EMERGY SYNTHESIS 5:
Theory and Applications of the Emergy Methodology

Proceedings from the Fifth Biennial Emergy Conference,
Gainesville, Florida

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December 2009

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Landscape Evaluation and Carrying Capacity Calculation on the Mogi-Guaçu and Pardo Watershed

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ABSTRACT

The lack of quantitative data of landscape use can affect in a negative form the elaboration of public policy related to land occupation for agricultural or urban purposes. Some tools can be used for this purpose, but only emergy approach is able to account all energy inputs (from nature and economy). In this sense, the Landscape Development Intensity Index (LDI) that uses emergy synthesis as basis is a useful tool to show in a map form the areas with different impacts on the environment. In a parallel way, it is very important to get a general indicator that shows the systems sustainability in an easy-to-understand way. In this sense there are two main approaches: support area calculation through Net Primary Productivity and support area through Renewable Empower Density. The main purpose of this study was to calculate LDI index and the Support Area of Mogi-Guaçu and Pardo watershed, in Sao Paulo State, Brazil, to show human impact on the environment in a quantitative form. Emergy synthesis and Geographical Information System (GIS) was used as essential tools. The LDI index obtained for the watershed was 8.0, indicating an intense use of non-renewable resources on the landscape. Additionally, for the support areas calculation, the two approaches indicate that are necessary 16 million hectares of additional forest area (5.4 times the watershed's total area) for that the watershed reach the sustainability.

INTRODUCTION

The need for reliable and up-to-date environmental information is essential for prediction and decision making on regional, national and international levels. This information is the key to identify and priority land areas to protection and restoration the ecosystem.

A healthy ecosystem has been defined as one that is free from distress and degradation, maintains its organization and autonomy over time, and is resilient to stress (Patil et al., 2001). The landscape is an external manifestation, an indicator image or key reflecting the process (natural and human) that take place within a territory. Thus, it is possible to speak of landscapes with high human impacts and natural landscapes (Pastor et al., 2007), that can be represented by a number of methodologies with different philosophies: land use and the quality of ecological communities; classification systems for watersheds; biological indicators of ecosystem health; indices of biological integrity for streams; and so on.

We believe that only the methodology that account for all energy embodied in the system (from nature and economy) is able to get more precise quantity results about the human impact on the environment. In this sense, emergy analysis (Odum, 1996) appears as an appropriate tool. One important approach arisen from emergy theory was elaborated by Brown and Vivas (2005) and called Landscape Intensity Development Index (LDI) that is based on non-renewable emergy use, a characteristic common to all human dominated uses.

The LDI can provide information about the land use, showing where the human impact on the environment can occur, but can not provide information about the system sustainability. There are many tools that are used to get index about the system sustainability (Jha and Bhanu-Murty, 2003; Prescott-Allen, 1995; Wackernegal and Rees, 1996; Brown and Ulgiati, 1997; Samuel-Johnson and Esty, 2000; Esty et al., 2006), but only those that have international visibility are those divulgated by WWF (World Wide Fund for Nature) and by WEF (World Economic Forum): Ecological Footprint and the Environmental Sustainability Index. The ecological footprint can be used for different scales and its results are easily understood by society: area in hectares. The comparison and union between ecological footprint with emergy analysis has been studied in the last years (Siche et al., 2007a; Siche et al., 2007b). Brown and Ulgiati (2001) used the emergy analysis to calculate the carrying capacity (or support area) of economic investments through two approaches: renewable support area and synchronal support area. These approaches showed to be very useful in some works (Brown, 2003; Ulgiati and Brown, 2002), because it uses the concept of energy quality and supply results that can be easily understood.

The aim of this paper is to study the landscape on the Mogi-Guaçu and Pardo watershed through the calculation of Landscape Development Intensity (LDI) index and evaluate its sustainability through the Support Area calculation. For this, emergy synthesis and the Geographical Information System (GIS) were used as important tools.

METHODOLOGY

Emergy Synthesis and GIS

Emergy analysis is based on the works of Odum (1996), Ulgiati and Brown (1998) and Brown and Ulgiati (2004). Usually, emergy analysis is used to assess the upstream impacts caused by a system, where the energy and material flow that go into the system are basic and essential data for the evaluation. Considering one system with political boundaries (country, state, county, etc.), generally those raw data comes from databases, technical literature or information obtained through field work (small areas). When the study area is a large watershed there is a problem, since the watershed physical limits are not identical to those of counties or even states, which makes it difficult to obtain raw data (mainly in Brazil). Watershed diagnoses using Emergy are slowly appearing in scientific literature. Tilley and Brown (2006) studied the eco-hydrological model of a wetland; Tilley and Swank (2003) assessed the balance between nature and humanity in a small unpopulated watershed; Huang et al., (2007) investigated the relationship between the energy of a river and the energy hierarchy of land use.

To overcome the problem about lack of data for large watersheds, Agostinho et al. (under revision) obtained the emergy flows with the aid of a land use map and extrapolated them for all the watershed studied in her work. The authors made emergy synthesis for all crops (land use) and then extended the unitary emergy flows obtained ("reference emergy flows", in seJ/ha/yr) to the total area of the same crop in the watershed. Thus, the emergy flows in solar emjoules per year for each land use was obtained and the emergy indices were calculated for the watershed.

As suggested by Ulgiati et al. (1994) and further considered by Ortega et al. (2002), the renewability factor of each item was considered in this work to calculate the emergy indices (see Table 1). The incorporation of the renewability factor is particularly valid when the system uses materials and services purchased at the local or regional economy. Thus, the present paper considered the non-renewable emergy flows from nature (N) and the non-renewable from economy (Mn and Sn) in all approaches used. Detailed explanation about the approaches used in this work can be seen in the next items.

Landscape Development Intensity Index

Brown and Vivas (2005) developed a method to assess quantitatively the human impact on the landscape called Landscape Development Intensity Index (LDI). This tool can be applied to landscapes with different scales, from large watersheds to small wetland.

The calculation of LDI requires the land use map of study area as data input; when it is small, a simple draw can be used, but when the area is large, the use of geographical information system is

Table 1. Classification of Emergy flows used in environmental accounting.

Inputs and services	Description
I: Nature contributions	R + N
R: Renewable natural resources	Rain, materials, and services from preserved areas, nutrients from soil minerals and air.
N: Non-renewable natural resources	Soil, biodiversity, people exclusion.
F: Feedback from economy	F = M + S
M: Materials	$M = M_R + M_N$
M_R: Renewable materials and energy	Renewable materials of natural origin.
M_N: Non-renewable materials and energy	Minerals, chemicals, steel, fuel, etc.
S: Services	$S = S_R + S_N$
S_R: Renewable services	Manpower supported by renewable sources.
S_N: Non-renewable services	Other (external) services, taxes, insurance, etc.
Y: Total emergy	Y = I + F

necessary. In accordance to LDI's authors an influence area with 100m of *buffer* can be used for small scales, but when the study area is a watershed its physical limit is used as reference.

The calculation of LDI account for only the non-renewable emergy flow from nature and from economy, because the LDI is an index that measure the human activity that is characterized by the use of non-renewable resources. The unit of variables used in its calculation is emergy per unit area at a determined time (called Empower): solar emjoules per hectare per year (seJ/ha/yr).
Ortega et al. (2002), adapted from Odum (1996).

Recently, the LDI index was improved by Brown and Vivas (2007) and considered more robust. The LDI is calculated through the following equation:

$$LDI_{wat.}=10*\log[((R+Mr+Sr)_{region}+\Sigma(\%LU_{landuse\,i}*(N+Mn+Sn)_{landuse\,i}))/(R+Mr+Sr)_{region}] \qquad (1)$$

Where: $LDI_{wat.}$ = LDI ranking for landscape unit (watershed in this paper);
The definition of N, Mn, Sn, R, Mr and Sr can be found in Table 1;
$\%LU_{landuse\,i}$ = Percent of the total area of influence in land use "i";
"Region" means a referenced region.

Brown and Vivas (2005) argue that the use of the percentage of the total area of influence method (%LU) is less precise than the distance method, but the difference is not much significant. Thus, due to time necessary to use the second method, the first one must be used.

In this work the following procedure was used to calculate the LDI's value (Figure 1): (a) It was elaborated the land use map for the watershed under study through the use of *Landsat* satellite image. This work was made by ECOAGRI (2006); (b) It was considered only the non-renewable emergy flows in seJ/ha/yr for each land use calculated previously by Agostinho et al. (under revision); (c) Eq. (1) was used to calculate the LDI for each land use; (d) The LDI's spatial distribution on the watershed was made to identify areas with different human impact; (e) In a separated way, the LDI for the watershed as a whole was calculated through the Eq. (1).

Carrying Capacity

Carrying capacity calculation using Net Primary Productivity (NPP)

Ecologists defines carrying capacity as the maximum size of a species' population that a determined area can support without reducing its ability in maintenance this specie for an undefined time period (Daily and Ehrlich, 1992).

Carrying capacity (or "support area") can be determined based on the emergy requirements for a given population or the emergy intensity of a given economic development. The carrying capacity of

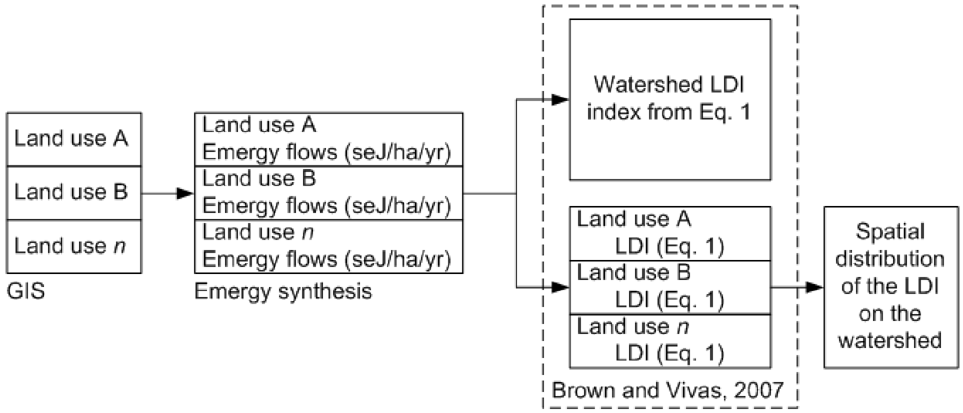

Figure 1. *Flowchart for LDI index calculation in this paper.*

an environment is determined by that environment's ability to supply the required emergy. A riche environment or landscape can support larger populations or more intense economic developments (Brown and Ulgiati, 2001).

Agostinho et al. (2007) suggested converting the non-renewable emergy used by a system in a forest equivalent area through the net primary productivity. The follow equation was suggested by those authors:

$$SA_{NPP} = (Mn_p + Sn_p + N_p) / (NPP * BE * Tr) \quad (2)$$

Where: SA_{NPP} = Renewable support area using NPP (ha);
Mn_p = Non-renewable materials used by process (seJ/yr);
Sn_p = Non-renewable services used by process (seJ/yr);
N_p = Natural non-renewable resources used by process (seJ/yr);
NPP = Net primary production;
BE = Biomass energy;
Tr = Biomass transformity.

The result of Eq.2 is a quantitative measure about the forest area necessary to supply in a renewable way all non-renewable emergy used by the system.

There are some controversies between researches about what would be an strong and weak sustainability and its indicators (Siche et al., in press), but in accordance with Brown and Ulgiati (1997), the sustainability of an economy is a function of its dependence on the local renewable emergy, on non-renewable emergy and the total load on the environment. The SA_{NPP} approach (Eq. 2) is a measure of the conversion of non-renewable emergy in renewable emergy. Thus, we believe that the SA_{NPP} supply an indicator about the system strong sustainability.

Carrying capacity calculation using renewable empower density

Brown and Ulgiati (2001) suggested that carrying capacity could be expressed as land area required supporting an economic activity solely on a renewable base. Carrying capacity calculated in this way may be a predictor of long term sustainability (strong sustainability). It is derived by dividing the total non-renewable emergy input to a process (or land use) by the average renewable empower density of the region in which it is located (Eq. 3).

$$SA_R = (Mn_p + Sn_p + N_p) / Remp_r \quad (3)$$

Where: SA_R = Renewable support area using renewable empower density (ha);
Mn_p = Non-renewable materials used by process (seJ/yr);

Sn_p = Non-renewable services used by process (seJ/yr);
N_p = Natural non-renewable resources used by process (seJ/yr);
$Remp_r$ = Renewable empower density of region (seJ/ha/yr).

The result of Eq. 3 is “the necessary area of the surrounding region that would be required if the economic activity were solely renewable emergy inputs” (Brown and Ulgiati, 2001, p.479).

An important point in the SA_R that affects significantly the results is the choice of the region of reference. In some cases, it can be a watershed, a town, state or country, but in accordance to the authors method, “there are no fixed criteria for establishing one” (Brown and Ulgiati, 2001, p.481). Thus, in the present paper was considered a Forest area as referenced region. The Forest area doesn’t use non-renewable emergy, thus can be assumed that the SA_R supplies a strong sustainability index.

STUDY AREA AND DATA

Description of the Study Area

This work addresses the Mogi-Guaçu and Pardo watershed, located in Sao Paulo State, Brazil (Figure 2). The total basin area is of 3,165,207 hectares including 94 counties. Land use is basically for sugar-cane production and animal raising, mainly for export (Table 2).

This watershed was addressed because of its economic importance and also because of the data made available by a strong research effort related to sustainability currently under way (ECOAGRI, 2006). Within this watershed there is a good variability of physical and social-economic models – the main soil types, topography and vegetation of Sao Paulo State are present. Moreover, this region presents a good diversity of agriculture systems with different land uses and different types of farmers and farm workers.

According to FAO (2005), Brazil is responsible for 32.7% of sugarcane, 8.6% of cattle, 29.4% of orange, 29.4% of coffee, and 24.8% of soybean world production. Furthermore, Brazil is one of the major exporters of ethanol, leather, leather shoes, and chicken.

Sao Paulo State is responsible for 60% of Brazilian sugarcane, 7% of cattle production, 80% of orange, 9% of coffee and 3% of soybean (IBGE, 2005).

From January to December, 2006, Sao Paulo State exports were of 45.93 billion USD (33.4% of Brazilian total), and imports were of 37.07 billion USD (40.6% of Brazilian total), representing an 8.86 billion USD surplus (IEA, 2007). In 2004, six out of ten major agricultural producers of Sao Paulo counties were located in Mogi-Guaçu and Pardo watershed (SEADE, 2004). These data show the great importance of this region for the Brazilian and global economies.

The majority of farming systems present in the watershed adopts the conventional model, based on industrial inputs; in other words, they potentially use excessive amounts of goods and services from the industrial economy and very few renewable resources from the local environment, causing high stress on the biological system.

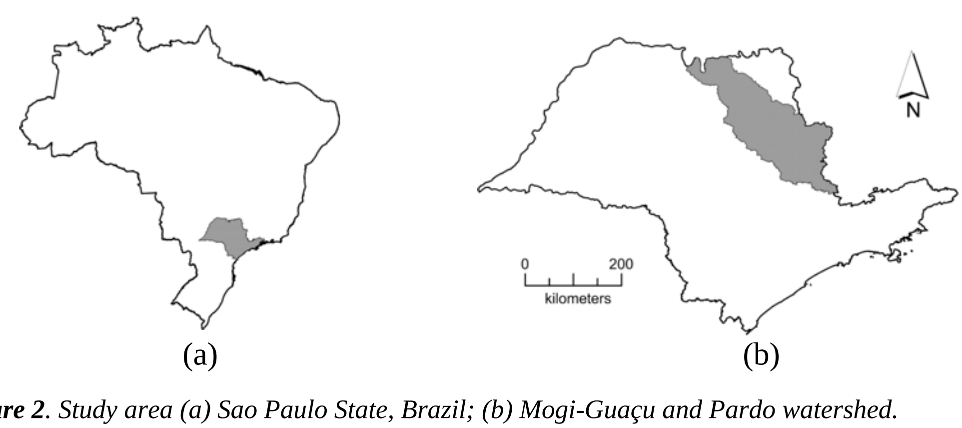

***Figure 2**. Study area (a) Sao Paulo State, Brazil; (b) Mogi-Guaçu and Pardo watershed.*

Table 2. Land use of Mogi-Guaçu and Pardo watershed in 2002.

Land use	Area (ha)	Percentage (%)
Sugar cane	1,629,027.76	51.5
Forest and riparian vegetation	464,160.55	14.7
Pasture	392,621.72	12.4
Orchards	236,288.75	7.5
Silviculture	109,710.43	3.5
Annual crops	80,862.36	2.6
Urban	75,502.06	2.4
Savanna	62,778.07	2.0
River, lake and water reservoir	49,773.10	1.6
Annual crops with irrigation by central	33,354.87	1.1
Coffee	22,588.20	0.7
Heveaculture	3,401.43	0.1
Other	4,481.99	0.1
Mining	655.76	0.0
Total	3,165,207.04	100.0

Source: ECOAGRI (2006).

Data

The emergy flows obtained by Agostinho et al. (under revision) for each land use listed in Table 2 (excluding mining and urban uses, rivers and lakes) was used to calculate the LDI and the Support Area indices. Others specific data for each approach considered in this paper can be seen in Table 3.

Due to the large area of Mogi-Guaçu and Pardo watershed, a stratification of sugar-cane and coffee systems was made, since farming of those cultures show different characteristics in different regions of the watershed. Thus, the area was divided in sub-areas to improve the accuracy of the final results.

RESULTS AND DISCUSSION

Mogi-Guaçu and Pardo Watershed's LDI

Through the emergy flows and the land use map for Mogi-Guaçu and Pardo watershed, it was possible to calculate the LDI index for each land use on the watershed (Table 4).

According to Brown and Vivas (2005), the LDI values of 1.0-2.0 correspond to watersheds that are nearly 100% natural lands; watersheds with LDI values between 2.0 and 5.0 are primarily agricultural while those greater than 5.0 are dominated by urban land uses. As mentioned before, the LDI approach was improved by Brown and Vivas (2007), thus those ranging values was converted through the polynomial regression (Figure 3) between the two LDI's approach. The new ranging values can be interpreted as: 0.0-0.4 corresponds to watersheds that are nearly 100% natural lands; watersheds with LDI values between 0.4 and 4.7 are primarily agricultural while those greater than 4.7 are dominated by urban land uses.

Table 4 shows that almost all systems have a LDI index ranging of 5.0 to 9.0. This is a strong indicator that these systems use large quantities of non-renewable resources (basically from oil), because they have values up to 4.7 and use non-renewable emergy like urbanized systems. Through Eq. 1 it was possible to calculate the watershed's LDI of 8.0 indicating that the landscape studied is dominated by urban uses.

The LDI index for each land use was used to elaborate a LDI map for the watershed (Figure 4) to show the regions where the human impact on the environment is more intense. The central and northwest regions causes much impact because they had LDI values between 4.7 to 9.2, but at the same

Table 3. Specific data for each approach considered in this paper.

Approach	Value considered and its source
LDI (Eq. 1)	• The referenced region considered was the Mogi-Guaçu and Pardo watershed with R+Mr+Sr of 4.62E+15 seJ/ha/yr from Agostinho et al. (under revision).
SA_{NPP} (Eq. 2)	• Net primary production of tropical rain forest of 13500 $kg_{biomass}$/ha/yr from Aber and Melilo (2001). • Biomass energy of 1.51E+7 J/kg from Prado-Jatar and Brown (1997). • Forest biomass transformity of Mogi-Guaçu and Pardo watershed of 10000 seJ/J from Agostinho et al. (under revision).
SA_R (Eq. 3)	• It was considered a Forest area as referenced region with renewable empower density of 219E+13 seJ/ha/yr from Agostinho et al. (under revision).

Table 4. LDI index for each land use on the Mogi-Guaçu and Pardo watershed.

Land use	Non-renewable emergy flows[A] (10^{13} seJ/ha/yr)	LDI
Forest and Riparian natural vegetation [B]	0.00	0.00
Savanna (Cerrado) [B]	0.00	0.00
Eucalypt and Pinus	742.32	4.16
Annual crop	851.01	4.54
Sugar-cane with Soybean	1035.18	5.11
Sugar-cane with Peanut and Soybean	1096.76	5.28
Sugar-cane with Peanut	1103.93	5.30
Sugar-cane	1129.52	5.37
Pasture	1371.64	5.99
Heveaculture	2494.08	8.06
Coffee (group 3)	2694.72	8.35
Coffee (group 1)	2980.95	8.72
Coffee (group 2)	2977.81	8.72
Coffee (group 4)	3144.38	8.92
Orchards	3291.88	9.10
Annual crop irrigated by central pivot	3342.15	9.16
Urban areas	55300.00[C]	20.82

[A] Non-renewable emergy flows from Agostinho et al. (under revision);
[B] Natural vegetation doesn't use non-renewable emergy;
[C] For the urban areas was considered the non-renewable emergy flow of 5530 x 10^{14} seJ/ha/yr calculated by Brown and Vivas (2005).

time, the northwest region has large quantities of natural systems in a disperse way as the southeast region (LDI ranging from 0.0 to 4.7). We can not see this due to map scale, but the numbers from ECOAGRI (2006) show it clearly. The central area is predominantly occupied by sugar-cane and obtained an intermediary performance (LDI=5.0; Table 4), but this region does not have natural vegetation (only a few fragments) that were extinct to produce sugar and ethanol from sugar-cane.

Considering that ecological agricultural production uses few quantities of non-renewable resources and preserve large areas of natural vegetation (Agostinho et al., 2008), the LDI obtained indicates that ecological management must be used in all systems present on the watershed with the aim to reduce the consumption of non-renewable emergy, because in accordance to Odum and Odum (2001, p.284):

> "…productivity of lands should be maximized by developing a mosaic of land uses, each managed with appropriate cycles. The mosaic should include areas of lower-intensity agriculture, strips of complex ecosystems capable of making agricultural land rotation

efficient while conserving high-diversity gene pools, areas for forestry plantations, areas for food-producing orchards and household gardens, and wetland areas for water management. Aid should be provided for the gradual substitution of fuel-using machinery, pesticide, and fertilizer by human labor and organic practices in the areas producing food, fiber, and wood".

Support Areas

Through Equations 2 and 3 it was possible to calculate the support area for the watershed (Table 5). In accordance with two approaches used (SA_{NPP} e SA_R), Table 5 shows that the areas occupied with orchard, sugar-cane, pasture, sugar-cane+peanut+soybean and sugar-cane+soybean, are the agricultural systems that need more support area. This is due to the large areas occupied with these systems on the watershed (mainly sugar-cane with 51% of total area – Table 2) and the use of large quantities of non-renewable emergy resource (orchard uses 77% of it's empower density from non-renewable source).

Considering all land use on the watershed, the additional forest area necessary to reach the strong sustainability calculated from SA_{NPP} approach is 16,373,928 ha. This value is equivalent to 5.4 times the actual total area of the watershed.

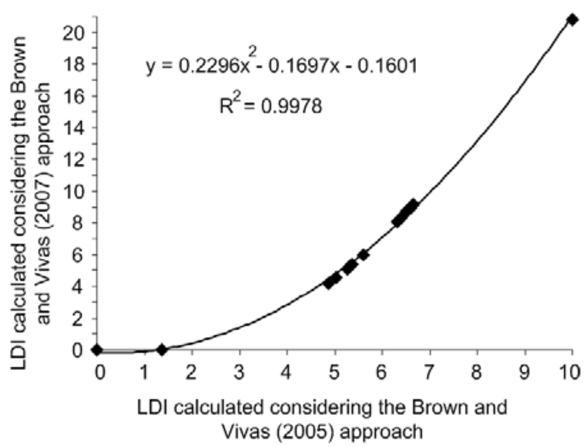

Figure 3. *Relation between two LDI's approaches.*

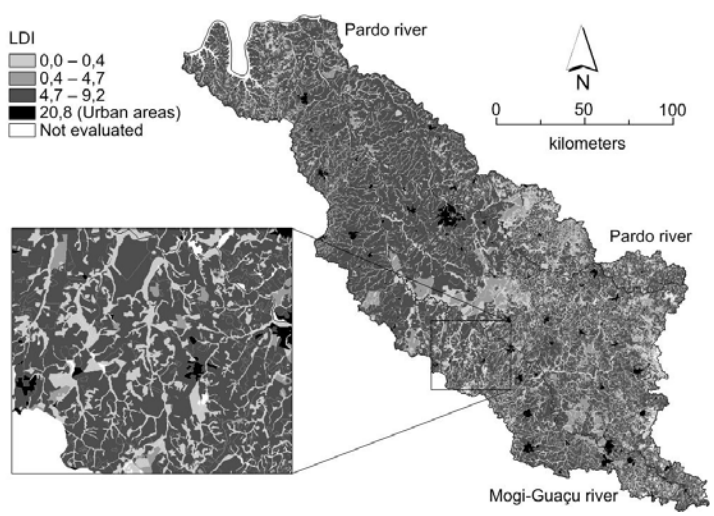

Figure 4. *Spatial distribution of the LDI on the Mogi-Guaçu and Pardo watershed.*

Table 5. Comparative support areas for each land use on the Mogi-Guaçu and Pardo watershed calculated through two approaches.

Land use	Forest region as referenced region	
	SA_{NPP} (ha)[A]	SA_R (ha)[B]
Forest [C]	0.00	0.00
Savanna (Cerrado)[C]	0.00	0.00
Coffee (group 4)	896.81	834.77
Coffee (group 3)	14,029.86	13,059.30
Heveaculture	41,616.08	38,737.16
Coffee (group 2)	105,484.59	98,187.37
Coffee (group 1)	208,346.84	193,933.80
Annual crop	337,575.06	314,222.27
Eucalypt and Pinus	399,510.65	371,873.27
Sugar-cane+Peanut	431,742.12	401,875.03
Annual crop - irrigated	546,857.88	509,027.30
Sugar-cane+Soyben	2,392,202.77	2,226,714.77
Sugar-cane+Peanut+Soybean	2,413,520.37	2,246,557.66
Pasture	2,641,823.18	2,459,066.92
Sugar-cane	3,488,764.58	3,247,418.53
Orchards	3,815,718.47	3,551,754.39
Total area[D]:	16,373,928.72	15,209,102.00
Total area / Actual area[E]:	5.40	5.01

[A]Obtained from Equation 2;
[B]Obtained from Equation 3;
[C]Natural vegetation doesn't use non-renewable resources and its support area is equal to zero;
[D]The actual forest area in the watershed was subtracted; thus, total area reveals the additional forest area;
[E] Actual area from Table 2.

SA_R indicates an additional area of region necessary to reach a strong sustainability on the watershed. The higher efficiency in the use of renewable resources (high renewable empower density) by the referenced region area, smaller it is the support area necessary because this region has the capacity to supply higher quantity of renewable resources per hectare. The support area obtained through SA_R approach is useful only to indicate the degree of impact produced by the system, but it has little practical use. If we think that a system needs determined region's area as support area by its non-renewable emergy use, we need also to account the necessity of support area of the region. Thus, in practical terms, it will be necessary infinitely additional support areas. To overcome this problem, natural forest areas could be used as referenced region, because it does not use non-renewable resources and show how many additional forest areas are necessary as support area. For the SA_R approach, Table 5 shows that when the referenced region is a natural forest vegetation, it would be necessary 5.01 times the total actual area of the watershed occupied with forest (15,209,102 ha).

The two approaches show a critical situation of watershed's unsustainability, because there are necessary additional areas to produce in a renewable way the non-renewable emergy used by them. This unsustainability occurs due to use of oil, but when this non-renewable energy resource finished or when its price goes up, the watershed may enter into collapse. Thus, it is very important to reduce the use of non-renewable emergy. This could be possible through the change of agricultural management, adopting ecological practices instead of conventional ones.

Considering the change in the use of non-renewable emergy and the change of land use on the watershed, some simulations could be made to study the support area dynamics. There exist many combinations between the variables, but it was considered the following one: conversion of 30% of sugar-cane areas in forest areas; reduction of 50% of non-renewable emergy used by sugar-cane, orchard and pasture. This new scenario shows that watershed's sustainability would be reached if the actual total non-renewable emergy used was reduced in 88% (Figure 5). Without the reduction of the non-renewable emergy resources, it would be necessary from 6.5 to 7.0 millions hectares with forest area to reach the sustainability. These values are very high!

The reduction of 30% on the sugar-cane areas and the reduction of 50% on its non-renewable emergy use as suggested by scenario above is a very difficult goal to be realized due to the growing market of ethanol. On the other hand, there are some other variables that can be changed to get many different results. In a future work, these scenarios will be elaborated and discussed.

Renewable Support Area to Dilute the By-products

The support area method initially proposed by Brown and Ulgiati (2001) is very important to show the dependency that the system has about the non-renewable emergy resources in a language of easy understandable: hectares of forest vegetation.

The two approaches used in this work (SA_{NPP} e SA_{R}) accounted for only non-renewable emergy used by the system to calculate the support area, but what about the concentrated by-products? The residue produced and not diluted (called as negative externalities) is a big problem to the society and the environment (Figure 6a). This by-product must be considered when a systemic thinking is used.

Hence, the support area calculation using emergy is improved in the work of Ulgiati and Brown (2002) that estimated the support area necessary to dilute the gas concentration on the atmosphere that was resulted of electricity energy production in Italy. Thus, the total support area must to account the area necessary to dilute the by-products (Figure 6b). Here appears one question: The support area calculated before by SA_{R} or SA_{NPP} approaches is not sufficiently to dilute the by-products? Is it not double account? We believe that the renewable emergy produced by the support areas calculated before will be totally used to convert the non-renewable emergy used by the system. Thus, this area does not have more renewable emergy to be used for the by-products dilution.

Each system produces different negative externalities and all of them need specific and individual studies. To be considered as a complete indicator of strong sustainability, the support area index must to consider the forest area equivalent and the emergy used to dilute the by-products.

CONCLUSIONS

The two approaches used in this work (LDI and Support Areas) showed clearly where are located the areas with high human impact on the environment and the unsustainability of the watershed studied. Some specific conclusions are given below:

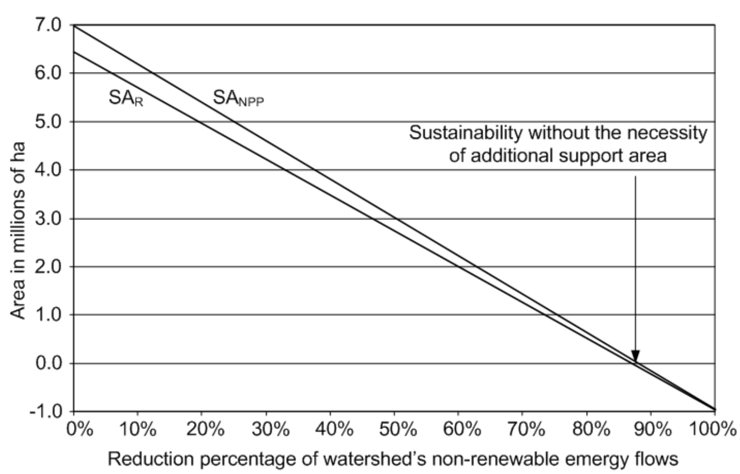

***Figure 5**. Relation between the percentage reductions of total non-renewable emergy used by watershed in relation of support area necessary to reach the sustainability. Data obtained from the simulated scenario described in the main text.*

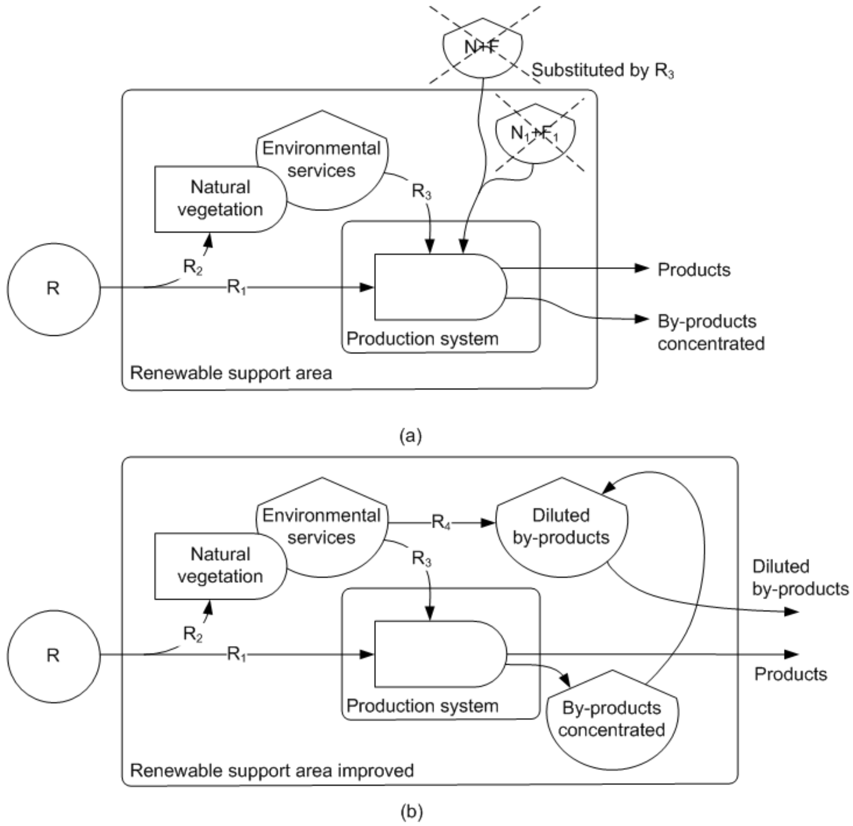

Figure 6. *(a) Systemic diagram that shows the renewable support area of a generic production system in accordance with original method proposed by Brown and Ulgiati (2001); (b) Renewable support area improved for the same production systems in (a), but considering the dilution of by-product through renewable emergy. Adapted from Ulgiati and Brown (2002).*

(a) The LDI obtained for majority land use on the watershed was higher than 4.7, indicating the dependency of non-renewable emergy likely urbanized systems. The watershed as a whole obtained a LDI of 8.0, indicating an intense use of non-renewable resources by the landscape;
(b) The simultaneous use of LDI and Geographical Information Systems (GIS) showed to be an important tool for the decision makers. The LDI spatially distributed on the watershed helped in the fast identification of regions that potentially have high impact on the environment; central and northwest regions. This information could be important in the elaboration of public policy for specific regions;
(c) The watershed areas occupied with orchard, sugar-cane, pasture, sugar-cane+peanut+soybean and sugar-cane+soybean are the systems that needs more support areas because uses large quantities of non-renewable emergy and/or are present in large areas of the watershed. Intensive actions on these systems will result in significant improvement on the watershed's carrying capacity;
(d) The results from S_{AR} and SA_{NPP} approaches are very similar and showed that are necessary from 15 to 16 millions of additional hectares with forest to supply in a renewable way all non-renewable emergy used by the watershed. This is equivalent to approximately from 5.01 to 5.40 times the watershed's total actual area and shows the watershed's unsustainability;
(e) The use of S_{AR} and SA_{NPP} approaches to realize simulations showed to be a powerful tool. The scenario considered in this paper showed that we can change the variables actual area and non-renewable emergy flow to elaborate many others scenarios that could be useful to the decision makers.

ACKNOWLEDGEMENTS

The authors are grateful to the ECOAGRI project for the raw data and GIS information and to João Paulo de Carvalho (Instituto Agronômico de Campinas) for his valuable help concerning the use of the ArcGIS 9.0 software. This research work had financial support of FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo – Process 2002/06685-0) and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico).

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