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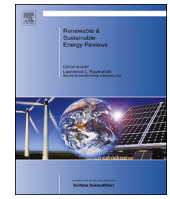

A review of emergy theory, its application and latest developments

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The ability to assess energy, matter and information in equal terms makes the emergy analysis an attractive tool to perform sustainability evaluation of all sorts of systems. In recent years, emergy analysis has been applied to assess emergy performance of buildings, industrial processes, urban areas and countries. Emergy is a relatively new concept so its acceptance within and outside the academic world still faces several challenges and criticism. Over the years, researchers have been working to prove EmA's validity: EmA has been combined with other methodologies or techniques scientifically more consolidated – life cycle assessment, ecological footprint, geographical information systems and strategic environmental assessment; emergy researchers also tried to overcome criticism by clarifying emergy algebra specificities and the relationship between emergy and exergy; different approaches were also used to perform uncertainty analysis on EmA. Despite those efforts, EmA is not as scientifically and technically consolidated as emergy researchers wanted it to be. More research should be done to improve EmA as a management tool by taking into account recent improvements made to the methodology and making it usable at a strategic and/or operational level within an organization.

Contents

1. Introduction

Emergy analysis (EmA) is part of a broader theory developed by Odum on the functioning of ecology systems [1]. Emergy theory was developed from the perception of how important is energy quality and how convenient it is to use a common denominator for different types of energy flows. Odum developed the idea that energy provides a common basis for integrating economic and ecological sciences by using energy systems language to study open systems (from a thermodynamic point of view). When the first major energy crisis emerged in the 1970s, and as human

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activity's environmental impacts became evident, Odum realized that economic activities are not only shaped by economic rules but also by ecosystem's constraints.

Emergy is defined as the available energy that was previously used, directly or indirectly, to produce a product or service and is accounted by using in a single unit of energy [2]. EmA is a quantitative analysis that evaluates resources, goods or services in common units of solar energy and measured as solar emergy (sej). In order to do so, all system's inputs (including different types of energy and energy inherent to different materials and services) must suffer a conversion process to emergy units using a conversion factor called *transformity*. Transformity is a fundamental concept of EmA. It is defined as the solar emergy required to provide a Joule of a product or service (emergy per energy unit, sej/J). The relationship between emergy of a fuel i (Em_i) and its energy content (E_i) is given by its transformity (Tr_i):

$$Tr_i = Em_i / E_i \quad (1)$$

2. Emergy analysis application

Over the last decade several scientific papers addressing EmA have been published, especially in the last 3–4 years. EmA offers an approach reliant on average values and has considerable uncertainty associated to its calculations. That frailty, however, has always been assumed by EmA researchers. It is their position that EmA's usefulness and interest goes beyond that limitation.

EmA provides a life cycle approach that, in comparison to traditional Life Cycle Assessment (LCA), synthesizes information and uses a smaller amount of data. EmA has the ability to assess all resources, goods and services under a single unit of measurement. By using this feature it is possible, for example, to fill the gap that typically exists on several studies between economic and environmental views of the same problem. This feature also enables EmA as a good option for sustainability assessment of any system and thus helps decision-making on energy, environmental and social issues.

As it would be shown over the next sections of this chapter, EmA has been applied to all sort of systems: either a nation's economy or waste management solutions. As a result of a literature review, examples of EmA application are grouped and classified according to the following categories: geographical area, buildings, industrial processes, information and services.

2.1. Geographical area

Applying EmA to geographical areas provides a unique insight into the environment-economy interface and allows their comparison through the use of evaluation indices: resource use intensity, trade balances, and sustainable production. Odum [2] presented a procedure that could be used to evaluate emergy performance of nations and/or regions, and tested it evaluating the United States of America.

The same procedure was used to study other geographical areas:

- The island of Taiwan was analyzed by Huang [3]. Using emergy analysis, the study concluded that, in 50 years, the region changed from a rural economy based on primary goods production to an highly industrialized economy with low self-sufficiency regarding emergy use.
- Campbell and Hort [4] developed a global database containing primary information and respective transformities and energy conversion factors, thus enabling emergy flows calculation for 134 countries.
- Brown et al. [5] used Sweeney's database to assess sustainability and efficiency of several nations. They used the concept of Emergy Sustainability Index (EmSI) as an indicator of multi-dimensional long-term sustainability [6]. Their results appointed for a general conclusion: most developed countries have less sustainable economies (low EmSI), while developing countries with small economies are more sustainable (higher EmSI).
- EmA was used by Lomas et al. [7] to assess economic and environmental performance of Spain during a 20 year period. They concluded that over that period, despite the increase of natural protected area and respective available budget, Spain's sustainability decreased mainly due to construction activities associated with tourism.
- Integrating Ecological Footprint (EF) method and EmA allowed Siche et al. [8] to assess Peru's sustainability. For the year 2004, load capacity factor obtained was 4.23, meaning that Peru can support a population 4.23 times bigger.
- The Italian region of Abruzzo was evaluated and emergy flows were spatially represented using geographic information systems [9]. Concentration of emergy flows, depending on local communities activities, showed variable levels of environmental load in different areas.
- Brown and Ulgiati [10] intended to explain last worldwide economic meltdown from a biophysical point of view by performing a global emergy analysis. Their results showed that while renewable emergy inflow to the planet has remained constant over the years, its share of total emergy driving the geobiosphere has decreased markedly (in 1900, 97% was renewable emergy, while in 2008 it was only 14%).

At a smaller scale, urban areas have been study through emergy analysis, particularly in China:

- Lei et al. [11] studied the impact of tourism and commercial links with China on Macao's sustainability. They used two aggregated emergy-based indicators, expanding “net emergy surplus” concept: net emergy (NE) and net emergy ratio (NER). They concluded that those two emergy indicators would better fit the use of EmA on urban areas than EmSI indicator.
- A new methodology integrating EmA and life cycle analysis (LCA) to evaluate metabolic performance of residential urban areas was tested using of Beijing as a case study [12]. Evaluation results reflected buildings as responsible for half of total environmental impacts on urban area.
- Several Chinese cities were evaluated by Liu et al. [13] using a emergy-based urban ecosystem health index (EUEHI). By clustering cities with similar health levels, their spatial distribution was found to be arch-shaped, increasing initially and then decreasing from coast to inner land.
- A study conducted by Yang et al. [14] compared three major Chinese cities – Shanghai, Beijing and Guangzhou – according to their emergy intensity, environmental pressure and resource use efficiency. They concluded that different results arise from different geographical locations, resources endowments, industrial structures and urban orientations.
- Using historical data (1990–2004) and a set of emergy indicators, Yang et al. [15] concluded that urban Beijing's metabolic processes have been increasing and that the city is excessively dependent on non-renewable resources.
- Lei et al. [16] tried to understand the advantages and drawbacks of different emergy accounting approaches. The idea was to provide a correct technique that could be used to assess sustainability of tourism at local or national levels. They used Macao as a case study, and their analysis showed that more emergy wealth is imported than exported in Macao's tourism industry.