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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:

$$TotalEmergy = \sum_{i=1}^{n} E_i xUEV_i = (E_1 xUEV_1) + (E_2 xUEV_2) +_{.....} + (E_n xUEV_n)$$

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

(TEV) generated by the specific ecosystem. When applying the benefit transfer method for ecosystem services evaluations at the national scale, some aspects need to be considered: 1) ecosystem boundaries often do not correspond with administrative boundaries; 2) ecosystem services could be provided in an area and used elsewhere; 3) some ecosystems act as connecting areas of provision and use of ecosystem services (Fisher et al.,2009; Burkhard et al.,2012; Syrbe and Walz, 2012); 4) the extension of small size/fragmented ecosystems with high service value per unit area (such as small wetlands and rivers) is often underestimated in satellite based land-cover datasets (Di Sabatino et al., 2013); 5) the total value of marine ecosystem services depends on the criteria used to mark national marine boundaries (Konarska et al., 2002; Troy and Wilson, 2006; Barbier, 2012). Different assumptions and considerations on these aspects may influence the results of ecosystem services evaluations.

Despite being rough approximations, the values calculated via benefit transfer are suitable to be used at the national scale, while the method is consistent with the approach taken in GDP accounting, i.e. the multiplication of price times quantity performed for the different sectors of the economy (Costanza et al., 2014b). The benefit transfer is thus considered as sufficiently accurate producing rightful comparisons between national TEV and national GDP (Sutton and Costanza, 2002; Coscieme et al., 2014).

Due to data availability in historical series we only considered 2 different ecosystem types in Brazil: i.e. forests and agricultural land that, as classified by the United Nations' Food and Agriculture Organization Statistical Programme (FAOSTAT), cover together more than 90% of the country. Data on the extension of these ecosystem types have been collected from 1990 to 2011 (http://fao.org/faostat last accessed: January 2017). Data on forests extension were not available for 1981 and 1989. Consequently, ecosystem service values have not been calculated for 1981, while the forest area in 1990 has been considered as a good approximation for 1989.

We considered a unitary value of ecosystem services equal to 5.382 2007US$/ha/yr for forests, and 5.567 2007US$/ha/yr for agricultural land, according to Costanza et al. (2014b). After calculation, the TEVs have been converted from 2007US$ to 2011US$ (2011 being the most recent year considered in this analysis) by using purchasing power parity rates.

In order to test for the calculated TEV values to be representative enough of ecosystem service value of the complex ecosystem mosaic of Brazil, we compared it with estimations of TEV for 6 ecosystem types, also calculated through benefit transfer. In order to do that, 5′x5′ Moderate Resolution Imaging Spectroradiometer (MODIS) land cover data in the International Geosphere-Biosphere Programme (IGBP) Land Cover Type Classification have been collected from Channan et al. (2014) and Friedl et al. (2010) (data available from the Global Land Cover Facility at http://glcf.umd.edu/data/lc last accessed: January 2017), and extracted for Brazil from 2000 to 2011 (the available data span). The 17 original IGBP land cover categories have been grouped and re-classified into 6 biomes following Costanza et al. (2014b) and Di Sabatino et al. (2013) (Table 1). The "Lakes/Rivers" biome is classified within the IGBP Land Cover Type 11 "Permanent Wetlands". Unitary ecosystem service values have been taken from Costanza et al. (2014b) and TEV values have been expressed in 2011US$.

As a further test, the TEV values used in this study have been also compared with annual Natural Capital contributions (NC) to the Inclusive Wealth Index calculated by the United Nations' University International Human Dimensions Programme (UNU-IHDP and UNEP, 2014). Data are available for Brazil and other countries for the following years: 1990, 1995, 2000, 2005, 2010. Natural capital values have been converted into 2011US$ and related to the exact, or the most recent, year of the historical series.

Table 1
Aggregation scheme of the International Geosphere-Biosphere Programme Land Cover Type Classification (IGBP) and Biomes (after Costanza et al., 2014b and Di Sabatino et al., 2013).

IGBP Land Cover Type Classification		Biome
Value	Label	
0	Water	Water
1	Evergreen Needleleaf forest	Forest
2	Evergreen Broadleaf forest	Forest
3	Deciduous Needleleaf forest	Forest
4	Deciduous Broadleaf forest	Forest
5	Mixed forest	Forest
6	Closed shrublands	Grass/Rangelands
7	Open shrubland	Grass/Rangelands
8	Woody savannas	Grass/Rangelands
9	Savannas	Grass/Rangelands
10	Grasslands	Grass/Rangelands
11	Permanent wetlands	Wetlands
12	Croplands	Cropland
13	Urban and built-up	Urban
14	Cropland/Natural vegetation mosaic	Cropland
15	Snow and ice	Ice/Rock
16	Barren or sparsely vegetated	Ice/Rock

Natural capital includes all natural resources, and physical, biological and chemical processes underpinning the production of ecosystem services. Economic values include the value of fossil fuels, minerals, forest resources and agricultural land, estimated by evaluating stock changes and social (shadow) prices (UNU-IHDP and UNEP, 2014). This last comparison allowed us to test for the effect of using a particular method (i.e. benefit transfer versus natural capital accounting) in economic evaluations of Naturés contributions to welfare at the national scale.

3. Results and discussion

Table 2 shows the results of the ecosystem service valuation for Brazil. The NC contributions are slightly higher than ecosystem service values. In this case, results calculated from FAOSTAT on the extent of forest and agricultural land are a good approximation of economic values calculated from remote sensing land-cover data at the national scale, and represent the most complete available data series. On average, TEV calculated from FAOSTAT and MODIS-IGBP show a difference of less than 1% between each other. However, by including a more complete set of ecosystems, the basket of ecosystem services considered would expand, allowing trade-off analyses and the calculation of more accurate TEVs and TEV historical series.

Results from Table 2 show that the TEV in Brazil remained constant or slightly increased, while NC slightly declined over time. These trends contrast with the declining trends observed at the global scale when considering a larger set of ecosystems (UNU-IHDP and UNEP, 2014; Costanza et al., 2014b). From 1981 to 2011, forest conversion is apparently offset by the higher value associated to agricultural land (see Mendoza-Gonzalez et al., 2012; Lawler et al., 2014 and Li and Ding, 2017 for further investigations and scenarios on land use change effects on TEV). This aspect is influenced by the fact that agricultural land provides a broad range of goods and services which values are relatively easy to be expressed in monetary terms, being direct use values. As a consequence, ecosystem services evaluations of agricultural land are probably more comprehensive than evaluations of services provided by forests. Forests in fact provide a large set of fundamental ecosystem services that are however more difficult to be expressed in monetary terms, being associated to cultural, existence and bequest values or the indirect value provided by

Table 2
Total Ecosystem Service Values (TEV) and annual Natural Capital contributions to wealth (NC) for Brazil calculated from different sources: unit ecosystem service values are from Costanza et al. (2014b) and have been converted into 2011$ through purchasing power parity rates; FAOSTAT data for the extension of forests and agricultural land are from http://fao.org/faostat; MODIS-IGBP land cover data for 17 ecosystem types are from http://glcf.umd.edu/data/lc; annual Inclusive Wealth Index (IWI) Natural Capital contributions are from UNU-IHDP and UNEP, 2014.

	Source/year	1981	1989	1996	2000	2002	2004	2007	2008	2011
$TEV/10^{12}$ US$	FAOSTAT		4.63	4.65	4.60	4.59	4.56	4.56	4.56	4.55
$TEV/10^{12}$ US$	MODIS-IGBP				4.20	4.51	4.51	4.69	4.79	4.92
$NC/10^{12}$ US$	IWI		5.82	5.70	5.55		5.41			5.25

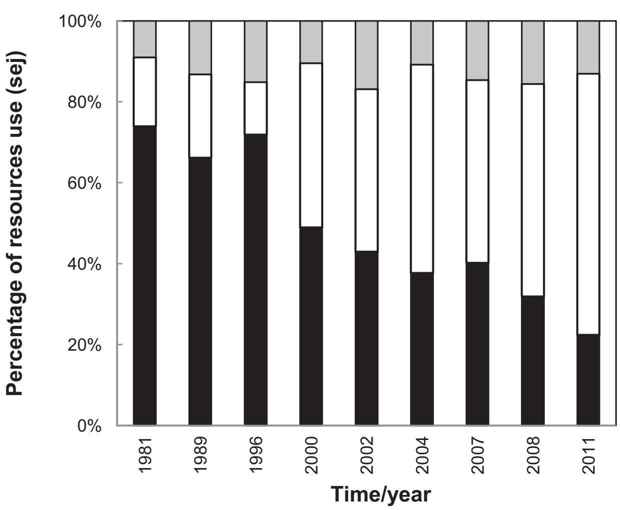

Fig. 1. Variation in the share of resources used in Brazil from 1981 to 2011; (■) Renewables. (□) Non-renewables. (▨) Imports.

biodiversity to welfare (TEEB, 2010). This might cause an underestimation of the total ecosystem service value of forests.

The decline in the value of NC suggests that ecosystem services are being used at a faster rate than their regeneration rate, though this needs further analysis in order to be sustained.

Braziĺs TEV, as well as Braziĺs GDP, are produced from different kinds of input resources. These resources can be quantitatively and qualitatively assessed on a common basis through emergy accounting. Fig. 1 and Table 3 synthesize the results of the emergy analysis. From Fig. 1, it can be noted a sharp declining in the share of renewable resources used from 1981 to 2011. This occurred together with an increasing use of non-renewables while the share of imported resources remained practically constant over the years. After 2002, the use of non-renewables in Brazil surpassed the use of renewables. The increasing in non-renewable use has been driven by an increasing exploitation of metals and minerals for industrial processes, and increasing consumption of fertile soil for agricultural and livestock production. The increase in use of these resources led to an increase in GDP and a higher efficiency of Brazilian economy. However, being non-renewables characterized by a distinct gap between the rate of extraction and their natural regeneration rate (Tiezzi, 2003), increasing the use of non-renewables is ultimately unsustainable from an environmental point of view, and unreliable from a long-term economic perspective. The exploitation of non-renewables in a quasi-sustainable manner is only possible by limiting their rate of extraction and use to the rate of use of renewable substitutes. This requires that any investment in non-renewables should come together with investments in renewable substitutes (Daly, 1990; Costanza and Daly, 1992).

In Table 3, the different resource categories are indicated as: Renewables (R), Non-renewables (N), and Imports (F). The total emergy (U), is the sum of R, N and F, and represents the emergy supporting the economy in the specific year. The EMR is calculated as U/GDP, and represents the translation ability of inputs into outputs characterizing the Brazilian economy. Since the ecosystem functioning is solely based on renewable resources, the RER is calculated as R/TEV, and represents the translation ability of inputs into valuable outputs of the ecosystem mosaic within the territory of Brazil, as considered in this study.

From Table 3 it is notable that ecosystems provided greater contribution to national welfare than the national economy, for the entire period investigated. Along the historical series TEV shows values from 1.8 up to 7 times higher than GDP. This is in line with what pointed out by Costanza et al. (1997, 2014b) and a vast series of subsequent literature (e.g. Sutton and Costanza, 2002; MA, 2005; Coscieme et al., 2014). Furthermore, ecosystems contributions are characterized by very high stability (i.e. TEV coefficient of variation = 0.007), much higher than GDP that, on the contrary, shows higher oscillations (GDP coefficient of variation = 0.56).

The dynamics of GDP are strongly linked with the total resource use and vice versa, as already highlighted by Ward et al. (2016) and Pulselli et al. (2015), among others. This relationship, however, assumes different forms due to the complexity of the overall production processes occurring at the national scale, and due to external drivers to national GDP.

The nexus between the processes of the technosphere and the biosphere are drawn in Figs. 2, 3 and 4. Analyzing GDP and the

Table 3
Emergy accounting, GDP and TEV of Brazil between 1981 and 2011. Different resource categories are indicated; R: renewables, N: non-renewables, F: imports. EMR is calculated as U/GDP; RER is calculated as R/TEV. Emergy data from (a) Giannetti et al. (2013); (b) calculated in this study (Appendix A) (c) Sweeney et al. (2007); (d) Faria (2015) (Appendix B).

	Unit/year	1981[a]	1989[a]	1996[a]	2000[a]	2002[b]	2004[c]	2007[a]	2008[c]	2011[d]
$R/10^{24}$	sej/yr	3.25	3.12	3.34	3.46	3.11	3.07	3.11	3.07	3.11
$N/10^{24}$	sej/yr	0.75	0.97	0.60	2.87	2.91	4.2	3.5	5.06	8.97
$F/10^{24}$	sej/yr	0.39	0.62	0.70	0.74	1.22	0.88	1.13	1.50	1.81
$GDP/10^{12}$	$/yr	0.6	0.84	0.82	0.79	0.65	0.78	1.6	1.66	2.48
$TEV/10^{12}$	$/yr		4.63	4.65	4.60	4.59	4.56	4.56	4.56	4.55
$U/10^{24}$	sej/yr	4.40	4.72	4.65	7.07	7.24	8.15	7.74	9.63	13.9
$EMR/10^{12}$	sej/$	7.3	5.6	5.7	9.0	11.2	10.4	4.8	5.8	5.6
$RER/10^{12}$	sej/$		0.67	0.72	0.75	0.68	0.67	0.68	0.67	0.68

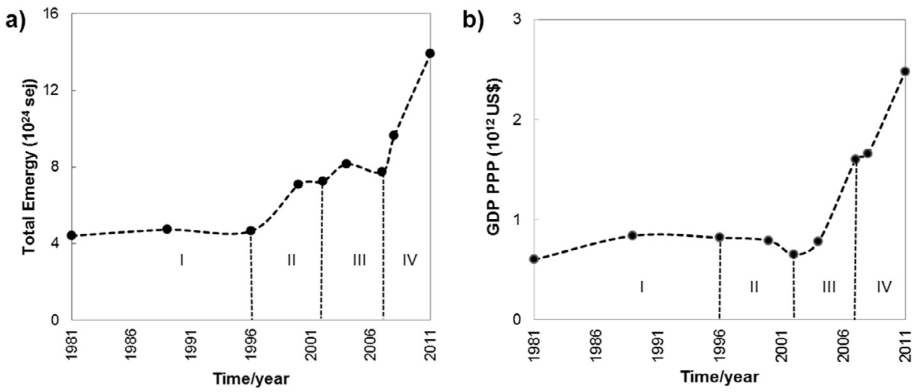

Fig. 2. Historical series of a) Total Emergy (U); b) GDP at Purchasing Power Parity Rates for Brazil (1981–2011).

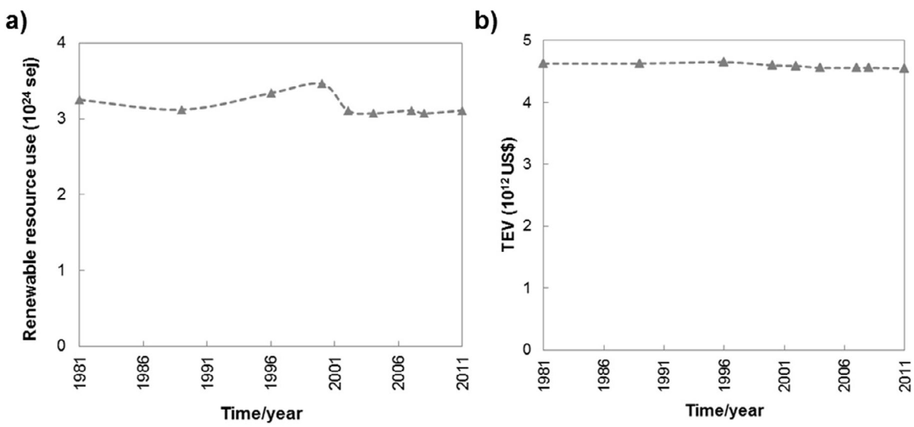

Fig. 3. Historical series of a) Renewable Emergy (R); b) Total Ecosystem Service Value (TEV) for Brazil (1981–2011).

total use of resources, expressed as total emergy, 4 different periods can be detected for the case of Brazil from 1981 to 2011 (Fig. 2). Period I (1981–1996) is characterized by a slightly increasing/almost constant total emergy; GDP, however, increased significantly during the first half of the period. During these years the economic system was based on a large share of renewable resources, effectively translated into economic output. On the contrary, during Period II (1996–2002) the total emergy grew exponentially while GDP declined. This worsening in the effectiveness of national economic functioning happened together with the increasing non-renewable resources share. Economýs dynamics in this period can be explained by the strong devaluation of the countrýs currency in 1999, the possible effect of the early 2000́s global recession, and a precautionary behavior of domestic investors reacting to the election of the Workerś Party President Luiz Ignacio Lula da Silva (the so-called "efeito Lula"). This trend inverted in Period III (2002–2007), when devaluation slowed down and global economic activity stabilized, until the 2008 economic crisis. During these years total emergy growth slowed down, while GDP experienced an exponential growth. In the last period, Period IV (2007–2011), the economy was affected by the global economic crisis, as can be noted by a slight depression in the GDP trend. However, total emergy continued to grow exponentially, as well as GDP soon after 2008, indicating a possible fast recovery from the crisis which dynamics could be further investigated.

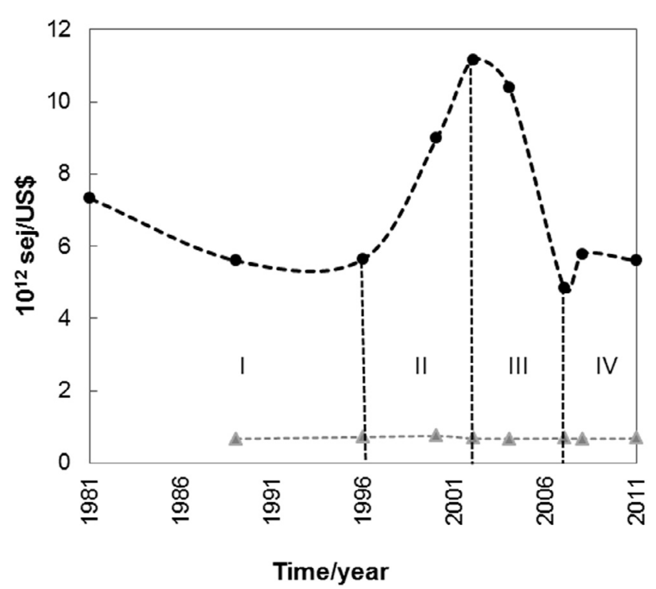

Fig. 4. Historical series of Emergy to Money Ratio (● EMR = U/GDP) and Renewable Emergy to Ecosystem Service Ratio (▲ RER = R/TEV) for Brazil (1981–2011).

From Fig. 2a and b a close link between the total use of resources and GDP emerges. However, this relationship changes along different periods (e.g. Period II is characterized by increasing non-renewable use and decreasing GDP, while after 2002 Braziĺs economy has been characterized by increasing non-renewables and increasing GDP). Additional aspects should be considered in order to fully explain resource use and GDP trends and causality links needs to be further investigated (Warr and Ayres, 2010). Fig. 3a and b show, respectively, the total flow of renewable resources and the TEV for the ecosystems of Brazil, as considered in this study (see Table 2). By comparing Fig. 2a and b with Fig. 3a and b, it is notable that ecosystem functioning and translation ability of energy inputs into valuable outputs are characterized by more stable dynamics than economic functioning. Furthermore, ecosystem services production remains almost constant despite a certain degree of variability observed in renewable flows.

The effectiveness of Braziĺs economy versus ecosystems in translating energy inputs into services contributing to national welfare is synthesized in Fig. 4, where EMR and RER are represented. The economy is more energy consuming per monetary unit of service produced. In addition to that, economic functioning is highly variable, going through 4 distinct periods, while during the same years the ecosystem mosaic of Brazil keeps providing a constant flow of services with a constant, and higher, effectiveness.

It is notable that EMR values are always at least one order of magnitude higher than RER values (Table 3). This highlights how ecosystem settings are able to translate energy and matter inputs into valuable services much more effectively than the national economic system. This result is in line with what observed by Coscieme et al. (2014) for a large set of countries and by comparing EMR and RER at the global scale.

The EMR and RER are influenced by the share of different resources used, as well as by GDP and TEV (Fig. 1, Tab. 3). When performing comparisons (Figs. 3, 4), it is worth noticing that GDP and TEV express different sets of contributions to welfare. These contributions overlap or complement each other. For example, the value of goods provided by agricultural land is included in both economics and ecosystem services accounting (i.e. GDP and TEV). On the other hand, the value of services related to the regulation of ecosystem processes (e.g. climate regulation, pollination, etc.), is largely missing from economic accountings, although fundamental for human survival and national welfare. These differences in welfare conceptualization and accounting have to be kept in mind. In order to produce welfare, interactions between the biosphere

Appendix A

Emergy accounting of Brazil for the year 2002.

	Item	Flow	Flow unit	UEV (sej/unit)	*	Emergy (sej)
Renewable resource						
1	Solar radiation	3.88×10^{22}	J	1	[a]	3.88×10^{22}
2	Rain (chemical energy)	3.97×10^{19}	J	3.05×10^{4}	[b]	1.21×102^{4}
3	Rain (geopotential)	7.04×10^{18}	J	4.70×10^{4}	[b]	3.31×10^{23}
4	Wind	2.29×10^{20}	J	2.45×10^{3}	[b]	5.62×10^{23}
5	Waves	2.35×10^{18}	J	5.10×10^{4}	[b]	1.20×10^{23}
6	Tide	8.71×10^{18}	J	7.39×10^{4}	[b]	6.43×10^{23}
7	Deep heat	1.59×10^{19}	J	5.80×10^{4}	[c]	9.24×10^{23}
Internal transformations						
8	Hydroelectricity	1.14×10^{15}	J	3.36×10^{5}	[a]	3.81×10^{20}
9	Agriculture production	1.98×10^{21}	J	3.36×10^{5}	[d]	6.66×10^{26}
10	Livestock production	2.61×10^{20}	J	3.36×10^{6}	[d]	8.77×10^{26}
Non-renewable resource						
11	Fisheries	4.21×10^{15}	J	8.40×10^{6}	[d]	3.54×10^{22}
12	Firewood production	7.15×10^{16}	J	3.45×10^{4}	[e]	2.47×10^{21}
13	Forestry	8.37×10^{15}	J	3.80×10^{4}	[e]	3.18×10^{20}
14	Topsoil loss	2.70×10^{12}	g	1.68×10^{9}	[a]	4.54×10^{21}
15	Gás Natural	5.83×10^{14}	J	6.80×10^{4}	[f]	3.96×10^{19}
16	Oil	5.40×10^{17}	J	1.30×10^{5}	[a]	7.02×10^{22}
17	Coal	1.49×10^{17}	J	6.69×10^{4}	[a]	9.97×10^{21}
18	Minerals	2.44×10^{14}	g	1.86×10^{9}	[j]	4.54×10^{23}
19	Metals	3.57×10^{14}	g	6.54×10^{9}	[k]	2.33×10^{24}
Imports						
20	Fuels	1.73×18^{18}	J	1.04×10^{4}	[l]	1.80×10^{23}
21	Metals	8.45×10^{11}	g	6.72×10^{10}	[m]	5.67×10^{22}
22	Minerals	9.42×10^{12}	g	1.07×10^{10}	[n]	1.01×10^{23}
23	Foods and products agriculture	1.16×10^{17}	J	3.36×10^{5}	[d]	3.90×10^{22}
24	Livestock products	4.32×10^{14}	J	3.36×10^{6}	[d]	1.45×10^{21}
25	Plastic and syntentic rubber	6.33×10^{15}	J	1.11×10^{5}	[a]	7.01×10^{20}
26	Chemicals	8.37×10^{12}	g	1.48×10^{10}	[g]	1.24×10^{23}
27	Finished products	1.74×10^{13}	g	5.72×10^{9}	[e]	9.96×10^{22}
28	Machine and equipments	7.44×10^{13}	g	6.70×10^{9}	[h]	4.99×10^{23}
29	Services in Imports	4.72×10^{10}	$	2.60×10^{12}	[i]	1.23×10^{23}
*Exports***						
30	Fuels	1.21×10^{18}	J	1.11×10^{5}	[o]	1.97×10^{23}
31	Minerals	$2.54x10^{12}$	g	2.26×10^{9}	[n]	6.21×10^{22}
32	Metals	1.90×10^{14}	g	2.02×10^{9}	[p]	7.95×10^{22}
33	Foods and products agriculture	5.86×10^{17}	J	3.36×10^{5}	[d]	1.34×10^{23}
34	Livestock products	1.85×10^{16}	J	3.36×10^{6}	[d]	3.83×10^{23}
35	Plastic and syntentic rubber	1.45×10^{18}	J	1.11×10^{5}	[a]	2.54×10^{21}
36	Chemicals	5.30×10^{12}	g	1.48×10^{10}	[g]	7.84×10^{22}
37	Finished products	1.79×10^{13}	g	4.45×10^{9}	[n]	9.40×10^{21}
38	Machine and equipments	1.40×10^{12}	g	6.70×10^{9}	[h]	1.61×10^{23}
39	Services in exports	5.89×10^{10}	$	5.61×10^{12}	[i]	8.21×10^{23}

[a] Odum, 1996; [b] Odum et al., 2000; [c] Odum, 2000; [d] Brown and McClanahan, 1996; [e] Brown and Buranakan, 2000; [f] Romitelli, 2000; [g] Brown and Arding, 1991; [h] Brown and Bardi, 2001; [i] Calculed in this study; [j] Bastianoni et al., 2005; Odum, 1996; [k] Cohen et al., 2006; Odum, 1996; [l] Bastianoni et al., 2005; Demetrio, 2011; Odum, 1996; [m] Cohen et al., 2006, Brown and Buranakan, 2000, Odum 1996; [n] Brown and Buranakan, 2000, Odum, 1996; [o] Romitelli, 2000, Odum, 1996; [p] Brown and Buranakan, 2000, Odum, 1996, Odum and Arding, 1991.

* Values of UEV based on the total emergy flow of 15.83×10^{24} sej/year and their respective data sources.

** Not accounted in Total Emergy.

and the technosphere are required. Thus an effective economy should co-exist with an effective ecosystem mosaic. The TEV could be combined with GDP (after correcting for negative externalities and income inequality, among other aspects; see Kubiszewski et al., 2013; Fioramonti, 2013) to better envisioning and assessing sustainable development.(See Appendix A)

4. Conclusions

This paper presents a very first emergy analysis and ecosystem services accounting of Brazil in historical series. Extensive and intensive resource use indicators are calculated, filling a gap in emergy literature. The emergy function as a transdisciplinary tool able to describe the processes of the technosphere and the biosphere, and human-nature nexuses, on a same basis is highlighted. (See Appendix B)

Market-based benefits and contributions to welfare depend on land-based benefits and contributions. However, a larger amount of energy is necessary to provide equal contribution through the economic system, than the ecosystems. Further research should be directed towards verifying or confuting the fact that ecosystems (including a more complete set of ecosystems than the set considered in this study) are less prone to be influenced by external dynamics that, in the present globalized economy, are increasingly driving national economic functioning as suggested for Brazil from 1981 to 2011. The worst levels of effectiveness of the economy in contributing to welfare, as measured by the Emergy to Money Ratio, have been observed between 2000 and 2004. During this period, the share of non-renewable resource use increased, while GDP decreased. On the other hand, higher effectiveness has been observed when the share of renewable resource use was higher, from 1981 to 1996. Between 2002 and 2007, Brazilian economy has been increasingly effective, with increasing GDP, a constant share of renewable use, and a high use of non-renewables. After 2007, the effectiveness of the economy decreased again, together with an increase in GDP, an increase in non-renewable resource use, and a decreasing trend in renewable resource use.

Appendix B
Emergy accounting of Brazil for the year 2011.

	Item	Flow	Flow unit	UEV (sej/unit)	*	Emergy (sej)
Renewable resource						
1	Solar radiation	3.88×10^{22}	J	1	[a]	3.88×10^{22}
2	Rain (chemical energy)	3.97×10^{19}	J	3.05×10^4	[b]	1.21×102^4
3	Rain (geopotential)	7.04×10^{18}	J	4.70×10^4	[b]	3.31×10^{23}
4	Wind	2.29×10^{20}	J	2.45×10^3	[b]	5.62×10^{23}
5	Waves	2.35×10^{18}	J	5.10×10^4	[b]	1.20×10^{23}
6	Tide	8.71×10^{18}	J	7.39×10^4	[b]	6.43×10^{23}
7	Deep heat	1.59×10^{19}	J	5.80×10^4	[c]	9.24×10^{23}
Internal transformations						
8	Hydroelectricity	3.88×10^{22}	J	1	[a]	3.88×10^{22}
9	Agriculture production	3.97×10^{19}	J	3.05×10^4	[b]	1.21×102^4
10	Livestock production	7.04×10^{18}	J	4.70×10^4	[b]	3.31×10^{23}
Non-renewable resource						
11	Fisheries	5.99×10^{15}	J	8.40×10^6	[d]	5.04×10^{22}
12	Firewood production	2.67×10^{17}	J	3.45×10^4	[e]	9.22×10^{21}
13	Forestry	7.59×10^{17}	J	3.80×10^4	[e]	2.88×10^{22}
14	Topsoil loss	1.22×10^{15}	g	1.68×10^9	[a]	2.06×10^{24}
15	Gás Natural	9.05×10^{17}	J	6.80×10^4	[f]	6.15×10^{22}
16	Oil	4.22×10^{18}	J	1.30×10^5	[a]	5.49×10^{23}
17	Coal	1.58×10^{17}	J	6.69×10^4	[a]	1.05×10^{22}
18	Minerals	7.55×10^{14}	g	1.91×10^9	[j]	1.44×10^{24}
19	Metals	4.30×10^{14}	g	1.16×10^{10}	[k]	4.97×10^{24}
Imports						
20	Fuels	2.10×10^{18}	J	1.10×10^5	[l]	2.32×10^{23}
21	Metals	1.15×10^{13}	g	6.04×10^9	[m]	6.95×10^{22}
22	Minerals	1.41×10^{13}	g	7.85×10^9	[n]	1.11×10^{23}
23	Foods and products agriculture	1.32×10^{17}	J	3.36×10^5	[d]	4.42×10^{22}
24	Livestock products	2.60×10^{15}	J	3.36×10^6	[d]	8.74×10^{21}
25	Plastic and syntentic rubber	1.00×10^{17}	J	1.11×10^5	[a]	1.11×10^{22}
26	Chemicals	3.24×10^{13}	g	1.48×10^{10}	[g]	4.79×10^{23}
27	Finished products	5.99×10^{12}	g	5.14×10^9	[n]	3.08×10^{22}
28	Machine and equipments	5.84×10^{12}	g	6.70×10^9	[h]	3.91×10^{22}
29	Services in Imports	2.26×10^{11}	$	2.60×10^{12}	[i]	5.88×10^{23}
*Exports***						
30	Fuels	3.22×10^{18}	J	8.24×10^4	[o]	2.65×10^{23}
31	Minerals	2.89×10^{12}	g	1.71×10^9	[n]	2.89×10^{21}
32	Metals	2.88×10^{14}	g	1.51×10^9	[n]	4.34×10^{23}
33	Foods and products agriculture	5.42×10^{17}	J	3.36×10^5	[d]	1.82×10^{23}
34	Livestock products	2.60×10^{15}	J	3.36×10^6	[d]	8.74×10^{21}
35	Plastic and syntentic rubber	5.68×10^{16}	J	1.11×10^5	[a]	6.29×10^{21}
36	Chemicals	6.63×10^{12}	g	1.48×10^{10}	[g]	9.81×10^{22}
37	Finished products	5.76×10^{13}	g	5.59×10^9	[n]	3.22×10^{23}
38	Machine and equipments	6.63×10^{12}	g	6.70×10^9	[h]	4.44×10^{22}
39	Services in exports	2.56×10^{11}	$	5.61×10^{12}	[i]	1.44×10^{24}

[a] Odum, 1996; [b] Odum et al., 2000; [c] Odum, 2000; [d] Brown and McClanahan, 1996; [e] Brown and Buranakan, 2000; [f] Romitelli, 2000; [g] Brown and Arding, 1991; [h] Brown and Bardi, 2001; [i] Calculed in this study; [j] Bastianoni et al., 2005; Odum, 1996; [k] Cohen et al., 2006; Odum, 1996; [l] Bastianoni et al., 2005; Demetrio, 2011; Odum, 1996; [m] Cohen et al., 2006, Brown and Buranakan, 2000, Odum, 1996; [n] Brown and Buranakan, 2000, Odum, 1996; [o] Romitelli, 2000, Odum, 1996.

* Values of UEV based on the total emergy flow of 15.83×10^{24} sej/year and their respective data sources.

** Not accounted in Total Emergy.

The fact that the ecosystem service value in Brazil remained practically constant from 1981 to 2011 hides the occurrence of forest conversion in favor of the expansion of agricultural land. There is no evidence that this scenario would ensure a constant high value of ecosystem services in the next future. A diverse ecosystem mosaic should be preserved through policymaking in order to ensure the provision of multiple goods and services, also considering the importance of climate regulation services provided by Brazilian forests at the global scale.

Ecosystems conservation embodies an important insurance-value, maintaining vital and functioning a stable source of essential benefits. National economic and environmental policymaking should be informed by Science in order to understand to which degree the role of the economic system should be limited whenever ecosystem services can directly contribute to national welfare.

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