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Human-nature nexuses in Brazil: Monitoring production of economic and ecosystem services in historical series

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ABSTRACT

Human-Nature nexuses are evident when we evaluate the different contributions of economic systems and ecosystems to human well-being. In this paper, the amount of services for well-being and the effectiveness in producing them has been assessed for the national economy and national ecosystem mosaic of Brazil, in historical series (1981–2011). The emergy methodology has been used as a tool able to evaluate different contributions to well-being on the same basis, thus allowing rightful comparisons. Results show that the monetary value of Nature's contributions to national welfare is higher than contributions from the economy. Furthermore, ecosystems provide services in a more effective and sustainable way, relying on a lower amount of total resources and using exclusively renewable resources. In addition, Nature's contributions are almost constant throughout the historical series considered, where services from the economy oscillate, representing a less stable source of well-being. This study confirms results already highlighted at the global and national scales by previous studies, adding a time-series perspective to that. These results inspire a re-consideration of the interactions among the biosphere and the technosphere in order to better address trade-offs between different forms of services.

1. Introduction

The Gross Domestic Product (GDP) is the standard indicator used to measure the economic progress of a country. It represents the sum, in monetary terms, of all final goods and services produced in a country during a certain period. The human economy is a subsystem of the biosphere and economic development is ultimately based upon natural resources (Giannetti et al., 2013; Costanza et al., 1997; Wackernagel et al., 2002; Murphy and Hall, 2011). The strict link between economic development and natural resources (Ward et al., 2016) explains why a country's development is often perceived as a compromise between economic goals and environmental protection. In this context, GDP demonstrated to be a misleading tool in the way it forces development towards economic growth, largely disregarding nature's conservation and a vast series of social aspects (Costanza et al., 2014a; van den Bergh, 2009; Fioramonti, 2013).

During the last decades, several methods have been proposed to develop alternative-to-GDP measures (Frugoli et al., 2015; Giannetti et al., 2015; Pulselli et al., 2006). In particular, monetary evaluations of the goods and services provided by Nature have been highlighting the positive economic effects of preserving and restoring ecosystems (MA, 2005; Diaz et al., 2015). In a seminal paper published in 1997 by Robert Costanza and co-authors, the economic value of global ecosystem goods and services has been calculated as 1.8 times the Global GDP (Costanza et al., 1997). In 2014, this estimate has been updated, also calculating that from 1997 to 2011 we have lost a total value of $4.3–20.2 trillion/yr due to land use change. Finally, monetary accounting of ecosystem goods and services has made "*abundantly clear that the choice of 'the environment* versus *the economy' is a false choice*", and that preserving ecosystems is essential for a sustainable development, also from an economic perspective (Costanza et al., 2014b).

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Within these different ways of measuring development, there is a call to investigate and express the relationships between the use of natural resources and economic processes (i.e. the human-nature nexuses) in both extensive and intensive terms (Pulselli et al., 2015; Ward et al., 2016). Extensive analyses are needed in order to measure and monitor the overall quantity of resources used, from the scale of production up to the global scale. Intensive analyses are important to understand the amount of resources embodied in a single unit of product, or a production phase, thus enabling to develop and select better technologies and practices in terms of sustainability. The use of intensive indicators is particularly crucial in contexts where resources are largely abundant. In these cases, in fact, there is a risk to justify the application of production techniques with high environmental impact if development is solely informed by extensive measures. Such an example is the case of Brazil, where a vast national territory, a high availability of natural resources, a relatively limited populated area, and a growing economy co-exist.

In this paper, an insight on how human-nature nexuses in Brazil changed over time (from 1981 to 2011) is provided by quantifying the resources supporting the economy and the ecosystems, using the emergy methodology (Giannetti et al., 2010, 2013; Odum, 1996; Pereira and Ortega, 2012; Sweeney et al., 2007). Emergy is used because it allows normalization and aggregation of variables having different physical (and monetary) units into meaningful indicators. In fact, the emergy methodology provides objective criteria for choosing an appropriate aggregating method that justifies comparisons and ensures transparency in evaluations of market and non-market based economic and ecological services (Giannetti et al., 2006; Almeida et al., 2007; see Almeida et al., 2013 for an overview). In particular, two intensive indicators are calculated to express the translation ability of resources into economic outputs: 1) the Emergy to Money Ratio (EMR), as the overall amount of resources used by the economy divided by GDP (Odum 1996); and 2) the Renewable Emergy to Ecosystem Services Ratio (RER), as the overall amount of resources used by the ecosystems divided by the economic value of the ecosystem goods and services provided (Coscieme et al., 2014).

More specifically, this paper explores relationships between resource use and welfare in order to confute/support the idea that direct and indirect benefits from the ecosystems are higher, when expressed in monetary terms, than benefits from the economy. Furthermore, a comparative analysis is performed to investigate how much different data sources influence the calculation of total values of ecosystems and their services. Through a time-series analysis, this paper also aims at investigating which class of contributions to welfare remains more stable over time. The use of the emergy methodology allows the development of indicators that can be used to compare the efficiency of ecosystems and national economies. This approach aims at providing monitoring tools on different contributions to national welfare that can also inform alternative-to-GDP measures.

Beyond being a relevant case study, this analysis presents the use of the emergy methodology as a holistic tool to build transdisciplinary bridges, being able to describe the processes of the technosphere and the biosphere through the use of a common language. This analysis develops some novel aspects within the applications of emergy theory, being relevant within single-year cross-country analyses of EMR (Brown, 2003; Campbell et al., 2005; Campbell and Ohrt, 2009; Lomas et al., 2008; Lei et al., 2008; Campbell and Tilley, 2014; Coscieme et al., 2014), and contributing to the literature that present this indicator in historical series (e.g. Zhang et al., 2011; Campbell et al., 2014; Giannetti et al.,2013; Lei et al., 2012).

2. Data and methods

2.1. Emergy accounting

Emergy is a tool able to measure both the work of nature and that of humans in generating products and services (Zhao et al., 2005). It is expressed in solar emergy joules (*sej*), representing the equivalent solar energy that have been necessary to obtain a product or service through the network of energy transformations within the ecosystems and the economy. The factors enabling to express different energy forms in solar equivalent are called Unit Emergy Values (UEVs) and represent the quantity of solar energy directly or indirectly necessary to produce 1 J of a product or a different kind of energy (Brown and Ulgiati, 2004). The Total Emergy supporting ecosystems or economies is thus given by the following formula:

$$TotalEmergy = \sum_{i=1}^{n} E_i x UEV_i = (E_1 x UEV_1) + (E_2 x UEV_2) +_{.....} + (E_n x UEV_n)$$

where Ei are the natural renewable inputs used by ecosystems to self-maintain and function; or the renewable, non-renewable, and imported inputs used by economic systems functioning.

The main advantage of using emergy for resource use accounting is that it allows comparing very different environmental and economic production processes on the same basis. The general methods for employing emergy accounting are described by Odum (1996) and Odum et al. (2000).

The overall resources used by the Brazilian economy from 1981 to 2011 have been calculated in emergy terms using data from Giannetti et al. (2013), Faria (2015), Sweeney et al. (2007), and by collecting new data. Data for the emergy calculation for the year 2002 were obtained from government databases. In particular, data on fossil fuel consumption are from the National Agency of Petroleum, Natural Gas and Biofuels (Agência Nacional de Petróleo, Gás Natural e Biocombustíveis, ANP, 2017); data on hydroelectric energy are from the Brazilian electricity company ELETROBRAS (2017), data on minerals and metals are from the National Department of Mineral Production (Departamento Nacional de Produção Mineral, DNPM, 2017); demographic data and data on agriculture are from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística, IBGE, 2017); data on imports and exports are from the Ministry of Development, Industry and Foreign Trade (Ministério do Desenvolvimento, Indústria e Comércio Exterior, MDIC, 2017). The emergy accounting was performed following Sweeney et al. (2007) (see Appendix A, B). All emergy analysis has been performed under the 15.83×10^{24} sej/year baseline (Odum, 2000). Data on GDP have been retrieved from the same sources.

Uncertainty levels associated with the results of the emergy analysis depend on raw data uncertainty. Being raw data derived from multiple sources, it is not trivial to estimate the overall uncertainty associated with the results. This is a criticism raised against the accuracy of emergy evaluations that has been, and is being addressed in dedicated literature (e.g. Ingwersen, 2010; Li et al., 2011; Hudson and Tilley, 2014).

2.2. Ecosystem services valuation

The economic value of goods and services produced by the ecosystems in Brazil has been calculated through benefit transfer. The benefit transfer method implies that a unitary economic value per hectare of ecosystem type is multiplied by the total amount of hectares of that type, calculating the Total Ecosystem Service value