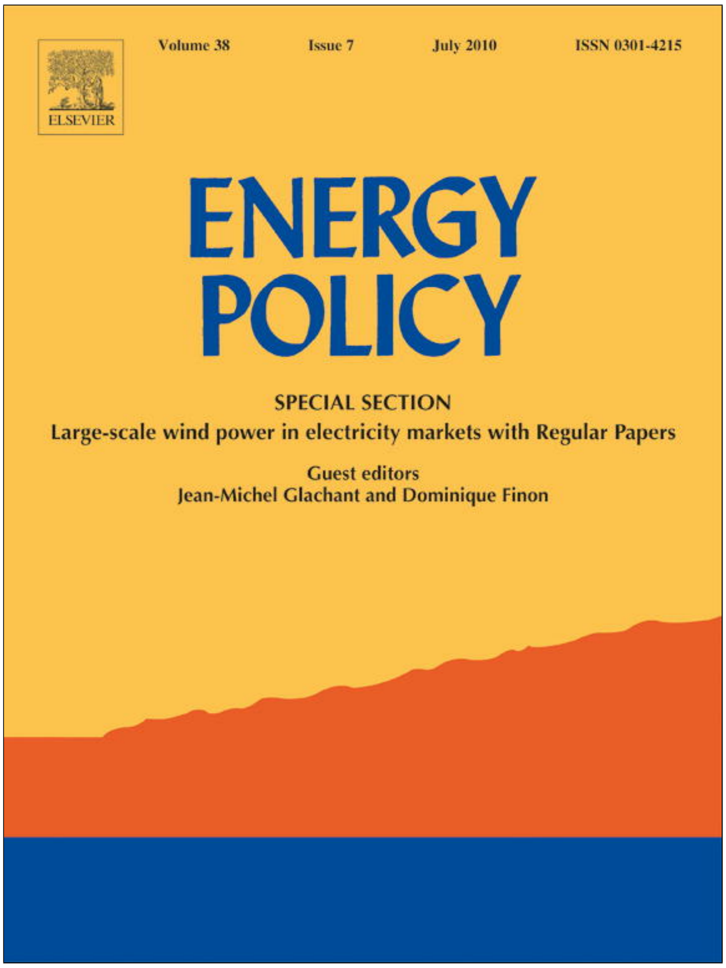
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Comparing emergy accounting with well-known sustainability metrics: The case of Southern Cone Common Market, Mercosur

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ABSTRACT

The quality and the power of human activities affect the external environment in different ways that can be measured and evaluated by means of several approaches and indicators. While the scientific community has been publishing several proposals for sustainable development indicators, there is still no consensus regarding the best approach to the use of these indicators and their reliability to measure sustainability. It is important, therefore, to question the effectiveness of sustainable development indicators in an effort to continue in the search for sustainability. This paper compares the results obtained with emergy accounting with five global Sustainability Metrics (SMs) proposed in the literature to verify if metrics are communicating coherent and similar information to guide decision makers towards sustainable development. Results obtained using emergy indices are discussed with the aid of emergy ternary diagrams. Metrics are confronted with emergy results, and the degree of variability among them is analyzed using a correlation matrix created for the Mercosur nations. The contrast of results clearly shows that metrics arrive at different interpretations about the sustainability of the nations studied, but also that some metrics may be grouped and used more prudently. Mercosur is presented as a case study to highlight and explain the discrepancies and similarities among Sustainability Metrics, and to expose the extent of emergy accounting.

1. Introduction

The search for sustainability and, consequently, the search for a way to measure and monitor the actual environment and the steps forward the sustainability belong to a field with less than forty years old. The essence of sustainability, that is, the effect that ecosystems and anthropogenic systems have on each other has become a framework for studying the interactions of the modern technological/economical society with the environment. The "ideal metric" should be able to detect or quantify how wise is the balance among development, environmental health and societal equity (Giannetti et al., 2009).

The concept of sustainable development is essentially simple, and there are two distinct components to deal with. The intra-generational component in which the use of the limited natural resources of the Earth by a minority of people living in the wealthy nations jeopardizes the desired global sustainability, and the inter-generational component, in which the same disproportional use of these resources deprives future generations of the welfare enjoyed by the present ones. Both components of sustainability depend on the availability and the distribution of non-renewable resources (Giannetti et al, 2009), and any proposed metric to measure or monitor the sustainability might include this parameter.

Up till now, there is no indicator or metric universally accepted. The field is now making the transition to gathering the data that characterize the natural environment and its interactions with social, economic and technical environments. Different ways to measure the sustainability have been developed, but they still lack agreement. Among the reasons for this lack of agreement, one may cite the ambiguous and numerous definitions for sustainable development (Parris and Kates, 2003), which includes the confusion of terminology, different forms of data collection and data analysis, and different methods of measurement. One may cite also the split between The Post-Normal Science approach and the Normal Science approach in the academic communities of scientists using quantitative analyses in the field of sustainability (Giampietro et al., 2006). Scientists accepting the Post-Normal approach recognize the need to deal with a preliminary semantic check when defining a problem related to analysis of sustainability. Concepts such as sustainability or progress cannot be once for all defined. In this approach it is also accepted that predicting the future with quantitative analyses will always be affected by a high level of uncertainty (Giampietro et al., 2006).

One of the efforts of the scientific community is related to the construction Sustainability Metrics (SMs) with possible composite environmental indexes (CEIs), which seek to offer concise

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environmental information for decision making, performance monitoring, policy progress evaluation and benchmarking comparisons. SMs may include physical, biological and chemical indicators, but also include indicators of environmental pressures, states and societal responses. A different approach is proposed by emergy synthesis. But, despite of different points of view and targets, methods proposed in the literature to measure sustainability are used separately, in many instances to rank countries in an attempt to provide a classification to substitute that supplied by gross domestic product (GDP) or human development index (HDI). No matter how, the uncertainty due to the disagreement among the proposed metrics in communicating coherent and similar information to guide decision makers towards sustainable development clearly denotes the lack of a "science of sustainability" (Giannetti et al., 2009; Giannetti et al., 2004).

The future development of sustainability indicators requires metrics that are broader in order to be accessible to a wide user group for differing case circumstances. There is also the need for more standardized metrics that give more transparent results. As a consequence, there are several works in the literature comparing and discussing metrics and the interpretation of their results (Wilson et al., 2007; Siche et al., 2007; Nourry, 2008).

Applicability of a single metric approach has been also criticised. Assessing sustainability requires the consideration of economic, environmental and social issues and equity, and none of the current popular proposals seems to be able to include all these considerations simultaneously (Gasparatos et al., 2009a). There are propositions to combine poverty and hunger index with HDI (Gentilini and Webb, 2008) in order to refine the methods used for measuring progress, and new indexes are suggested to improve or complement the existent ones (Van de Kerk and Manuel, 2008). There are also proposals combining emergy synthesis with the ecological footprint (Siche et al., 2007; Siche et al., 2009a, 2009b; Chen and Chen, 2006; Zhao et al., 2005; Huang and Chen, 2006), and with exergy-economic accounting (Verdesca et al., 2006).

Emergy synthesis is a strong science-based methodology, which presents the ability to represent environmental and economic values in a common energy unit. The methodology can include in a relatively simple evaluation the contributions of human labour, societal services, free environmental resources and services and information. That is, all fluxes that carry energy and are supported by indirect flows of materials and resources. The methodology provides a uniform set of indicators of resource use, partitioning, trade, environmental condition, and to provide information on the contribution of the ecological processes to human wealth and progress. (Jiang et al., 2007; Dong et al., 2008a, 2008b; Zhang and Chen, 2007; Gasparatos and Gadda, 2009; Chen and Lin, 2008).

Four emergy indices (the environmental yield ratio (EYR); the environmental investment ratio (EIR); the environmental load ratio (ELR), and the environmental sustainability indice (ESI)) were compared to widespread Sustainability Metrics (SMs), which propose composite welfare or sustainability indices to evaluate and categorize countries regarding their sustainability. The SMs selected from the literature include the ecological footprint (EF), the surplus biocapacity measure (SB), the environmental sustainability index (ESI2005), the wellbeing index (WI), the ecosystem services product (ESP), and the sum of GDP+ESP= SEP, which is a measure of the subtotal ecological–economic product. GDP is a metric that reckons economic growth as a driving force of sustainable development (OECD, 2001; Beckermann, 1992; CEC, 2001). HDI is a social metric that considers sustainable development tied to human development. It includes life expectancy representing a long and healthy life; knowledge accounted by adult literacy and combined gross enrolment in primary, secondary and tertiary level education, and a decent standard of living represented by GDP. GDP and HDI approaches differ drastically from the strong sustainability defined by Goodland and Daly (1992), but are also included in this comparison as both are worldwide accepted measures of prosperity. Each of these measures was used to position countries by their relative sustainability and to provide quantitative comparisons of sustainability. Ranks obtained by each measure intend to compare countries according to their performance against a corresponding sustainability standard and against one another.

This paper confronts emergy indices with five widely accepted global Sustainability Metrics (SMs) in providing information to conduct decision makers towards sustainable development. In this work, the degree of variability between metrics is analyzed using correlation analysis. Mercosul is presented as a case study to highlight and explain the discrepancies between SMs.

1.1. Methods

This section is divided in four items as follows:

1.1 Correlation analysis: where criteria used in this work to establish strong, medium and weak correlation is described.
1.2 Mercosur: shows a brief description of the Southern Cone Common Market.
1.3 Sustainability metric #1 emergy accounting: describes the four emergy indices and the use of the ternary diagram for data interpretation.
1.4 Sustainability metrics for comparison (SMs #2–6): describes briefly the five popular metrics contrasted to emergy analysis.

Metrics chosen for comparison include tools that employ a "subjective preference" theory of value (GDP, HDI, WI and ESI2005), system's emissions (ESI2005, EF and SB), energy consumption (EF and SP) and energy memory (EYR, EIR, ELR and ESI). Notwithstanding the number of metrics found in the literature offering some kind of measure of sustainability (O'Regan et al., 2009; Ukidwe and Bakshi, 2005; Hutchins and Sutherland, 2008; Pan and Kao, 2009; Distaso, 2007), and despite of the great potential of some of them such as extended exergy analysis (Sciubba and Ulgiati, 2005; Chen and Chen, 2009), metrics chosen for the comparison in this work were those providing ranks in their corresponding sustainability standard and positioning countries according to their performance against one another, especially those of Mercosur.

1.1.1. Correlation analysis

Correlation analysis was used successfully by several authors to compare sustainability metrics (Sutton and Costanza, 2002; Wilson et al., 2007, Siche et al., 2007; Ayres, 2008; Mayer, 2008; Kemmler and Spreng, 2007). All correlations between metrics were based on the ranks of countries. The relationship between the metrics was analyzed measuring the degree to which a linear predictive relationship exists between two variables. If both variables increase together across countries, a positive correlation results in a value from 0 to +1.0. Conversely, an inverse relationship between the metrics would yield a negative correlation coefficient, between 0 and -1.0. Correlations above 0.6 were considered strong, medium correlations were between 0.4 and 0.6, and weak correlations that were lower than 0.4.

1.1.2. Mercosur (Southern Cone Common Market)

The common market of Argentina, Brazil, Uruguay and Paraguay (Mercosur) was created in 1991 by the Asuncion Treaty. Mercosur (called Mercosul in Brazil) established a program of gradual, automatic and across-the-board elimination of import duties, promoting free trade and the fluid movement of goods, people and currency.

The original bloc comprises a population of more than 265 million people (4.03% of the World population) (Department of Economic and Social Affairs Population Division, 2006), and the combined Gross Domestic Product of the member nations is in excess of 2.9 trillion dollars a year according to World Bank numbers (World Bank, 2007), making Mercosur the fifth largest economy in the World. The regional trade agreement between Argentina, Brazil, Paraguay and Uruguay has been one of the more successful trade agreements in the region, and was marked by the recent associate membership of Chile and Bolivia. Venezuela applied for membership in June 2006, and the Brazilian representative in the Mercosur Parliament approved its participation in February 18th, 2009. The protocol of accession was considered by the Commission of Foreign Affairs and National Defense and voted in its complete form by the Brazilian Senate in the end of 2009 (Senado Multimedia, 2010). The Paraguayan Congress will discuss whether Venezuela should be allowed to join the trade group in 2010.

The environmental policy of Mercosur deals with the inclusion of environmental costs in cost analysis; adoption of adequate practices and sustainable management of natural resources; control of potential adverse activities; adoption of minimization and treatment practices; cleaner technologies and recycling; monitoring of shared ecosystems; co-ordination of international acts; and institutional strengthening and environmental management of tourism (Virasoro, 1996). Trade liberalization has increased dependence on industries that are natural-resource intensive (Deere and Esty, 2004), and monitoring the environmental–economic development of this bloc would be useful for definition of future policies and decision making.

1.1.3. *Sustainability metric #1: Emergy synthesis*

Emergy indices, developed by Odum, were defined for sustainability assessment with respect to resource quantity and quality, according to the sustainability principles introduced by Daly (1990). Emergy was defined as the quantity of solar energy necessary (directly or indirectly) to obtain a product by a given process or to support a regional system (Odum, 1996). Its units are solar emergy joules (sej). This environmental accounting method considers energy flows that are economically free and therefore generally ignored in traditional balances. To convert energy inputs and other flows into their solar equivalent, solar transformities are used.

It is important to highlight that transformity is a physical quantity and not a weighting factor. Transformity stands for the emergy of one type required to make a unit of energy of another type. This concept was introduced by Odum to represent "energy quality" and "energy transformation ratio". The concept of transformity was further specified as the ratio of "input emergy dissipated (availability used up)" to the "unit output exergy" (Sciubba and Ulgiati, 2005), and as a strong indicator of the efficiency of a system (Jørgensen, 2000, Brown et al., 2004; Ulgiati and Brown, 2009), and global productivity (Almeida et al., 2010; Bonilla et al., 2010). It is important to highlight that transformity is a physical quantity and not a weighting factor.

The transformity can estimate the higher level of quality of any output (Giannantoni and Zoli, 2010), which is defined on the basis of non-conservative emergy algebra (Brown and Herendeen, 1996), and leads to the definition of the total emergy as:

$$\text{Emergy} = \text{energyquality(transformity)} \times \text{energyquantity(exergy)} \quad (1)$$

where exergy stands for the energy multiplied by the Carnot coefficient. Transformity, in turn, can be articulated in two distinct factors:

$$\text{Tr} = \text{Tr}_{\text{ex}} \times \text{Tr}_{\theta} \quad (2)$$

where Tr_{ex} accounts for the exergy used up during the production process of a given good or service, whereas Tr_{θ} accounts for the ever-increasing content of ordinal information, and this is why transformity is understood in an ordinal sense, although represented as an algebraic cardinal factor (Giannantoni and Zoli, 2010).

Data relating emergy of the Mercosur countries were taken from Rótolo et al., 2007. The total emergy used can be divided into different resource categories: imported from outside the system (F), renewable resources (R) and non-renewable resources (N). The output of the system Y equals R+N+F. The classification of flows allows the calculation of the emergy indices (Table 1).

1.1.3.1. *Graphical representation using the emergy ternary diagram.*

Accordingly to Gasparatos et al. (2008), the use of ternary diagrams, which visually represent some of the indices mentioned above corresponds to a fourth step of emergy synthesis that can assist the comparison of different development paths, and further facilitate the communication of the results and the decision making process.

To evaluate emergy results using ternary diagrams, the three components, R, N and F are represented in an equilateral triangle with height 1 (Giannetti et al, 2006; Almeida et al, 2007). In Fig. 1, the point that represents Brazil shows a system composed by three inputs: 12% sej/sej of F, 50% sej/sej of N and 38% sej/sej of R. This device is possible because the sum of such perpendiculars is independent of the position of the point. The point that

Table 1
Emergy indices, description and equations.

Symbol	Description	Equation
EYR	This indicator computes the process ability to profit from local resources. The lower the portion of the economic input (F) the higher is this ability. However, this index does not differentiate local and imported resources.	EYR=Y/F=(R+N+F)/F
EIR	The EIR shows the relation between the emergy of the economic inputs with those provided by the environment, renewable or not.	EIR=F/(N+R)
ELR	The ELR is an indicator of the stress of the local environment due to the production activity. The lower the portion of renewable emergy used the higher the pressure on the environment.	ELR=(N+F)/R
ESI	This indice aggregates the measure of yield and environmental loading. The objective function for sustainability is to obtain highest yield ratio at the lowest environmental loading. The ESI arises from the ratio of EYR to ELR, which is a sustainability function for a given process or economy. The fact that it is preferable to have a higher emergy yield per unit of environmental loading defines this index that evidences if a process offers a profitable contribution to the user with a low environmental pressure (Brown and Ulgiati, 1997).	ESI=EYR/ELR

R: renewable resources, N: non-renewable resources and F: feedback from the economy.

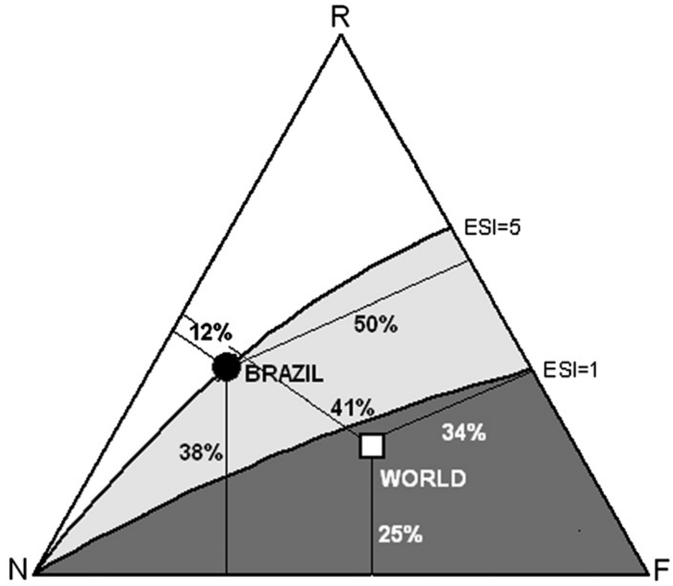

Fig. 1. Representation of the World's (□) and Brazil's (●) total emergy composition in a ternary diagram and the sustainability regions: white—long term sustainability, light gray—medium term sustainability and dark gray—short term sustainability. Data for World total emergy was taken from Sahel Project, 2000. R: renewable resources, N: non-renewable resources and F: feedback from the economy.

corresponds to the World's total emergy composition is also shown (R=25% sej/sej, N=34% sej/sej and F=41% sej/sej) for comparison.

The ternary diagram permits to draw lines shown in Fig. 1, indicating constant values of the sustainability index (ESI). The sustainability lines depart from the N apex in direction to the RF side, and allow the division of the triangle in sustainability regions, which are very useful to identify and compare the sustainability of products, processes or nations. When ESI $<$ 1 (dark gray region), nations are not sustainable in a long term (Brown and Ulgiati, 1997). Systems presenting 1 $<$ ESI $<$ 5 (light gray region) may be sustainable for medium periods and nations with ESI $>$ 5 can be considered sustainable in a long term (white region).

1.1.4. Sustainability metrics (SMs) used for comparison

1.1.4.1. SM #2 Ecological footprint (EF). The concept was developed by Rees and Wackernagel (1996). Global results were released as part of Living Planet Report, updated annually as part of the Living Planet Report series. The ecological footprint measures how much bioproductive area (land or water) a population would require to produce all the resources it consumes and to absorb the waste it generates, using the prevalent technology. This metric indicates the demand for resources and is constructed from impact measurements for managing the use of croplands, grazing lands forests, fisheries, infrastructure and fossil fuels. Data used for this study were based on the The Living Planet Report 2005 update (Wackernagel et al., 2005).

1.1.4.2. SM #3 Surplus biocapacity (SB). Similar to the ecological footprint metric, SB measures the sustainability of consumption patterns, but accounts the difference between a country's ecological footprint and its domestic production area of the ecologically productive land and water. The biocapacity (BC) measures the bioproductive supply, i.e., the biological production in a given area, which may include built or degraded land. Biocapacity is dependent not only on natural conditions but also on current farming/forestry practices. Surplus biocapacity (SB=EF−BC) was reported in both the Footprint of Nations report and in the Living Planet reports (Wackernagel et al., 2005).

1.1.4.3. SM #4 The environmental sustainability index (ESI2005). This index was developed by the World Economic Forum's Global Leaders for Tomorrow Environment Task Force, the Yale Centre for Environmental Law and Policy (YCELP), and the Columbia University Centre for International Earth Science Information Network (CIESIN). As its first version published in 2002 (ESI2002), the ESI2005 consists of five components: environmental systems, reducing environmental stresses, reducing human vulnerability, social and institutional capacity and global stewardship. Each of these components is made up of a number of indicators, which include indicators of physical, biological and chemical state, as well as indicators of environmental pressures, and the responses of society. The ESI2005 presents the results of a study that ranks 146 countries and involves 76 underlying variables aggregated in 21 indicators. Data used for this study were based on the 2005 update (Esty et al., 2005). Unfortunately, the 2006 version of this index, called EPI 2006 (Esty et al., 2006), does not include Uruguay due to the lack of data, which impedes its inclusion in this paper.

1.1.4.4. SM #5 The wellbeing index (WI). The WI is a composite index of 88 indicators based on the equally weighted average of human wellbeing index (HWI) and ecosystem wellbeing index (EWI). This metric was developed by Robert Prescott-Allen in collaboration with the International Development Research Centre (IDRC) and the World Conservation Union. Results for 180 countries were released in 2001. The HDI comprises health and population, household and national wealth, knowledge and culture, community and equity. EWI includes land, water, air, species and genes and resource use. Data used were based on Prescott-Allen, (2001).

1.1.4.5. SM #6 The Ecosystem Services Product (ESP) and the subtotal ecological–economic product (SEP). Sutton and Costanza (2002); estimated globally marketed and non-marketed economic value from two classified satellite images with global coverage at 1 km^2 resolution. GDP (a measure of marketed economic output) was correlated with the amount of light energy (LE) emitted by a nation as measured by nighttime satellite images. The Ecosystem Services Product (ESP) was calculated, based on unit ecosystem-service values previously calculated by (Costanza et al., 1997a, 1997b) and (Sutton and Costanza, 2002). The addition of ESP values per ecosystem per country yielded total dollar value of ecosystem services per country. The sum of GDP+ESP equals SEP (subtotal ecological−economic product), which is a measure of the marketed plus a significant portion of the non-marketed values of a country. Data used for this study were based on reference (Sutton and Costanza, 2002).

2. Results and discussion

2.1. Emergy results

The annual emergy use might also be useful for evaluating the contribution of goods and services to the society well-being. However, when dealing with sustainability, the meaning of its value is not univocal and depends on several factors such as the makeup of emergy (its percentage of renewable and non-renewable inputs, its dependence on other ecosystems, etc.) and economic results (the foreseen outcome of private consumption,

Fig. 2. Ternary diagram of Mercosur's countries, with regions of short term sustainability (dark gray), medium term sustainability (light gray) and long term sustainability (white). The size of the points representing the countries is proportional to their total emergy. R: renewable resources, N: non-renewable resources and F: feedback from the economy.

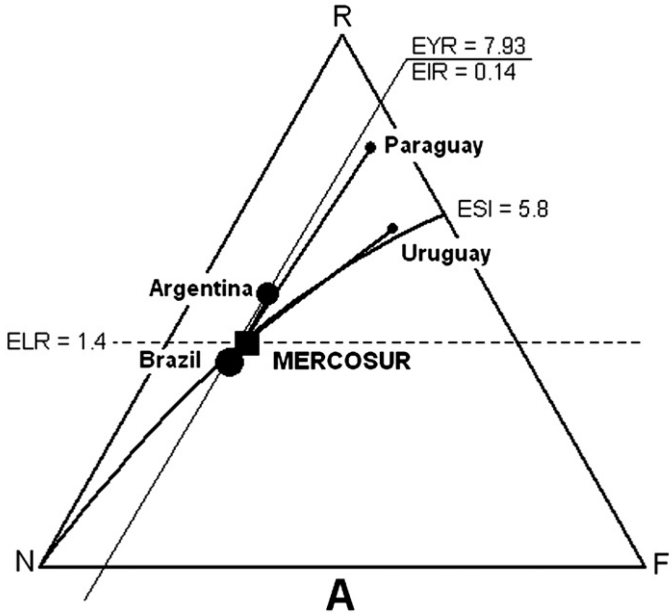

Fig. 3. Ternary diagram of Mercosur's countries (●) and of Mercosur (■). The size of the points representing the countries is proportional to their total emergy. R: renewable resources, N: non-renewable resources and F: feedback from the economy.

investments and public expenditure). The representation of emergy accounting using ternary diagrams permits to compare countries ranked, distinguishing the total emergy components in a way that sustainability may be evaluated, accordingly to the use of natural and economic resources (Giannetti et al, 2006; Almeida et al., 2007).

Fig. 2 shows the four Mercosur countries represented in the ternary diagram (Giannetti et al, 2006; Almeida et al, 2007). It is easy to observe the position of each country in relation to the sustainability regions. It is also interesting to note that Brazil, Argentina and Paraguay have a similar percentage of purchased resources (about 12% sej/sej, F=0.12), and that Paraguay and Uruguay count with practically the same percentage of non-renewable resources (about 7% sej/sej, N=0.07). Argentina, Paraguay and Uruguay are located in the region of the diagram where ESI > 5, corresponding to a condition of long term sustainability. Brazil lies on the limit between long and medium term sustainability (Brown and Ulgiati, 1997).

The ternary diagram allows the representation of the whole Mercosur (Fig. 3), that is the combined set of all four countries (Giannetti et al, 2006; Almeida et al, 2007). The point that corresponds to the resulting bloc is located near the point that represents Brazil, which accounts for approximately 70% of the total emergy of the bloc, but the sustainability indice for Mercosur shifts slightly to the long term sustainability region due to the presence of the other three countries, especially Argentina, which contributes with 28% to the Mercosur's total emergy.

The environmental loading of Mercosur (ELR=1.4) may be considered low (Brown and Ulgiati, 1997). EYR equals 7.93. This value is a measure of the ability of the bloc to exploit and make available local resources by investing outside resources. Thus, the appropriation of local resources by the Mercosur can be read as a contribution of the bloc to the global economy. The emergy investment ratio is the ratio of the emergy inputs received from the economy to the emergy investment from the free environment. The less the ratio, the less the economic costs. So, the value of EIR=0.14 for Mercosur indicates that it competes and prospers

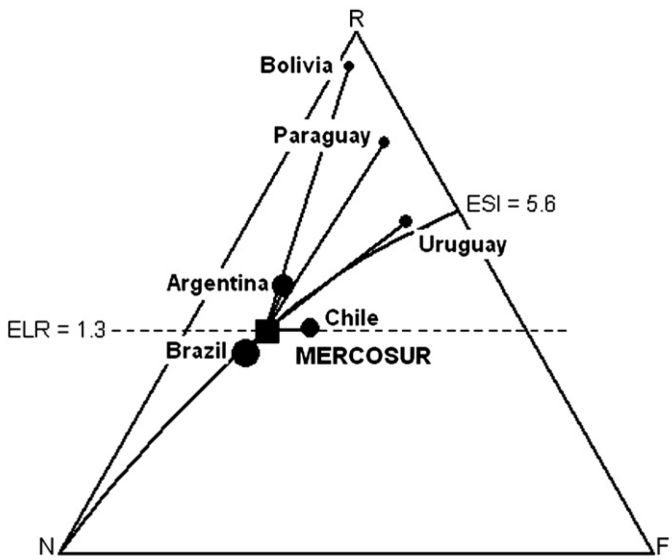

Fig. 4. Ternary diagram of Mercosur's countries (●), plus Chile and Bolivia and the new Mercosur including the associate members (■). The size of the points representing the countries is proportional to their total emergy. R: renewable resources, N: non-renewable resources and F: feedback from the economy.

in the global market supplying natural free resources to the global economy.

Fig. 4 illustrates the case in which associate members, Bolivia and Chile, were included in Mercosur. Bolivia has a high sustainability indice, but its total emergy contributes with less than 1% to the total emergy of Mercosur. The inclusion of Chile lowers the sustainability indice of the bloc from 5.8 to 5.6, but Mercosur remains in the region of long term sustainability. Fig. 5 includes Venezuela. The total emergy of this country corresponds to 9% of the total emergy of the bloc. The inclusion of Venezuela lowers the ESI to 5.5.

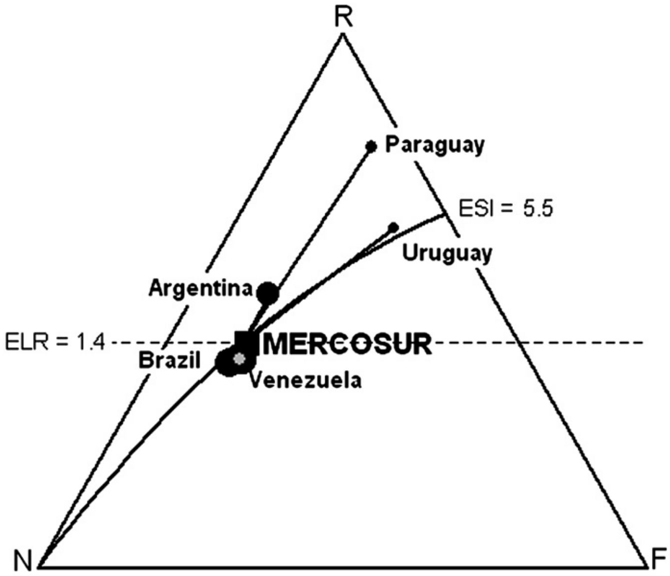

Fig. 5. Ternary diagram of Mercosur's countries (●) plus Venezuela and the new Mercosur composed by five countries. The size of the points representing the countries is proportional to their total emergy. R: renewable resources, N: non-renewable resources and F: feedback from the economy.

Table 2
Raw data scores by country for each emergy indice. Each line shows the position of the country in the respective rank (in bold) and the value for each indice within brackets.

	EYR [a]	EIR [a]	ELR [a]	ESI [a]
Argentina	**1** (8.20)	**1** (0.14)	**4** (0.96)	**3** (8.5)
Bolivia	**3** (6.81)	**3** (0.17)	**2** (0.62)	**1** (49.2)
Brazil	**2** (8.15)	**2** (0.15)	**5** (1.61)	**5** (5.0)
Chile	**6** (5.37)	**6** (0.23)	**7** (3.98)	**7** (1.4)
Paraguay	**4** (6.39)	**4** (0.18)	**1** (0.27)	**2** (24.8)
Uruguay	**7** (3.76)	**7** (0.36)	**3** (0.57)	**4** (6.6)
Venezuela	**5** (5.39)	**5** (0.23)	**6** (1.62)	**6** (3.4)

Emergy Yield Ratio (EYR); Emergy Investment Ratio (EIR); Environmental Load Ratio (ELR) and Environmental Sustainability Indice (ESI).

[a] All indices are dimensionless.

The evaluation of Mercosur using the emergy ternary diagram showed that Brazil is the main component of the bloc in terms of environmental performance, and that the addition of Venezuela, Chile and Bolivia causes no improvement or worsening to the environmental performance of the bloc. The classification of Mercosur's countries accordingly to emergy accounting is shown in Table 2 in order to compare this classification with those performed by the other five metrics selected. It is clear that results from EYR and EIR, which consider the balance between the emergy of the economic inputs with those provided by the environment, differ from that obtained with ELR and ESI, which give more importance to the use of renewable resources.

2.2. Comparison of emergy results and other SMs

Table 3 presents the raw data scores by country for the five metrics used for comparison. It is clear that the individual sustainability metrics present divergent results for all countries. No country appeared in the same position for all metrics, suggesting a lack of consistency among them, and that the analysis of various indicators would be necessary to drive policy and decision makers towards a reliable conclusion concerning the countries' sustainability.

Results shown in Table 3 suggest that selected metrics for sustainability monitoring provide conflicting assessments of countries' sustainability. However, it is important to evaluate the correlation among them. The relationship between metrics was analyzed measuring the degree to which a linear predictive relationship exists between two variables. There is high positive correlation among the ESI2005, WI, HDI and GDP per capita, but there is high negative correlation between these four indices and the EF, ELR and ESI. This suggests that the EF group and the ESI2005 group provide conflicting sustainable development guidance.

Results for Mercosur are similar to those found by Sutton and Costanza (2002) who found no statistically significant relationship between the ESP and ESI2002 (the previous version of ESI2005), nor any significant relationship between EF and ESI2002. However, the correlation between the ESP and EF was both positive and statistically significant. Siche et al. (2007), in a study that included twelve countries compared ESI with EF and ESI2005 and found no correlation between ESI2005 and ESI and a medium correlation between ESI and EF.

Metrics in Table 4 were divided in three groups according to the sustainability's standard dimensions that appear to strongly influence the selected metrics. Clearly, metrics explored in this analysis emphasizes different aspects of sustainability (environmental, social and/or economical), and the sustainability priority of each metric can help to understand the variability among them.

The first group shown in Table 4 includes indices with environmental–social–economic variables. The HDI appends social dimensions to GDP/capita, and both are obviously correlated. ESI2005 and WI are strongly correlated with each other and with HDI and GDP/capita. The ESI2005 and WI are dominated by social indicators and include the GDP/capita assuming that economic wellbeing is the basis of sustainability. There is a medium correlation with emergy indices EYR and EIR, which are associated to the relation between the economic investment and the use of free local resources. In this group, Uruguay (1st by ESI2005 and by WI) occupies the first position (Table 3).

The second group includes two emergy indices (EYR and EIR) and SEP (Table 4). This intermediary group incorporates indices based on environmental–economic variables. There is a high correlation among the metrics within the group, and a medium correlation of emergy indices with GDP/capita and HDI. EF presents a medium correlation with SEP, and a low correlation with EYR and EIR. Argentina and Brazil are first in this group. Argentina has the 1st position by EYR and EIR (Table 1) and 2nd by SEP (Table 3). Brazil holds the 1st position by SEP (Table 3) and 2nd by EYR and EIR (Table 2).

In the third group shown in Table 4, metrics emphasize the environmental dimension of sustainability, accordingly to the strong sustainability model (Goodland and Daly, 1992). Most of the indices in this group, except EF, have none or negative correlation with indices of the first and second groups. Despite the substantial difference between attaching a value to resources through emergy (ESI and ELR) or area evaluation (EF and SB) and assigning them a market price (ESP), metrics of the third group are highly correlated. These metrics are all based on the Herman Daly's sustainability principles (Daly, 1990), and point to the need to change, redirect or decelerate economic growth. It is implicit in

Table 3
Ranking for Mercosur's countries for each metric. HDI and GDP per capita are included as both are worldwide accepted measures of development. Each line shows the position of the country in the respective rank (in bold) and the value for each indice within brackets.

	ESI ([a])	**EF** (ha/capita)	**SB** (ha/capita)	**ESI2005** (1–100)	**WI** (1–100)	**SEP** (10^6 US$)	**ESP** (%)	**HDI** (0–1)	**GDP per capita** (US$/capita)
Argentina	**3**	**5**	**5**	**2**	**3**	**2**	**6**	**1**	**1**
	(8.5)	(3.18)	(4.28)	(62.7)	(47.5)	(564,923)	(51)	(0.853)	(10,880)
Bolivia	**1**	**1**	**1**	**4**	**2**	**4**	**1**	**7**	**7**
	(49.2)	(1.67)	(8.91)	(59.4)	(48.5)	(324,217)	(94)	(0.681)	(2,460)
Brazil	**5**	**3**	**4**	**3**	**6**	**1**	**3**	**5**	**3**
	(5.0)	(2.39)	(4.75)	(62.2)	(40.6)	(3,559,661)	(73)	(0.775)	(7,700)
Chile	**7**	**6**	**7**	**6**	**5**	**5**	**5**	**2**	**5**
	(1.4)	(3.04)	(1.21)	(55.1)	(42.5)	(264,511)	(57)	(0.839)	(4,820)
Paraguay	**2**	**2**	**2**	**5**	**7**	**6**	**2**	**6**	**6**
	(24.8)	(2.29)	(5.37)	(59.7)	(40.5)	(82,696)	(79)	(0.751)	(4,610)
Uruguay	**4**	**7**	**3**	**1**	**1**	**7**	**6**	**3**	**2**
	(6.6)	(3.32)	(4.95)	(77.8)	(56.5)	(49,645)	(51)	(0.833)	(7,830)
Venezuela	**6**	**4**	**6**	**7**	**4**	**3**	**4**	**4**	**4**
	(3.4)	(2.42)	(1.32)	(53.0)	(44.5)	(530,439)	(63)	(0.778)	(5,380)

Environmetal Sustainability Indice (ESI); Ecological Footprint (EF); Surplus Biocapacity (SB); Environmental Sustainability Index (ESI2005); Wellbeing Index (WI); Subtotal Ecologic–economic Product (SEP); Ecosystem Services Product (ESP); Human Development Index (HDI) and Gross Domestic Product (GDP).

[a] dimensionless.

Table 4
Mercosur rank according to the metric selected, identification of the standard dimensions of sustainability of each metric, and the degree of correlation among metrics. Emergy indices are shown in bold letters.

Metric	**Sustainability dimension**			**Degree of correlation**							
	Environmental	Social	Economical	High				Medium			Low
First group					$R^2 \geq 0.6$			$0.4 \leq R^2 < 0.6$			$R^2 < 0.4$
ESI2005	◆	◆	◆	GDP/capita	HDI	WI	x	–	–	x	–
WI	◆	◆		GDP/capita	HDI	ESI2005		–	–		–
GDP			◆	WI	HDI	ESI2005		**EYR**	**EIR**		–
HDI		◆		GDP/capita	WI	ESI2005		**EYR**	**EIR**		-
Second group											
EYR	◆		◆	SEP	**EIR**	–		HDI	GDP/capita		**ESI**
EIR	◆		◆	SEP	–	–		HDI	GDP/capita		–
SEP	◆		◆	**EYR**	**EIR**	–		EF	–		–
Third group											
SB	◆			**ELR**	EF	ESP		**ESI**	**-**		–
%ESP	◆			EF	SB	–		–	–		–
ELR	◆			**ESI**	SB	–		EF	–		–
ESI	◆		◆	**ELR**	SB	–		EF	–		–
EF	◆			ESP	SB	–		**ESI**	–		**ELR**

Environmetal Sustainability Index (ESI2005); Wellbeing Index (WI); Gross Domestic Product (GDP); Human Development Index (HDI); Emergy Yield Ratio (EYR); Emergy Investment Ratio (EIR); Subtotal Ecologic–economic Product (SEP); Surplus Biocapacity (SB); Ecosystem Services Product (ESP); Environmental Load Ratio (ELR); Environmental Sustainability Indice (ESI) and Ecological Footprint (EF).

these metrics that economic growth cannot exceed ecological limits.

The absence of correlation of the third group indices with ESI2005, WI, HDI and GDP/capita shows that these metrics are based on different sustainability standards. While the metrics of the third group are related to the concern of the proper use of resources, metrics of the first group are related to the hypothesis that the decrease of social and economical impacts of growth may lead to sustainable development. As expected, metrics based on variables predominantly environmental reward countries with low GDP/per capita and low population (Sutton and Costanza, 2002). In this group Bolivia and Paraguay hold the top positions. Bolivia has the first position by ESI, EF, SB and ESP (Table 3) and second by ELR (Table 2). Paraguay holds the 1st position by ELR (Table 3) and 2nd accordingly to ESI, EF, SB and ESP (Table 3).

There is high correlation between the SB and ELR and ESP. Despite of EF and SB adopt the same sustainability approach, they show medium correlation in their results. EF presupposes a global perspective, where sustainability is evaluated based on the assumption that equal shares of the earth's productive capacity are distributed among the world's population. SB considers each country as a sustainability unit. Thus, the difference between these approaches could be due to the different scale with which sustainability is evaluated by each metric (Wilson et al., 2007).

The correlation analysis shown in Table 4 provides a better understanding of the relationship between corresponding metrics. Thus, users of SMs information could pick any measure within a group knowing which other metrics could provide similar results, and which metric should complement these results through the assessment of another dimension of sustainability.

It is worthy to note that emergy is the only metric that has indices which correlate with indices of all three groups, and despite of the medium correlation with indices of the first group, it may cover practically all dimensions of sustainability considered by the other metrics. From the theoretical viewpoint, in-depth research into the relationship between economic and emergy evaluations and their interaction is still required. While GDP/capita is a purely economic indicator of wealth strongly linked to economic or technological conditions it does not completely reflect the extent of well-being that a society may experience. Emergy, in turn, determines the weight of a good or a service on the basis of a common unit (solar energy) accounting for the withdrawal of natural local resources and quantifying resources feedback by the economy. This is an objective measure of the amount of real wealth used by a society that may express the extent of well-being in a more complete way.

The results of an emergy evaluation can then be related to several economic or socio-economic parameters such as GDP/capita, education and health (HDI), and the import of goods and services. In particular, the annual emergy use (the sum of indigenous resources used and imports) may be defined as the amount of welfare that a society may sustain (Odum, 1996).

3. Conclusions

As an emerging field, the science of sustainability comes with challenges such as establishing itself as a unique field, gaining academic merit, developing quality standards and establishing metrics. Within this context, distinct research branches have emerged, but they are certainly not yet unified.

All six metrics evaluated intend to compare the degree of sustainability of the nation states, and it is critical to recognize that all of them only assess a part of sustainability, as the emphasis of what drives or constitutes sustainability differs among metrics. Evaluation of the several sustainability dimensions is problematic given the great scientific uncertainty and ignorance in many relevant fields of the environmental and social sciences, the subjective nature of monetary valuations and the considerable uncertainties of biophysical models especially when the scale of the sustainability assessment is extended (Gasparatos et al., 2009b). Aggregation through monetary and/or composite indices includes the acceptance of the equivalence between environmental and human resources leading to weak sustainability evaluations that might not always be beneficial. The use of composite indices may cause loss of important information during the aggregation of the different sustainability variables (Giannetti et al., 2009).

The correlation analysis performed for Mercosur provided a better perception of the relationship between the metrics assessed. The juxtaposition of results explicitly illustrates that metrics arrive at different interpretations about the sustainability of nations, but that indices may be grouped and used more judiciously. Users of SMs information could choose any measure within the groups with the knowledge of what other metrics could provide complementary information for decision making.

The future SMs development meets the challenges of being based on a strong theoretical background and for succinct analyses on a more diverse range of assessment situations. Results obtained confirm the idea that there is not yet an unique metric, which can cover all aspects of sustainability (economic, social and environmental). However, an analyst that intends to use only one metric, should take into account that emergy was the only metric with indices with positive correlation with all three groups of indices, and may provide a more consistent and complete coverage of the dimensions of sustainability, when a single metric is used.

As a donor value-based thermodynamic concept, emergy presents the available energy content accumulated through distinguished pathways at global scale and over ecological evolution phases. The donor-quality assessment measures the average ecological cost of each country facilitating the evaluation. Since the renewable and nonrenewable environmental resources from the biosphere and purchased resources from the human-dominated economic systems are systematically accounted in the procedure, local sustainability is represented by the set of emergy indices.

In particular, emergy accounting offers important beneficial features:

1. Emergy accounts for all the solar energy necessary (directly or indirectly) to obtain a product by a given process or to support a regional system (Odum, 1996), and it avoids the step of selecting and classifying variables. During the construction of SMs, scientists select and classify the most representative basic variables (Yuan et al., 2003; Esty et al., 2005). For this, a review of the literature in the environmental field must be performed, along with discussion with many experts from across the environmental sciences, government, business, non-governmental groups, research centers and the academic sector. The difficulty arises as scientists designated to select these variables may not agree on the nature of the variables to be selected or on the relative importance of one among others.
2. Emergy avoids the difficulty one would face in normalizing and aggregating variables having different units. In all five SMs evaluated, environmental variables are normalized before the aggregation into an overall index by some aggregating method. There is still a need of objective criteria for choosing a suitable aggregating method to enable international comparability (Giannetti et al., 2006; Almeida, et al., 2007).
3. Emergy gives transparency in evaluating systems, as weighting factors, which are value judgments and can be prone to errors, are not employed. Expert weighting for environmental indicators quite often includes factors of subjective nature, inaccurate knowledge, sometimes even vague or conflicting information, which may lead to distorted opinions that eventually compromise the clarity and objectiveness of the analysis.
4. Emergy can also account directly or indirectly for the "free" ecological services, their contribution to human economy and the effect on it if their functioning is compromised.
5. Emergy graphical representation permits to compare the sustainability of different systems (such as countries), to evaluate the result of the composition of different systems (such as the Mercosur) and, at the same time, provide information related to the use of renewable and non-renewable resources (Giannetti et al., 2006; Almeida, et al., 2007).
6. Emergy has a rigorous scientific basis (Odum, 1996).

In this way, among all SMs assessed, emergy evaluation seems to be the more adequate and transparent metric for measuring the real impact of human activity on a territory and the combined expressions of human behaviour that affect the external environment in different ways.

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References

Almeida, C.M.V.B., Barrella, F.A., Giannetti, B.F., 2007. Emergetic ternary diagrams: five examples for application in environmental accounting for decision-making. Journal of Cleaner Production. 15, 63–74.

Almeida, C.M.V.B., Rodrigues, A.J.M., Bonilla, S.H., Giannetti, B.F., 2010. Emergy as a tool for Ecodesign: evaluating materials selection for beverage packages in Brazil. Journal of Cleaner Production 18, 32–43.

Ayres, R.U., 2008. Sustainability economics: where do we stand? Ecological Economics 67 (2), 281–310.
Beckermann, W., 1992. Economic growth and the environment: whose growth? Whose environment? World Development 20, 481–496.
Bonilla, S.H., Guarnetti, R.L., Almeida, C.M.V.B., Giannetti, B.F., 2010. Sustainability assessment of a giant bamboo plantation in Brazil: exploring the influence of labour, time and space. Journal of Cleaner Production 18, 83–91.
Brown, M.T., Herendeen, R.A., 1996. Embodied energy analysis and EMERGY analysis: a comparative view. Ecological Economics 19, 219–235.
Brown, M.T., Ulgiati, S., 1997. Emergy-based indices and ratios to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation. Ecological Engineering 9, 51–69.
Brown, M.T., Odum, H.T., Jorgensen, S.E., 2004. Energy hierarchy and transformity in the universe. Ecological Modeling 178, 17–28.
CEC—Commission of the European Communities, 2001. A sustainable europe for a better world: the european union strategy for sustainable development. Commission of the European Communities, Brussels.
Chen, B., Chen, G.Q., 2006. Ecological footprint accounting based on emergy—a case study of the Chinese society. Ecological Modelling 198, 101–114.
Chen, G.Q., Chen, B., 2009. Extended-exergy analysis of the Chinese society. Energy 34, 1127–1144.
Chen, C.Z., Lin, Z.S., 2008. Multiple timescale analysis and factor analysis of energy ecological footprint growth in China 1953–2006. Energy Policy 36, 1666–1678.
Costanza, R., d'Arge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Naeem, S., Limburg, K., Paruelo, J., O'Neill, R.V., Raskin, R., Sutton, P., van den Belt, V., 1997a. The value of the world's ecosystem services and natural capital. Nature 87, 253–260.
Costanza, R., d'Arge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Naeem, S., Limburg, K., Paruelo, J., O'Neill., R.V., Raskin, R., Sutton, P., van den Belt, V., 1997b. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Daly, H., 1990. Towards some operational principles of sustainable development. Ecological Economics 2, 1–6.
Deere, C.L., Esty, D.C., 2004. Greening the Americas: NAFTA's lessons for hemispheric trade journal international environmental agreements: politics. Law and Economics Publisher Springer Netherlands 4, 96–100.
Department of Economic and Social Affairs Population Division, 2006. World Population Prospects, Table A.2 (PDF). United Nations. Retrieved on 2008-10-25.
Distaso, A., 2007. Well-being and/or quality of life in EU countries through a multidimensional index of sustainability. Ecological Economics 64, 163–180.
Dong, X., Ulgiati, S., Yan, M., Zhang, X., Gao, W., 2008a. Energy and eMergy evaluation of bioethanol production from wheat in Henan Province China. Energy Policy 36, 3882–3892.
Dong, X., Ulgiati, S., Yan, M., Gao, W., 2008b. Progress, influence and perspectives of emergy theories in China, in support of environmentally sound economic development and equitable trade. Energy Policy 36, 1019–1028.
Esty, D.C., Levy, M.A., Srebotnjak, T., de Sherbinin, A., 2005. 2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship. Yale Center for Environmental Law and Policy, New Haven, Connecticut.
Esty, D.C., Levy, M.A., Srebotnjak, T., de Sherbinin, A., Kim, C.H., Anderson, B., 2006. Pilot 2006 environmental performance index, New Haven: Yale Center for Environmental Law & Policy. Wiley, New York, US.
Gasparatos, A., Gadda, T., 2009. Environmental support, energy security and economic growth in Japan. Energy Policy 37, 4038–4048.
Gasparatos, A., El-Haram, M., Horner, M., 2009a. The argument against a reductionist approach for measuring sustainable development performance and the need for methodological pluralism. Accounting Forum 33, 245–256.
Gasparatos, A., El-Haram, M., Horner, M., 2009b. Assessing the sustainability of the UK society using thermodynamic concepts. Renewable and Sustainable Energy Reviews 13, 1071–1074.
Gasparatos, A., El-Haram, M., Horner, M., 2008. A critical review of reductionist approaches for assessing the progress towards sustainability. Environmental Impact Assessment Review 28, 286–311.
Gentilini, U., Webb, P., 2008. How are we doing on poverty and hunger reduction? A new measure of country performance. Food Policy 33, 521–532.
Giannantoni, C., Zoli, M., 2010. The four-sector diagram of benefits (FSDOB) as a method for evaluating strategic interactions between humans and the environment: the case study of hydrogen fuel cell buses. Ecological Economics 69, 486–494.
Giampietro, M., Mayumi, K., Munda, G., 2006. Integrated assessment and energy analysis: quality assurance in multi-criteria analysis of sustainability. Energy 31, 59–86.
Giannetti, B.F., Bonilla, S.H., Almeida, C.M.V.B., 2004. Developing eco-technologies: a possibility to minimize environmental impact in Southern Brazil. Journal of Cleaner Production 12, 361–368.
Giannetti, B.F., Barrella, F.A., Almeida, C.M.V.B., 2006. A combined tool for environmental scientists and decision makers: ternary diagrams and emergy accounting. Journal of Cleaner Production 14, 201–210.
Giannetti, B.F., Bonilla, S.H., Silva, C.C., Almeida, C.M.V.B., 2009. The reliability of experts' opinions in constructing a composite environmental index: the case of ESI 2005. Journal of Environmental Management, In Press, Corrected Proof, Available online 14 March 2009.
Goodland, R., Daly, H., 1992. Environmental sustainability: universal and non-Negotiable. Ecological Applications 6, 1002–1017.
Huang, S.L., Chen, C.W., 2006. Theory of urban energetics and mechanisms of urban development. Ecological Modelling 189, 49–71.
Hutchins, M.J., Sutherland, J.W., 2008. An exploration of measures of social sustainability and their application to supply chain decisions. Journal of Cleaner Production 16, 1688–1698.
Jiang, M.M., Chen, B., Zhou, J.B., Tao, F.R., Li, Z., Yang, Z.F., Chen, G.Q., 2007. Emergy account for biomass resource exploitation by agriculture in China. Energy Policy 35, 4704–4719.
Jørgensen, S.E., 2000. Thermodynamics and ecological modeling. CRC Press, Massachussets, US.
Kemmler, A., Spreng, D., 2007. Energy indicators for tracking sustainability in developing countries. Energy Policy 35 (4), 2466–2486.
Mayer, A.L., 2008. Strengths and weaknesses of common sustainability indices for multidimensional systems. Environment International 34, 277–291.
Nourry, M., 2008. Measuring sustainable development: some empirical evidence for France from eight alternative indicators. Ecological Economics 67, 441–456.
Odum, H.T., 1996. Environmental accounting: emergy and environmental decision making.. Wiley, New York, US.
OECD, (2001. The Well Being of Nations: The Role of Human and Social Capital. OECD Publication Available at: http://www.oecd.org. Retrieved on 2009-11-15.
O'Regan, B., Morrissey, J., Foley, W., Moles, R., 2009. The relationship between settlement population size and sustainable development measured by two sustainability metrics. Environmental Impact Assessment Review 2, 169–178.
Pan, T.C., Kao, J.J., 2009. Inter-generational equity index for assessing environmental sustainability: an example on global warming. Ecological Indicators 9, 725–731.
Parris, T.M., Kates, R.W., 2003. Characterizing and measuring sustainable development. Annual Review of Environmental Resources 28, 559–586.
Prescott-Allen, R., 2001. The Well-Being of Nations: A Country-by-Country Index of Quality of Life and the Environment. Island Press, Washington, DC.
Rees, W., Wackernagel, M., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers, Gabriola Island, BC..
Rótolo, C.G., Rydberg, T., Lieblein, G., Francis, C., 2007. Emergy evaluation of grazing cattle in Argentina's pampas, agriculture. Ecosystems & Environment 119, 383–395.
Sahel Project, 2000. Environmental Accounting and Systems Synthesis of Land Management Interventions at Multiple Scales in the Sahel Region of West Africa. http://sahel.ees.ufl.edu/ Retrieved on 2009-05-08.
Sciubba, E., Ulgiati, S., 2005. Emergy and exergy analyses: complementary methods or irreducible ideological options? Energy 30, 1953–1988
Senado Multimedia (Senate Multimedia), 2010. http://www.senado.gov.br:80/agencia/verNoticia.aspx?codNoticia=88173&codAplicativo=2. (in Portuguese). Retrieved on 2010-01-05.
Siche, R., Agostinho, F., Ortega, E., Romeiro, A., 2007. Sustainability of nations by indices: comparative study between environmental sustainability index, ecological footprint and the emergy performance indices. Ecological Economics 66, 628–637.
Siche, R., Pereira, L., Agostinho, F., Ortega, E., 2009a. Convergence of ecological footprint and emergy analysis as a sustainability indicator of countries: Peru as case study. Communications in Nonlinear Science and Numerical Simulation, in press, Corrected Proof, Available online 31 October 2009.
Siche, R., Agostinho, F., Ortega, E., 2009b. Emergy net primary production (enpp) as basis for calculation of ecological footprint. Ecological Indicators 10, 475–483.
Sutton, P.C., Costanza, R., 2002. Global estimates of market and non-market values derived from nighttime satellite imagery, and cover, and ecosystem service valuation. Ecological Economics 41, 509–527.
Ukidwe, N.U., Bakshi, B.R., 2005. Flow of natural versus economic capital in industrial supply networks and its implications to sustainability. Environmental Science & Technology 39, 9759–9769.
Ulgiati, S., Brown, M.T., 2009. Emergy and ecosystem complexity. Communications in Nonlinear Science and Numerical Simulation 14, 310–321.
Van de Kerk, G., Manuel, A.R., 2008. A comprehensive index for a sustainable society: the SSI—the Sustainable Society Index. Ecological Economics 66, 228–242.
Verdesca, D., Federici, M., Torsello, L., Basosi, R., 2006. Exergy-economic accounting for sea-coastal systems: a novel approach. Ecological Modelling 193, 132–139.
Virasoro, C.L., 1996. Environmental aspects of regional integration in MERCOSUR. Review of European Community & International Environmental Law. 5, 38–45.
Wackernagel, M., Monfreda, C., Moran, D., Wermer, P., Goldfinger, S., Deumling, D., Murray, M., 2005. National Footprint and Biocapacity Accounts 2005: The Underlying Calculation Method. Global Footprint Network, Oakland, CA. www.footprintnetwork.org. Retrieved on 2008-06-18.
Wilson, J., Tyedmers, P., Pelot, R., 2007. Contrasting and comparing sustainable development indicator metrics. Ecological Indicators 7, 299–314.
World Bank, 2007. http://siteresources.worldbank.org/DATASTATISTICS/Resources/GDP_PPP.pdf. Retrieved on 2008-11-02.
Yuan, W., James, P., Hodgson, K., Hutchinson, S.M., Chi, C., 2003. Development of sustainability indicators by communities in China: a case study of chongming county, Shang Hai. Journal of Environmental Management 68, 253–261.
Zhang, L.X., Yang, Z.F., Chen, G.Q., 2007. Emergy analysis of cropping–grazing system in Inner Mongolia Autonomous Region. China Energy Policy 35, 3843–3855.
Zhao, S., Li, Z., Li, W., 2005. A modified method of ecological footprint calculation and its application. Ecological Modelling 185, 65–75.