

## Thermodynamic Input-Output Analysis of Natural and Economic Capital - Implications for LCA and Supply Chain Management

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It is widely recognized that preservation of ecological capital is essential for sustainable development. However, incorporation of ecological considerations in decision-making is hindered by inadequate appreciation of the role of ecosystems, and lack of scientifically rigorous techniques for including their contribution. This presentation applies a new thermodynamic accounting framework called Thermodynamic Input-Output Analysis to overcome these shortcomings. The resultant analysis successfully incorporates the contribution of ecological products and services to economic activity by appreciating the network structure of economic and ecological systems. A thermodynamic approach provides a common currency or a way to deal with a diverse set of units, as any system - economic or ecological, can be considered as a network of energy flows. The proposed approach is based on the concept of Ecological Cumulative Exergy Consumption (ECEC) (Hau and Bakshi, 2004). This approach is closely related to emergy analysis (Odum, 1996) but does not rely on any of its controversial claims.

This presentation illustrates the application of Thermodynamic Input-Output Analysis to LCA of Transportation Sectors. Transportation being critical to the economic system, directly influences LCAs of many other industrial activities. Existing tools for performing LCA of these sectors primarily focus on their life cycle emissions and energy requirements, but ignore the contribution of natural capital that refers to variety of "free" ecological products and services. Quantification of natural capital, and its juxtaposition with economic capital has direct implications to sustainability. Thermodynamic Input-Output Analysis is useful to delineate the myriad ways in which these sectors rely on ecosystem products and services, as well as to study flow of economic and natural capital through them. Relative magnitudes of economic and natural capital flows is represented by a variety of ratios such as, that of ECEC (renewable, nonrenewable and human resource inputs, and impact of emissions) to money. Other indicators of the degree of renewability and sustainability may also be defined. Such ratios indicate how each sector values ecosystem contribution, and represents the magnitude of the discrepancy between thermodynamic work needed to produce a good or service and the amount of money people are willing to pay for it.

Analysis of the US economy by the proposed method shows that the economic value of natural capital is least for the extractive industries, and increases along the supply chain. This observation has interesting implications for the strong and weak sustainability of various sectors, and the effect of outsourcing economic activities to developing countries. These will be discussed in greater detail for the 1997 US economy.

Hau, J. L. and B. R. Bakshi, Expanding Exergy Analysis to Account for Ecosystem Products and Services, *Env. Sci. Tech.*, accepted

Odum, H. T., *Environmental Accounting*, John Wiley, 1996

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