurated by using an energy quality factor. Notably, this valuation (or commensuration) problem is encountered in the application of all of the other Environmental Accounting methods

[2] We have maintained this Energy Analysis language that was used in the 1970s and persisted even into the late 1990s (Slesser, 1998) which is to use the term "partitioning problem". This is a somewhat loaded term as it assumes the 'multiple product problem' is to be solved by some form of 'partitioning' or 'allocation' of process outputs for the process of inputs. As it turned out, not all of the Environmental Accounting methods ended up resolving the 'multiple product problem' by using 'partitioning' or 'allocation' –eg, in Emergy Analysis the track-summing method of determining Unit Emergy Values does not use 'partitioning' or 'allocation', and in Life Cycle Assessment the system expansion method is used instead of direct 'partitioning' or 'allocation'.