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Emergy Footprint - Ecological Footprint based on Emergy: Brazil as Case Study

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ABSTRACT

Emergy accounting can evaluate natural capital and ecosystem services. It is able to quantify the work done by nature to produce resources. On the other hand, the Ecological Footprint method has been promoted as a planning tool for sustainability. Despite being one of the most popular methods nowadays, it has received many critiques, especially because of its anthropocentric point-of-view. A modified calculation combining those two methods was proposed by Zhao et al., but it is not adequate for solving all the problems found in the Ecological Footprint. The aim of this paper is to suggest some modifications and include the full concept of emergy into the calculation. The biocapacity was estimated as function of the renewable resources available. Consumption was grouped in categories: cropland (soy, sugar and alcohol, cereals and grains, beans, cotton, and fruits and vegetables), forestry (wood), animal husbandry (meat, milk, and fishery), and energy resources (coal, petroleum, natural gas, and hydroelectricity). All the energy flows were calculated in Joules and then transformed into solar emergy (sej/year) using the conversion factor "transformity" (sej/J). The emergy flows were divided by the "global emergy density" (sej/gha) to obtain the "equivalent global area". To demonstrate the mechanics of this new method, we applied it to the case of Brazil. The results were that Brazil has an ecological footprint of 41.95 gha/cap and a biocapacity of 61.51 gha/cap. Compared with conventional footprint calculations, the emergy based approach showed worse results for Brazilian ecological reality.

INTRODUCTION

As the concept of sustainable development has become more accepted and incorporated by the institutions, it becomes necessary to evaluate economy's performance based on a new method and not only on economic indicators such as GDP (Gross Domestic Product). In order to apply the concept of sustainable development, it's important to establish new indicators, objectives and targets that can provide the measure of a country's performance in terms of sustainability. Definitions and operational indicators are a pre-requisite to the practical implementation of the concept of sustainability.

There isn't a standard in the world scientific community concerning a methodology to evaluate the sustainability of a national economy. In a comparative study of sustainability indicators, Siche et al. (2005) concluded that Ecological Footprint and Emergy Analysis are good indicators to explain the ecological reality of a national system.

Ecological Footprint, created by Wackernagel and Rees (1996), has been promoted as a planning tool for sustainability and widely used by many countries and organizations, due to its didactic way to show the impact of human activities on the nature as the area needed to support consumption. Despite its popularity, it has received many critiques (Levett, 1998; van den Bergh and Verbruggen, 1999; Ayres, 2000; Moffatt, 2000; Opschoor, 2000; Rapport, 2000; van Kooten and Bulte, 2000; Pearce, 2000; Venetoulis and Talberth, 2007; Wiedmann and Lenzen, 2007; Lenzen et al., 2007), mainly because, it doesn't recognize the true value of nature's work on generating the resources consumed by human.

Emergy Accounting (Odum, 1996) has its roots on the General System Theory and its strong point is to evaluate natural capital and ecosystem services. Therefore, the methodology is able to quantify the work done by nature to produce resources.

A modified calculation combining those two methods was mentioned by Brown and Ulgiati (1998) and proposed by Zhao et al. (2005), but it is not adequate for solving all the problems found in the Ecological Footprint. Zhao's work didn't use or recognize the importance of system's diagram. It also didn't consider spaces such as deserts, frozen land and oceans in the calculation of biocapacity.

The aim of this paper is to analyze Zhao's proposal by suggesting some modifications and including the full concept of emergy into the calculation.

THE ECOLOGICAL FOOTPRINT

Ecological Footprint has been developed by Wackernagel and Rees (1996); Wackernagel et al. (1999). The basic idea is that every individual, process, activity, and region has an impact on Earth, via resource use, generation of waste and the use of services provided by nature. These impacts can be converted to biologically productive area (land able to perform photosynthesis and produce biomass). Ecological footprint calculations are based on 6 simple assumptions (Monfreda et al., 2004):

- The annual amounts of resources consumed and wastes generated by countries are tracked by national and international organizations.
- The quantity of biological resources appropriated for human use is directly related to the amount of bioproductive land area necessary for regeneration and assimilation of waste.
- By weighing each area in proportion to its usable biomass productivity (its potential annual production of usable biomass), the different areas can be expressed in terms of a standardized average productive hectare (global hectare).
- The overall demand in global hectares can be aggregated by adding all resource-providing and waste-assimilating areas required to support the demand.
- Human demand (Footprint) and nature's supply (Biocapacity) can be directly compared to each other.
- Demand area can exceed supply area.

If the ecological footprint of a region is larger than the carrying capacity, the region runs an ecological deficit. If the carrying capacity of a region is larger than ecological footprint, the region runs an ecological remainder.

In the analysis of ecological footprint, six main categories of productive area are distinguished: cropland, grazing, forest, fishing area, built-up and energy land. As the various ecological categories have differences in biological productivity, Wackernagel et al. (1999) uses "biological productive areas with world average productivity" as a common measurement unit for footprint and biocapacity. Using world average yield, consumption and waste absorption are translated into biologically productive areas. To aggregate the biologically productive areas in a more accurate and realistic way, they are multiplied by a "equivalence factor".

Some countries or regions are better endowed with ecological productivity by having either more space available and/or ecosystems and agroecosystems of higher productivity per unit area. Therefore, to document the ecological production available within a country or region, the number of physical hectares of biologically productive area that exist in each ecological category is multiplied by the factor by which the country's or region's ecosystem differ in productivity from the world average. This factor is the 'yield factor'. After the concept of ecological footprint was developed, some analyses include detailed descriptions of the ecological footprint method (Wackernagel et al., 1999; Haberl et al., 2001; Senbel et al., 2003; van Vuuren and Bouwman , 2005).

Critiques

The first objection against the Ecological Footprint has to do with the supposed attractiveness and strength of the method, namely that it provides a one-dimensional indicator by summing up all consumption related direct and indirect ecological impacts in terms of land use. This requires that different consumption categories are translated into land area. Evidently, this conversion is necessarily incomplete, while no account is taken of regional and local features of land types and land use. But the main problem is that physical consumption–land conversion factors are used as implicit weights in the conversion as well as the aggregation.

The physical weights used are regarded by the authors as consistent with ecological principles and thermodynamic laws, but they do not necessarily correspond to social weights. According to van den Bergh and Verbruggen (1999), they reflect neither relative scarcity changes over time nor variation over space. This problem is magnified by the choice of a fixed weighting scheme. This means that a fixed rate of substitution is supposed between different categories of environmental pressure. Even worse, some categories receive identical weight, even if it is clear that their environmental impacts are very distinct. For instance, in the EF procedure land use by infrastructure has the same weight as land use by agriculture, although designating land for road infrastructure clearly is more environmentally destructive than designating it for pasture.

Recent critiques deeper explore the methodology. For example, Wiedmann and Lenzen (2007) found inconsistence in the process of conversion of hectares to global hectares due to the fact that the Ecologial Footprint adjust primary production yields to global means, but doesn't apply the same concept to the secondary production. According to Venetoulis and Talberth (2007), the use of potential productivities to calculate the equivalence factors doesn't represent the true intensity of human pressure over ecosystems.

A second objection against the Ecological Footprint relates to the land use dimension. To begin with, although the EF denotes hypothetical land area there is a serious danger that it will be interpreted as actual or at least realistic land use, not only by the general public and politicians, but also by environmentalists and academic researchers. This can be regarded as a case of 'false concreteness' (Venetoulis and Talberth, 2007). The hypothetical nature of the Ecological Footprint means, for instance, that the world's footprint can exceed the world's total available productive land.

The third objection is related to the measure of impact associated with the use of energy. Areas required to fossil energy occupy more than 50% of the developed countries' footprint. This component consists of the estimated area needed for absorbing carbon dioxide. This idea is questionable, because the assimilation of CO_2 by forests is only one of the options to compensate the emission and, apparently, not the most effective. Moreover, Ecological Footprint considers a sequestration tax of 0.95 t C/ha/year[9]. Hence, for every tone of carbon emitted, there's a footprint of 1.05 hectare. The problem is that this estimative are based on the sequestration of CO_2 in two specific years (1980 and 1990), not considering that this tax changes according to tree's age, period of the year, ecosystem, etc.

Van den Bergh and Verbruggen (1999) indicate that this approach has two main problems. First, there may not be enough available and adequate land for forests. In other words, this sustainable energy scenario could be limited by technical and environmental obstacles. Secondly, the solution would depend on the availability and cost of land, as well as the productivity of the reforestation. All these aspects differ between countries and regions, because they depend on the level of development, technology and geographical circumstances (including climate and soil).

The conventional methodology of the Ecological Footprint arbitrarily excludes from the calculations areas considered as low productivity ones. Venetoulis and Talberth (2007) criticize this assumption, saying that the whole Earth is relevant because most of its surface participates of the carbon cycle. These areas include deserts, oceans and ice caps. It seems incoherent not to consider those areas, because they are very important to the geochemical cycles. The method fails as it doesn't recognize the roll of the ocean on the sequestration of CO_2. According to IPCC (2004), oceans are responsible for 2/3 of the total CO_2 absorption. Therefore, despite being regions with low production of useful biomass, these areas perform essential functions to the planet. Many ecosystems that are not directly used may have indirect benefits to human beings like providing biodiversity or environmental services (Van den Bergh and Verbruggen, 1999).

ZHAO'S ECOLOGICAL FOOTPRINT BASED ON EMERGY

Zhao et al. (2005) proposed a modified method of ecological footprint calculation. The main assumptions of the method are:

- Biocapacity is a function of the renewable resources;
- Consumption data can be converted into emergy flows;

The calculation of this new method consists of two components: the carrying capacity (biocapacity) and the footprint (consumption).

In order to express biocapacity in terms of area, Zhao proposed the use of the global empower density as a factor, which can be estimated dividing the total emergy of the Earth by the total area of the planet. The total emergy amount 1.583E+25 sej is taken from Odum et al. (2000) and represents the sum of the emergy of solar radiation, Earth deep heat and moon gravity force. The area of the Earth is considered to be 5.1E+14 m^2 or 5.1E+10 ha.

In the calculation of the total emergy of a region, five kinds of renewable resources emergy are considered: sun, wind, chemical energy in rain, geopotential energy in rain, and earth cycle energy. In order to avoid double counting, the largest item of emergy amount is considered the total emergy of a region. Thus, this amount is divided by the population.

The following equation is used to estimate the biocapacity or carrying capacity:

CC = e / p1, where **CC** is the carrying capacity (gha/cap); **e** is the renewable resources of emergy amount per capita and **p1** is the global emergy density.

The calculation of the footprint is composed by two parts: biological resources and energy resources. In the footprint accounting of biological resources, four kinds of the consumption emergy are distinguished: agriculture, forestry, animal husbandry, and fishery. In the calculation of energy resources, four kinds of commercial energies are considered: coal, natural gas, liquid fossil fuel, and electricity.

Consumption is estimated as the sum of production plus imports minus exports. The data obtained for each category can be converted into energy values (Joules). Then, each one is multiplied by its transformity, so the amounts can be translated into emergy flows. These emergy amounts are divided by the population. In order to express the consumption in terms of area, Zhao proposed the use of the local empower density **p2** as a factor, which can be estimated dividing the total emergy of the region by the total area of the region.

The following equation is used to estimate the ecological footprint: **EF = c / p2**, where **EF** is the ecological footprint (gha/cap); **c** is the consumption of emergy amount per capita (sej/cap) and **p2** is the local emergy density.

PROPOSED METHOD

The method proposed by Zhao et al. (2005) is very interesting because it introduces the concept of emergy on Ecological Footprint, but it's not complete. In this present work, some modifications are proposed with the objective of deeper introducing the concepts of Emergy Accounting into the Ecological Footprint:

- Draw the diagram of the system (country) analyzed;
- Divide the country by biomes and productive spaces to better understand and quantify the differences between them;
- Estimate the biocapacity as function of the largest renewable resource input;

- Include global environmental services production areas such as glaciers, deserts, corals, permafrost and oceans, in the biocapacity estimates;
- Estimate the transformities for biomass production of each biome and productive space, using NPP as a reference;
- In the consumption estimates, include new categories according to the analyzed country.

Biocapacity

Biocapacity was calculated as function of the available renewable resources. In order to avoid double counting, the largest item of emergy amount is considered the total emergy of the biome.

It was divided in four categories: **Natural Ecosystems** (Amazon, Atlantic, Savannah, Wetlands, Grasslands, Semi-Arid, and Continental Shelf), **Cropland, Pasture and Forestry** (Soy, Sugar Cane, Cereals and Grains, Beans, Cotton, Vegetables, Eucalyptus, Fruits and Pasture), **Human Area** (Urban), and **Biomes Not Dominated by Human** (Glaciers, Oceans, Deserts, Permafrost, and Corals).

For example, in the Amazon Forest, the largest resource is the Rain's Chemical Potential. With the amount of emergy input, it is possible to calculate the transformity of the biome's biomass (Figure 2). It's considered that 55% of the biomass is carbon (Ponce-Hernandez et al., 2004). In the case of natural ecosystems, considered area for the calculation was the preserved land according to data from the Brazilian Ministry of Environment (2007).

Figure 1. *Brazilian Biomes according to the Brazilian Institute of Geography and Statistics (IBGE, 2004).*

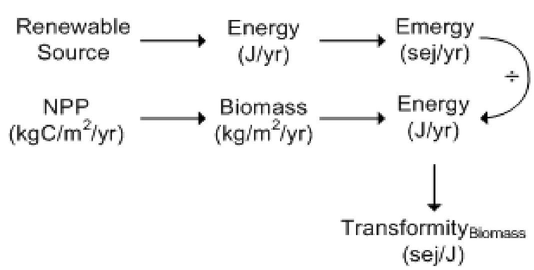

Figure 2 . *Steps for the calculation of biomass transformities.*

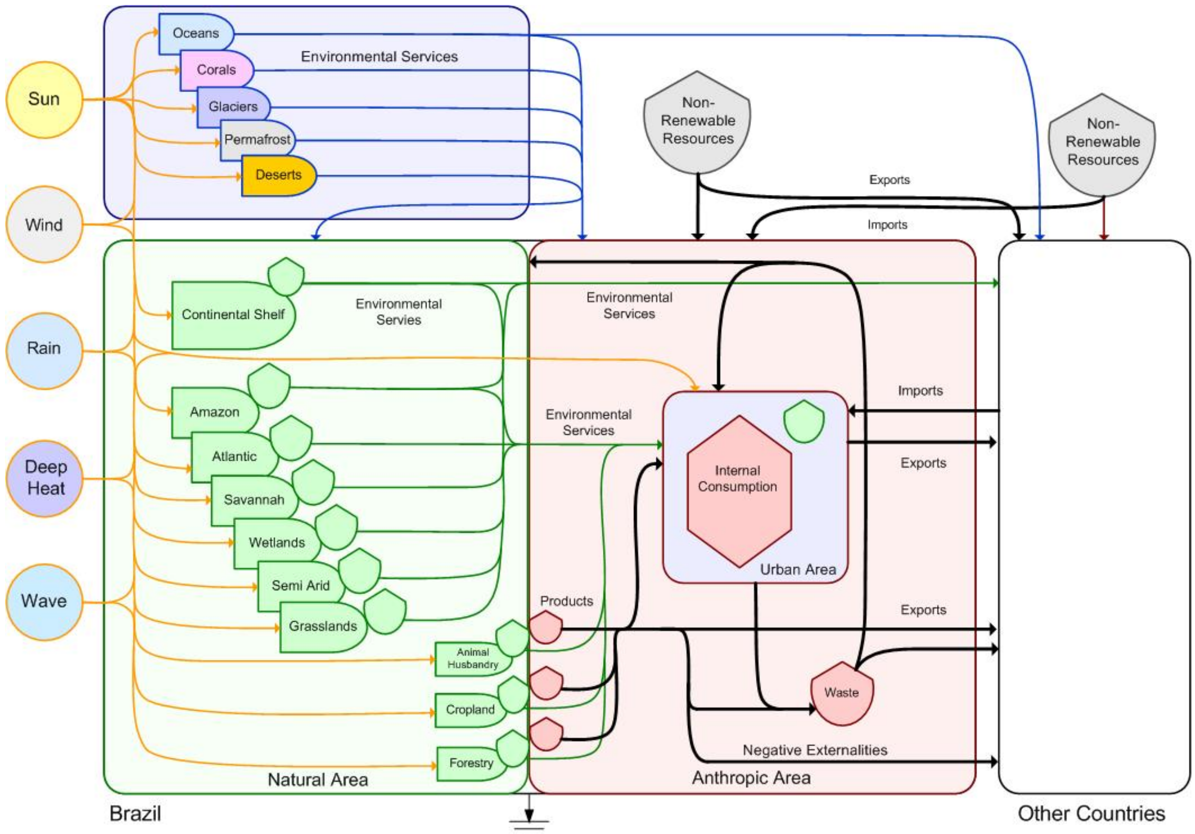

Figure 3. *System Diagram of Brazil.*

The conversion of energy to emergy flows was realized using the transformity. After that, the emergy per capita was calculated through the division of each emergy flow by the population of the country. In the case of the biomes not dominated by human it was considered that the total emergy input is distributed by the whole planet. So the emergy flows were divided by the entire population of the world. To obtain the biocapacity per capita (gha/cap), we divided the amount of emergy per capita of each flow by the Global Emergy Density (GED) which is 3.1E+14 sej/gha (Zhao et al., 2005).

Consumption

Consumption was also divided in four categories: **Cropland** (Soy, Sugar and Alcohol, Cereals and Grains, Beans, Cotton, and Fruits and Vegetables), **Forestry** (Wood), **Animal Husbandry** (Meat, Milk, and Fishery), and **Energy Resources** (Coal, Petroleum, Natural Gas, and Hydroelectricity).

Consumption of each category was calculated through the following expression:

Consumption = Production + Imports – Exports

The procedure to convert each flow in global hectares is similar to that used to calculate the biocapacity in this paper. Each consumption category was expressed in Joules and converted into emergy through transformity. The emergy per capita was obtained dividing the emergy flows by the Brazilian population. The global emergy density (GED) was used to convert each category to global hectares.

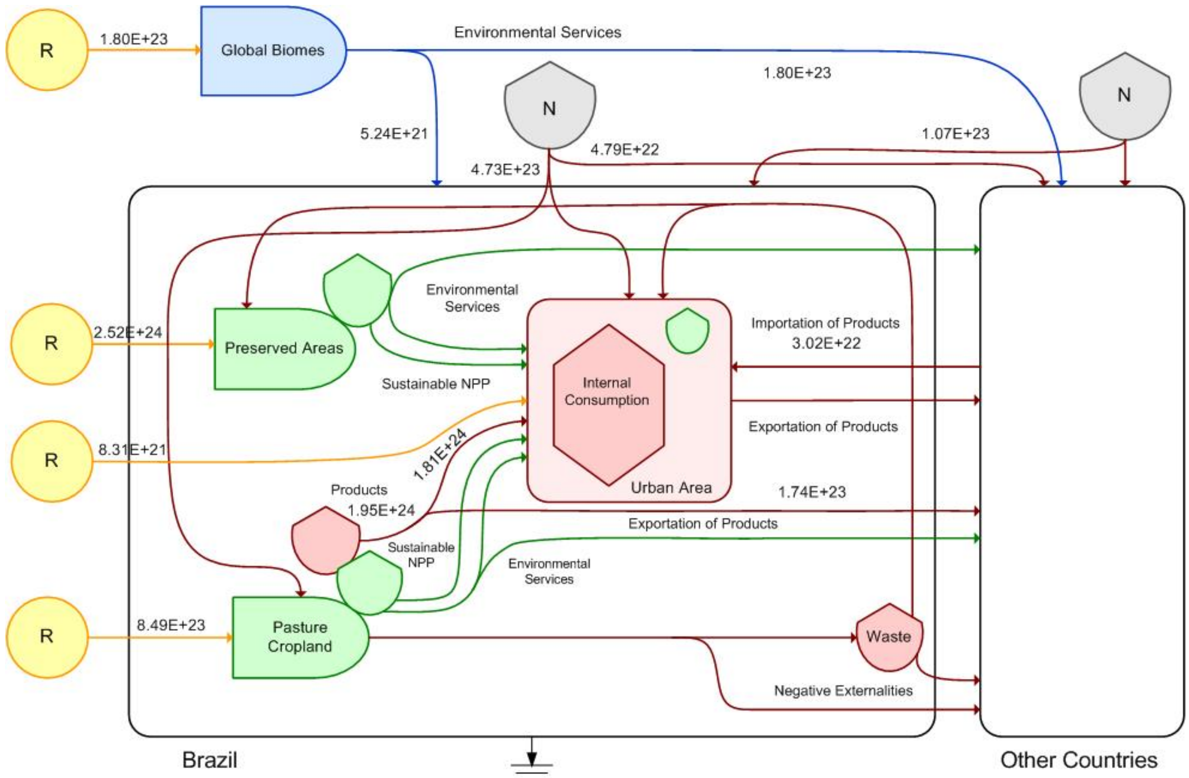

Figure 4. Resumed System Diagram of Brazil with Emergy Flows (sej/year).

The use of GED is different than the use of local emergy density (LED) as proposed by Zhao et al. (2005). In other words, to use LED (in seJ/ha, where ha is equivalent to local hectares) correspond to obtain a footprint in local hectares and to use GED (in seJ/ha, where ha is equivalent to global hectares) corresponds to obtain a footprint in global hectares. The footprint obtained using GED has the same basis used for biocapacity, so they can be compared.

BRAZIL AS CASE STUDY

Brazil is a continent sized country, well-known for its forests and natural resources. This description leads us to think that in a calculation of ecological footprint, the country would always have an ecological credit.

Although Brazilian population growth rate is higher than the developed country's rates, previsions are that the growth will reduce during the next few years. Population will still grow, but at lower rates: from 3% between 1950 and 1960, dropped to 1.44% in 2004, will reach 0.25% in 2050 and finally zero in 2062, according to the projections of the IBGE (Brazilian Institute of Geography and Statistics).In 34 years, Brazilian population nearly doubled from the 90 million inhabitants in 1970, and, between 2000 and 2004, grew in 10 million people. In 2050, there will be almost 260 million Brazilian and life expectancy will be 81.3 years (IBGE, 2004).

Despite population growth doesn't seem to be a severe problem for Brazil in the near future, one of the most important questions when it comes to carrying capacity, is not only the size of the population but the demand of resources that this population impose on the environment.

RESULTS AND DISCUSSION

According to Table 1, the biocapacity of Brazil for 2004 is 61.51 gha/cap, which means that renewable resources provide about 61 hectares as productive land and water for each Brazilian.

After analyzing the results presented in Table 1 and Figure 5 it becomes clear that Brazilian natural ecosystems are responsible for 73.5% of the total biocapacity of the country and that the Amazon Forest contributes with more than 47% of the total renewable resources. Comparing the biocapacity results with Table 2, the contribution of the Amazon Forest becomes even bigger: if its biocapacity isn't considered or extinguished, Brazil would run an ecological deficit.

One of the modifications proposed in this paper was to include global biomes not dominated by human in the estimates of the country's ecological footprint. As we can see from Table 1, their total contribution is less than 1gha/cap. Nevertheless, this value is bigger than the biocapacities from wetlands and grasslands, showing the importance of considering these biomes in the ecological footprint estimates.

Another objective of the present paper was to estimate transformity values for biomass production of Brazilian biomes. The values are listed in Table 3.

Table 1. Biocapacity Calculation for Brazil using Ecological Footprint based on Emergy with 2004 data.

Item	Flow	Total Area (m^2)	Preserved Area (m^2)	Emergy (sej/yr)	Emergy per capita (sej/cap)	Biocapacity (gha/cap)
1	**Natural Ecosystems**					**45.20**
1.1	Amazon	4.20E+12	3.57E+12	1.62E+24	8.99E+15	28.99
1.2	Rainforest	1.11E+12	3.05E+11	1.15E+23	6.40E+14	2.06
1.3	Savannah	2.03E+12	1.24E+12	3.75E+23	2.08E+15	6.71
1.4	Wetlands	1.50E+11	1.33E+11	2.52E+22	1.40E+14	0.45
1.5	Grasslands	1.76E+11	7.24E+10	1.37E+22	7.60E+13	0.24
1.6	Semi-Arid	8.44E+11	5.29E+11	7.20E+22	4.00E+14	1.29
1.7	Continental Shelf	6.70E+11	-	3.04E+23	1.69E+15	5.44
2	**Cropland, Pasture and Forestry**					**15.21**
2.1	Soy	2.07E+11	-	6.25E+22	3.47E+14	1.12
2.2	Sugar Cane	7.04E+10	-	2.66E+22	1.48E+14	0.47
2.3	Cereals and Grains	1.87E+11	-	7.05E+22	3.92E+14	1.26
2.4	Beans	4.00E+10	-	1.51E+22	8.40E+13	0.27
2.5	Cotton	1.30E+10	-	3.93E+21	2.18E+13	0.07
2.6	Vegetables	8.07E+09	-	3.05E+21	1.69E+13	0.05
2.7	Eucalyptus	3.50E+10	-	1.32E+22	7.35E+13	0.23
2.8	Fruits	4.04E+08	-	1.53E+20	8.48E+11	0.00
2.9	Pasture	1.73E+12	-	6.54E+23	3.63E+15	11.71
3	**Human Area**					**0.149**
3.1	Urban	2.20E+10	-	8.31E+21	4.62E+13	0.149
4	**Biomes Not Dominated By Human**					**0.94**
4.1	Glaciers	1.90E+13	-	1.19E+18	6.62E+09	0.00
4.2	Ocean	4.94E+03	-	3.70E+19	2.06E+11	0.01
4.3	Deserts	1.37E+13	-	2.11E+21	1.17E+13	0.37
4.4	Permafrost	1.05E+12	-	3.23E+21	1.79E+13	0.57
4.5	Coral	3.00E+11	-	1.97E+21	1.10E+13	0.35
Total						**61.51**

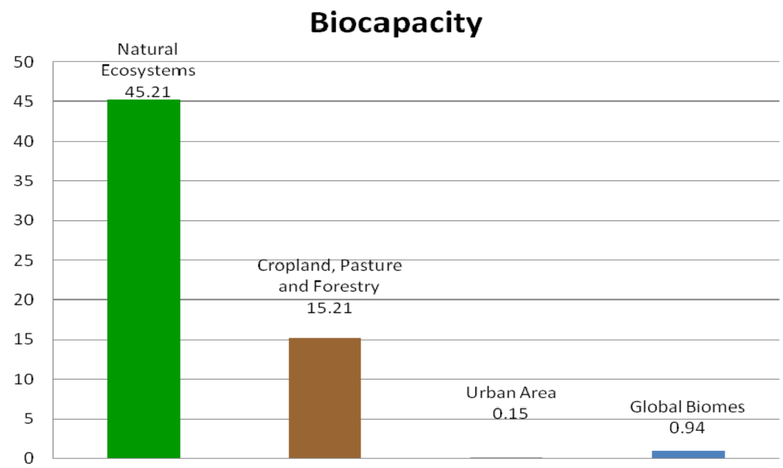

Figure 5. *Brazilian Biocapacity in gha/cap presented by categories.*

Table 2. Footprint Calculation for Brazil using Ecological Footprint based on Emergy with 2004 data.

Item	Flow	Production	Unit	Production Energy (J/yr)	Production Emergy (sej/yr)	Production Footprint (gha/cap)	Exported Footprint (gha/cap)	Imported Footprint (gha/cap)	National Footprint (gha/cap)
1	**Cropland**			**8.38E+18**	**1.16E+24**	**20.869**	**1.658**	**0.344**	**19.555**
1.1	Soy	5.84E+07	Mg/yr	7.82E+17	9.15E+22	1.640	1.092	0.000	0.548
1.2	Sugar and	4.58E+08	Mg/yr	6.13E+18	4.90E+23	8.786	0.182	0.000	8.604
1.3	Cereals and	6.38E+07	Mg/yr	8.55E+17	9.76E+22	1.750	0.019	0.255	1.986
1.4	Beans	3.30E+06	Mg/yr	4.42E+16	3.05E+22	0.547	0.001	0.017	0.563
1.5	Cotton	2.31E+06	Mg/yr	3.09E+16	5.88E+22	1.053	0.223	0.031	0.862
1.6	Fruits and	4.00E+07	Mg/yr	5.36E+17	3.96E+23	7.093	0.142	0.041	6.992
2	**Forestry**			**8.44E+17**	**2.95E+22**	**0.528**	**0.006**	**0.000**	**0.522**
2.1	Wood	1.40E+08	m3/yr	8.44E+17	2.95E+22	0.528	0.006	0.000	0.522
3	**Animal Husbandry**			**1.96E+17**	**7.58E+23**	**13.593**	**1.464**	**0.197**	**12.325**
3.1	Meat	1.72E+07	Mg/yr	7.93E+16	4.22E+23	7.569	1.423	0.015	6.160
3.2	Milk	2.45E+07	L/yr	1.13E+17	3.22E+23	5.774	0.032	0.180	5.922
3.3	Fishery	9.00E+05	Mg/yr	4.14E+15	1.39E+22	0.250	0.009	0.003	0.243
4	**Energy Resources**			**5.29E+18**	**4.73E+23**	**8.484**	**0.859**	**1.926**	**9.552**
4.1	Coal	5.19E+06	Mg/yr	1.51E+17	1.01E+22	0.180	0.000	0.000	0.180
4.2	Petroleum	5.48E+08	barrels/yr	3.34E+18	2.98E+23	5.334	0.859	1.606	6.082
4.3	Natural Gas	1.70E+10	m3/yr	6.37E+17	3.75E+22	0.671	0.000	0.320	0.991
4.4	Hydroelectricity	3.21E+11	kWh/yr	1.16E+18	1.28E+23	2.299	0.000	0.000	2.299
Total				**1.47E+19**	**2.43E+24**	**43.47**	**3.99**	**2.47**	**41.95**

Transformity values obtained for biomass production of Brazilian biomes (Table 3) may be compared with those listed in Folio #3 (Emergy of Ecosystems) (Table 4). Although most of the values in the folio are for subtropical ecosystems, the transformity for tropical savannah was very close (1.26E+04 sej/J and 1.05E+04 sej/J). Wetlands in Brazil have a biomass transformity value a bit different (5.26E+03 sej/J against 7.34E+04). Brazilian wetlands have low pluviosity levels, which can explain the low biomass transformity value.

Table 3. Transformities for Biomass Production of Brazilian Biomes.

Biome	NPP ($kgC/m^2/yr$)	Biomass ($kg/m^2/yr$)	Biomass Energy (J/yr)	Emergy (sej/yr)	Transformity (sej/J)
Amazon	0.93	1.69	1.01E+20	1.62E+24	**1.60E+04**
Rainforest	0.93	1.69	8.62E+18	1.15E+23	**1.33E+04**
Savannah	0.79	1.44	2.98E+19	3.75E+23	**1.26E+04**
Wetlands	1.18	2.15	4.79E+18	2.52E+22	**5.26E+03**
Grasslands	0.35	0.64	7.71E+17	1.37E+22	**1.77E+04**
Semi-Arid	0.07	0.13	1.13E+18	7.20E+22	**6.38E+04**

Table 4. Transformities for Biomass Production of Ecosystems (Brown and Bardi, 2001).

System	Transformity (sej/J)
Temperate Forest Watershed	4.70E+03
Tropical Dry Savannah	1.05E+04
Subtropical Mixed Hardwood Forest (Oak/Gum/Magnolia/Pine)	5.50E+03
Subtropical Pine Flatwood Ecosystem	1.07E+04
Tropical Mangrove Ecosystem	1.47E+04
Subtropical Herbaceous Wetland	7.34E+04

Table 5. Ecological Footprint Calculations for Brazil.

Work	Author	Biocapacity (gha/cap)	Footprint (gha/cap)
Living Planet Report 2006 (Conventional)	Loh and Goldfinger	**9.90**	**2.10**
Footprint of Nations 2005 (NPP based)	Venetoulis and Talberth	**29.16**	**14.11**
Ecological Footprint based on Emergy	Pereira and Ortega	**61.51**	**41.95**

According to Table 2, the ecological footprint of Brazil for 2004 is 41.95 gha/cap, which means that each person demands an area of 42 hectares of productive land and water to supply the demands of food, energy and products.

After analyzing the results presented in Table 2, we noticed that most of the Brazilian footprint is due to 5 itens: sugar and alcohol (8.6 gha/cap), fruits and vegetables (6.9 gha/cap), meat (6.1 gha/cap), milk (5.9 gha/cap), and petroleum (6.1 gha/cap). These results confirm the profile of Brazil: 1) a country that concentrates its agriculture on monocultures, especially on the production of sugar cane (460,000,000 tonnes/year), mainly as an energy supply product; 2) that has almost 50% of its productive land destined to pasture; 3) as most of the countries in the world, has a great consumption of petroleum to maintain, not only its vehicle’s fleet, but also its means of production.

Figure 6 shows that the main contribution to the ecological footprint of the country comes from the cropland category. This category is basically composed of commodities, which is supplied without qualitative differentiation across the international market.

In terms of international trade, as shown in Table 2, Brazil exports more than imports. Calculated as footprint, importation is 2.47 gha/cap, while exportation is close to 4 gha/cap. This means that approximately 720,000,000 ha of productive land and water are used to produce goodies for other countries. Considering exportation – importation, Brazil has a total 1.52 gha/cap or 273,600,000 ha productive land and water “appropriated” by other countries.

The system diagram (Figure 3) was built with the intention of dividing the systems in two parts: natural and anthropic area.

Natural Area is the space with renewable production composed by: preserved ecosystem areas (amazon, rainforest, savannah, wetlands, grasslands, and semi-arid), continental shelf, animal husbandry, cropland, forestry, and urban area. All of them have biomass stocks. Net primary production is considered the flow of renewable energy available for the system. We also added the flows of environmental services, but didn't estimate their amounts at this time.

Anthropic Area represents human production, consumption, importation, and exportation of products and non-renewable resources. It's important to notice that animal husbandry, cropland, forestry, and urban have renewable and anthropic production. Dark lines are the flows of products and energy consumed, imported and exported by the Brazilian economy. At this time, we didn't estimate the amounts of negative externalities and wastes generated.

Figure 4 is the resumed system diagram of Brazil with the emergy flows in sej per year. As we can see, the biggest input of renewable resources enters the preserved natural areas. Another interesting aspect is that Brazil exports more products' emergy (1.74E+23 sej/yr) than imports (3.02E+22). The opposite happens in terms of exportation and importation of non-renewable resources: Brazil exports 4.79E+22 sej/yr and imports 1.07E+23 sej/yr.

From the total emergy production of crops, animal husbandry and forestry (1.95E+24 sej/yr), 1.74E+23 sej/yr are exported, which represent only 9% of the total emergy produced in the country.

In a comparison of ecological balance, one could assume that Brazil has a better result with the emergy based approach (61.51 – 41.95 = 19.56 gha/cap), followed by Venetoulis and Talberth's methodology (29.16 – 14.11 = 15.05 gha/cap) and the conventional ecological footprint (9.90 – 2.10 = 7.8 gha/cap).

A much better analysis is made if we divide the biocapacity by the footprint. This fraction is called *Carrying Capacity Factor*, that is, how much a territory could support its population with its current lifestyle and not degrading the environment.

If biocapacity / footprint > 1, it means that the system is sustainable, if biocapacity / footprint < 1, it means that the system is unsustainable, and if biocapacity / footprint = 1, it means that the system is at the critical limit. Analyzing the relation biocapacity / footprint for the 3 prior approaches, it's possible to notice that the ecological situation of Brazil is better with the conventional methodology (BC/EF = 4.71). This value means that in 2004 the Brazilian territory could support up to 4.7 times its population. For Venetoulis and Talberth's methodology, BC/EF = 2.06 and for the ecological footprint based on emergy, BC/EF = 1.47 (Figure 7).

CONCLUSION

Emergy analysis overcomes some shortcomings of the conventional footprint method. The most attractive characteristic of emergy analysis is that its common unit (sej) allows all resources to be compared on a fair basis. In the conventional calculation of ecological footprint, an indirect weighing system is used to translate different pressures into an amount of land. An area based emergy analysis gives a more realistic picture of the ecological footprint.

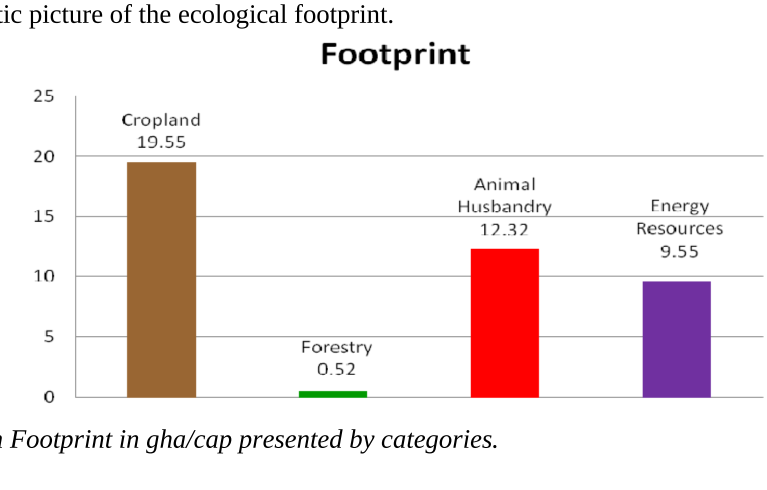

Figure 6. *Brazilian Footprint in gha/cap presented by categories.*

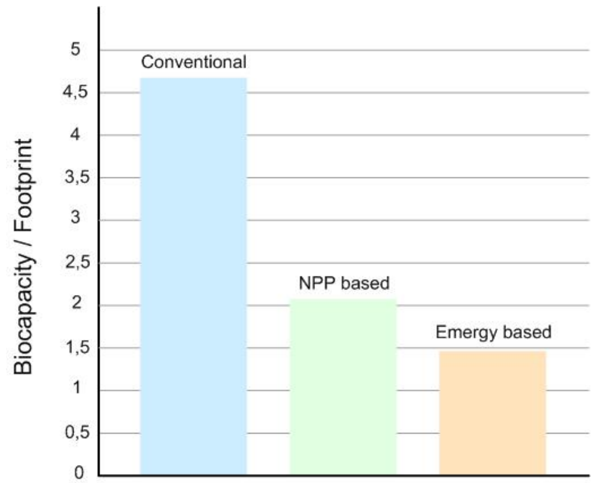

Figure 7. *Relation between Biocapacity and Footprint with the 3 approaches.*

The conventional calculation of carrying capacity refers only to land that is “ecologically productive for human purposes” and excludes, for example, deserts, glaciers and open sea. However, deciding which areas of land to exclude is completely arbitrary. These areas were included in our calculations and the results showed their contribution to the biocapacity of the country.

Many indirect human benefits of biodiversity and other ecosystem attributes present in these environments are not well known. In this paper, environmental services and negative externalities were acknowledged in the system diagram, but not estimated in the calculation. These estimates could be important for future works.

A major advantage of using emergy analysis on the ecological footprint is the possibility of measuring resource use of ecosystems. It has to be acknowledged, however, that the complexity of ecosystems will always make calculations of transformities difficult. There is no single transformity for any class of product or process. This will affect the reliability of conclusions at high levels of detail. Considerations made to estimate transformity values bring differences to the final results.

The proposed method in this paper showed that Brazil has a positive ecological balance. The same result was obtained with the conventional methods. However, the emergy footprint showed a clear scenario with smaller space to sustainability.

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