EMERGY SYNTHESIS 6:
Theory and Applications of the Emergy Methodology

Proceedings from the Sixth Biennial Emergy Conference,
January 14 – 16, 2010, Gainesville, Florida

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Assessment of Emergy Indices Dynamics on Agricultural Production of Mogi-Guaçu and Pardo Watershed, Brazil

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ABSTRACT

Nowadays, most of agricultural production uses conventional management that depends on chemical industry's products, fossil fuels and minerals. Besides that, specifically in Sao Paulo State, Brazil, sugarcane crops is expanding its area on others crops and natural vegetation. To avoid that the dependence of non-renewable resources by agricultural systems be larger than the biological capacity to supply them and, that the land use dynamics do not result in a monoculture, it is urgent to elaborate efficient public policies that aim sustainable development; but for that purpose, there is a need of diagnosis and scenarios studies. In this sense, Emergy Accounting has been used as powerful tool. The main objective of this work is to assess the emergy indices dynamics of Mogi-Guaçu and Pardo watershed, Brazil, considering the natural vegetation and agricultural land use. The simulation procedure covers a time period from 1988 to 2033, and a scenario approach was used from 2002 to 2033. The Land Use Cover Change (LUCC), submodel of the Multi-scale Integrated Model of Ecosystem Services (MIMES) was elaborated, calibrated, validated and ran in the Simile® software. Results showed that considering only the respect of current Brazilian environmental law (protecting areas with native vegetation), it is not sufficient to achieve good emergy performance for watershed (37.1% of %R; 1.38 of EYR; 0.82 of ESI); the respect of environmental law simultaneously with a reduction of 20% on current dependence on non-renewable resources showed better emergy performance compared to all scenarios (47.0% of %R; 1.45 of EYR; 1.29 of ESI). Aiming better emergy performance for the watershed, the environmental law should be respected, but simultaneously with a reduction bigger than 20% of current watershed non-renewable resources dependence.

INTRODUCTION

During the last two decades, the agricultural and industrial activity in the Mogi-Guaçu and Pardo watershed (Brazil) has increasing exponentially. This growth was based basically on the process of substitution of less economically profit crops by those ones more profitable, in which the agricultural technologies and management used for that purpose requires large amounts of fossil fuel and minerals associated to mechanization of agricultural operations with consequent decrease in labor. In the northwestern of Sao Paulo State, Ambrosio et al (2008a) showed that due to high profit of sugarcane crops related to ethanol and sugar market, sugarcane production is expanding its area on regions with natural vegetation. Agostinho (2009) showed the low emergy performance of agricultural production in Mogi-Guaçu and Pardo watershed, in which sugarcane, coffee, annual crops, orchard and pasture obtained renewability index ranging from 20% to 30%. Considering the current low emergy performance of agricultural production on the watershed and its land use dynamics, what are the effects on the watershed's sustainability considering a medium time period?

Trying to answer this question and considering the complexity of the watershed, it is mandatory a dynamic model that encompasses the most important variables that strongly influence on the results: the land use dynamics and the emergy flows for each land use. The Multi-scale Integrated Model of Ecosystem Services (MIMES) contains a sub-model called Land Use Cover Change (LUCC) whose algorithm allows simulating the land use dynamics. LUCC sub-model was considered in this work to provide reliable data about watershed's land use dynamic.

The identification and quantification of drivers that influence on LUCC should consider the opinion of experts and stakeholders, even thus to know all biophysical and socio-economics drivers are very difficult, if not impossible. Trying to overcome that issue, generally it is considered the scenarios approach. For this, it is considered the main drivers and the current trends in some issues that could influence the LUCC results, as those related to politics and market price.

The objective of this work is to assess the watershed's emergy indices dynamics through different scenarios for agricultural production and land use. For that purpose it was considered the LUCC sub-model in the Simile® environment to supply information about land use cover change dynamics. The LUCC output was used in Excel® software to calculate the emergy performance indices considering five scenarios as theoretical support. Similar work was made by Ambrosio et al (2008b), but here the model was strongly changed, the data were updated and the scenarios approach is different to previous work.

CONCEPTS AND THEORIES USED IN THIS WORK

System Modeling and Simulation

Ludwig von Bertalanfyy (von Bertalanfyy, 1973), defines a system as combined units in mutual interrelationship. That concept can be amplified for one configuration of physical components, items combined, aggregated or connected in a way that they become structured and acting as a unit or an entity. According to Becht (1974), each system component is connected with at least other component direct or indirectly in a determined time period, forming a causal network. The system components or entities can be persons, machines, objects, animals, the environment, information or even other system - in this case it is called subsystem. Those entities can be inherent or transient to the system, which establishes a boundary in which everything outside of it is called as system environment.

A computer simulation program is a set of sequential, logical steps that represent a system process. Simulation programs are often compared to cookbook recipes. Setting out a sequence of statements represents a system in a stepwise language. Although the universe in which we live is far too complex for the human mind to visualize in detail all at once, we can understand simplifications. The simpler concepts by which we think are often called models. Models represent systems, defined as a set of parts and their connected relationship. Typical parts of our planet are the lakes, rivers, oceans, mountains, organisms, people and cities, some large and some small. Processes connect everything directly and indirectly to everything else. Our world is really one huge, complex system. But in order for humans to understand it, we have to simplify it by creating models. To do that, we first put an imaginary box in our minds around the subjects of our interest, thus defining a system. Next we draw symbols representing the outside influences, the inside parts, and the connecting lines that represent relationships and flows. Then we add numerical values to make the model quantitative. Finally, we use one of several methods for simulating the model with a computer. Simulation usually means letting the computer calculations show what the model does over time (Odum and Odum, 2001).

Scenarios Approach

In accordance to Dow and Downing (2007), when our knowledge about future is uncertain, we use the term scenario to describe a possible alternative using several assumptions about causal drivers and its interrelationship. Scenarios are not previsions or prognosis, and sometimes it is based on storylines. Dockerty et al (2006) argues that scenarios are a plausible sequence of possible events used to inform future trends, potential decisions or consequences. Scenarios need to identify and incorporate the key drivers of future change.

Scenario development has become a popular tool for the assessment of land use change and a large number of studies using scenario approaches have been published during recent years (de Nijs et al, 2004; Ewert et al, 2005; among others). Scenarios provide a methodology for ordering perceptions about alternative future environments in which today's decisions might be played out. In practice, scenarios resemble a set of stories, written or spoken, built around carefully constructed plots often termed narrative storylines. Scenarios are not predictions; instead, scenarios are an approach to help manage the inherent uncertainties of decisions based on assumptions, rather than on facts, by examining several alternatives of how the future might unfold and compare the potential consequences of different future contexts (Shearer, 2005).

The storylines of the scenarios can be scaled down to assess the effects on land use patterns accounting for the hierarchical structure of land use driving factors. Global trade agreements and political structures may be an important factor explaining differences in agricultural and industrial development among continents and countries while local variations in social and biophysical conditions are important determinants of landscape patterns and variability. Furthermore, the driving factors of landscape pattern are often region-specific as a consequence of different contextual conditions, specific variation in the socio-economic and biophysical conditions, and the influence of land use history and culture (Verburg et al, 2006).

Multi-scale Integrated Model of Ecosystems Services (MIMES)

In accordance to Boumans and Costanza (2007), the MIMES project aims to integrate participatory model building, data collection and valuation, to advance the study of ecosystem services for use in integrated assessments. The MIMES is considered an open model, collaborative and modular. Its three major objectives are: (i) A suite of dynamic ecological economic computer models specifically aimed at integrating our understanding of ecosystem functioning, ecosystem services and human well-being across a range of spatial scales; (ii) Development and application of new valuation techniques adapted to the public goods nature of most ecosystem services and integrated with the modeling work; (iii) Delivery of the integrated models and their results to a broad range of potential users.

MIMES model is being updated frequently in which researches with different expertise around the world are collaborating on it in a participatory way. The MIMES model can be downloaded from *http://sourceforge.net/projects/mimes*. Subject-specific models in the MIMES were studied and transcribed for the software Simile® (*http://www.simulistics.com*), that it was chosen as declarative modeling environment for coding models to ensure that they were highly-transparent, easy to modify and easy to use.

The MIMES framework contains a sub-model called Land Use Cover Change (LUCC), whose algorithm allows simulate the dynamics of substitution between land uses on several scales. That subsystem is already done in MIMES considering a global scale, but in this present work it was moderately modified and down-scaled to incorporate the characteristics of the watershed under study.

METHODOLOGY

System Description

Mogi-Guaçu and Pardo watershed (Figure 1) was chosen as case study due to three main reasons: (1) Its economic importance for Brazil. In 2006, the agricultural production of Sao Paulo State exported out of Brazil almost 45.9 billion USD (33.4% of Brazilian total) and imported 37.1 billion USD (40.6% of Brazilian total), representing an 8.86 billion USD surplus (IEA, 2007). (2) There are several environmental and social problems in the watershed related to agricultural and industrial production, i.e. there are many research possibilities focusing on these issues. (3) There was a project whose acronym was ECOAGRI[1] in which several researchers of different fields applied their expertise to assess the environmental and social problems in the watershed; thus, there are several raw data available.

[1] Informations about ECOAGRI project are available in Portuguese language at http://ecoagri.cnptia.embrapa.br

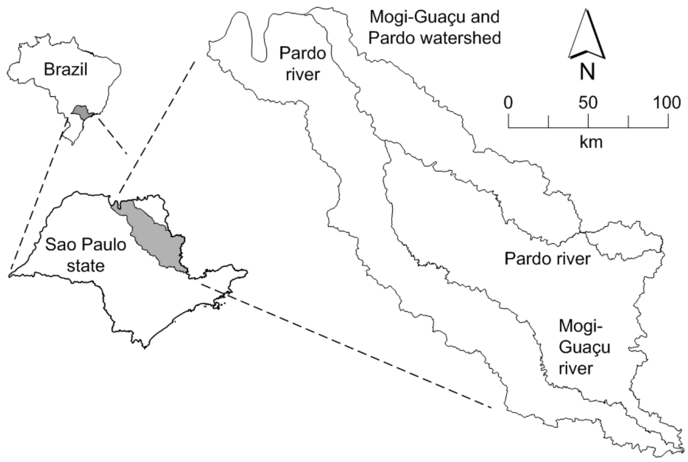

Figure 1. *Study area: Brazil, São Paulo State, Mogi-Guaçu and Pardo Watershed.*

Table 1. Land use of Mogi-Guaçu and Pardo watershed in 1988 and 2002.

Land use	Area in 1988 (ha)	%	Area in 2002 (ha)	%
Sugarcane	796,543	25.2	1,629,027	51.5
Forest	498,771	15.8	464,160	14.7
Pasture	786,763	24.9	392,621	12.4
Orchards	230,585	7.3	236,288	7.5
Tree plantation areas	104,812	3.3	109,710	3.5
NICP Annual crops [A]	538,237	17.0	80,862	2.6
Urban areas	55,966	1.8	75,502	2.4
Savanna	58,018	1.8	62,778	2.0
River, lake and water reservoir	48,987	1.5	49,773	1.6
ICP Annual crops [B]	16,446	0.5	33,354	1.1
Coffee	26,321	0.8	22,588	0.7
Heveaculture (rubber tree)	175	< 0.0	3,401	0.1
Other	2,940	0.1	4,481	0.1
Mining areas	643	< 0.0	655	< 0.0
Total:	3,165,207	100.0	3,165,207	100.0

Source: ECOAGRI Project (unpublished report).

[A] Non-irrigated by central pivot (NICP) annual crops. However, these annual crops can be irrigated by other kind of technology.

[B] Irrigated by central pivot (ICP) annual crops.

All data used in this work comes basically from Agostinho (2009; that have used data from ECOAGRI Project) and IEA (2007). The watershed has an area of 3,165,207 hectares and it is used basically for sugarcane crops and grasslands for livestock (Table 1). The emergy flows for each land use considered in this work were previously calculated by Agostinho (2009) and Agostinho et al (2010).

Assumed Specific Scenarios and their Driver Values

The knowledge of all drivers that influence on the land use cover change of watershed and its emergy performance is a hard if not an impossible task. Trying to overcome this problem, the most representative informations about drivers were considered in this work. We assumed as hypothesis that the current trends in agricultural politics, demand for food and biofuel, technology and management of agricultural production are the main strengths defining the following five drivers:

Driver #1 - Population: In 2002 the population in the watershed was 3,466,476 inhabitants (ECOAGRI project, unpublished report). Considering values from Waldvogel et al (2003), the population in the watershed could reach the maximum of 4,215,234 inhabitants in 2050 if the current trends continue. Population driver was considered as an influence on the urban areas in the watershed, in which an increase of population means increase of urban areas and consequently a reduction of available land for natural vegetation and/or agricultural use.

Driver #2 - Environmental law: It refers to current Brazilian's environmental law (Brazilian Forest Code, 1965) in which is established that lands classified as Permanent Protection Areas (PPA) and Legal Reserve (LR) must be preserved with natural vegetation to guarantees the environmental services production. PPA includes lands with high declivity, a buffer of at least 10m from rivers and 50m from water springs, and top of mountains. LR establishes that 20% of total agricultural area (excluding PPA) must be preserved. In PPA and LR is totally forbidden human-made activities, but unfortunately some of them are being used by farming crops. Environmental law driver can be considered in two ways during the simulation procedure in this work: "respect it" or "do not respect it". If the option "respect it" is switch-on, all lands with human activities that are located in PPA areas will be converted into natural vegetation.

Driver #3 - Economic issues: All other drivers are important to limit the area in which specific land use can be expanded, but the driver related to economic issues are the most powerful because the decision about what to produce is generally determined by it. The broad driver categories related to economic issues are: (i) Net Profit ($\$.ha^{-1}.yr^{-1}$); (ii) Turnover time of invested money (years); (iii) Government subsidy (money borrowed from banks through low tax; government guarantee to pay determined price for the harvest); (iv) Stability in crop production (risks related to plagues, climate issues and fire); (v) Market (is there market for the harvest?); (vi) Infrastructure available (railways and highways, hangars, trucks, etc). Quantify all these drivers and obtain a tendency for all of them are hard tasks due to lack of raw data and the subjectivity of this kind of information. Thus, we assume that a good approach is to consider only the market price paid to agricultural products using a temporal data series to verify its tendency.

Driver #4 - Agricultural technology: It tries to capture the influence of technology level on agricultural production, i.e. the use of tractors, machines, irrigation equipments, and so on. In this study, we considered that high technology level is synonymous of high dependency of non-renewable resources. In accordance to previous studies cited by Agostinho (2009), technology level values ranging from 90% less dependent on non-renewable resources to 100% more dependent of non-renewable resources can be found for Brazilian agricultural production.

Driver #5 - Agricultural management: It tries to capture the influence agricultural management on the dependence of renewable resources, in which increasing values of agricultural management driver means an ecological management and consequently an increase in the renewable resources use. In accordance to previous studies cited by Agostinho (2009), values ranging from 20% less ecological management to 80% more ecological management can be found for Brazilian agricultural production.

Considering the drivers and hypothesis above described, the five scenarios showed in Table 2 were assumed in this work.

Table 2. Scenarios and their respective drivers considered in the simulation procedure.

Scenarios	Drivers				
	Population	Brazilian environmental law	Market	Technology (non-renewable dependency)	Management (renewable dependency)
Baseline	Current trends	Not respected	Current trends	Current trends	Current trends
Scenario #1	Current trends	Not respected	Current trends	Increased, 20%	Decreased, 20%
Scenario #2	Current trends	Not respected	Current trends	Decreased, 20%	Increased, 20%
Scenario #3	Current trends	Respected	Current trends	Current trends	Current trends
Scenario #4	Current trends	Respected	Current trends	Increased, 20%	Decreased, 20%
Scenario #5	Current trends	Respected	Current trends	Decreased, 20%	Increased, 20%

Simulation Procedure

In this present work, the simulation procedure can be divided in the following steps: (i) Draw a complex systemic diagram of watershed using emergy symbols proposed by Odum (1996); (ii) Draw a reduced systemic diagram of the watershed, considering the main energy sources and drivers that manage the LUCC and emergy flows; (iii) Elaborate in a programming environment the mathematical representation of the reduced diagram previously drawn; (iv) Calibrate, validate and run the mathematical model considering the specific scenarios established; (v) Assess the emergy indices dynamic.

From all available emergy indices that assess the environmental performance of systems, this work considered five of them: Renewability, Emergy Yield Ratio, Emergy Investment Ratio, Environmental Loading Ratio and Emergy Sustainability Index. Deeper understanding about emergy indices can be found at Odum (1996) and Brown and Ulgiati (2004). In this work we have considered the partial renewabilities of each input to calculate the Renewability, Environmental Loading Ratio and Emergy Sustainability Index, as proposed by Ortega et al (2002) and used by Agostinho (2009), Agostinho et al (2008; 2010), Cavalett and Ortega (2009), Pereira and Ortega (2009), among others.

Simile® software was used due to its friendly-to-use interface and its availability at low cost. Moreover, the LUCC from MIMES project have been used Simile® environment, and here the basic model of LUCC was considered through moderate adaptations in its mathematical language. After run the LUCC model, the land use dynamics data were used in the Excel® software to calculate the emergy performance indices.

RESULTS AND DISCUSSION

Figure 2 represents a reduced model considered in the simulation procedure. It was derived from a more complex systemic diagram of Mogi-Guaçu and Pardo watershed that can be found in Agostinho et al (2010). It shows the environmental resources (separated in renewable and non-renewable) and economic resources (separated in materials and services) used by system. Deeper explanation about the

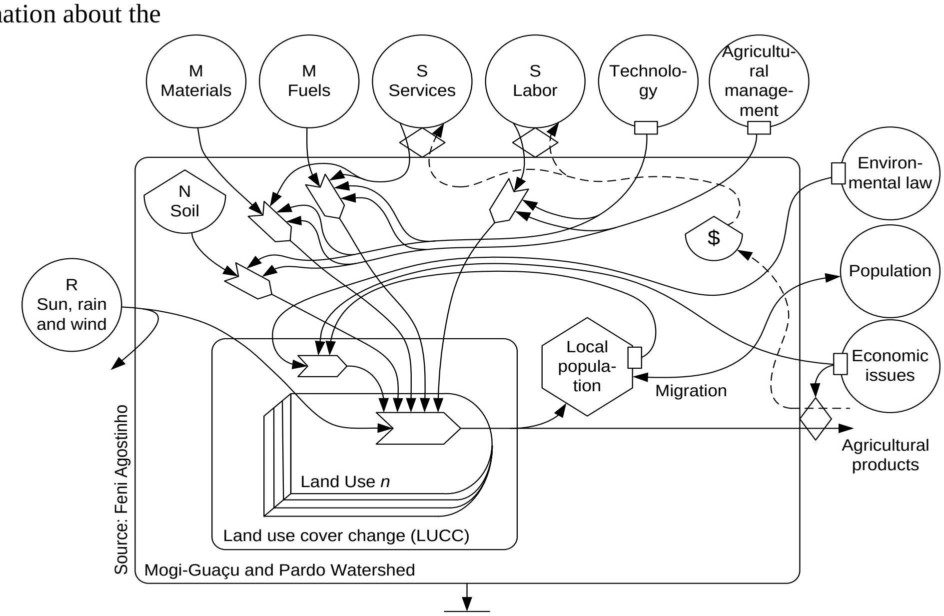

Figure 2. *Systemic diagram of Mogi-Guaçu and Pardo watershed showing the main energy sources and drivers that influence the land use change and the emergy flows. The drivers are technology, agricultural management, population and economic issues. R = renewable; N = non-renewable; M = Materials; S = Services.*

nomenclature and emergy symbols used in the diagram can be found in Odum (1996) and Brown (2004). Drivers influencing the LUCC subsystem are: (i) Local population size; (ii) Brazilian environmental law; (iii) Economic issues. The increase of population size results in enlargement of urban areas. Economic issues influence the land owner choice to produce determined agricultural product instead other one. Brazilian environmental law influences the availability of areas for agricultural production. Drivers influencing emergy flows are: (i) Technology; (ii) Agricultural management. It was assumed that high technology level means large dependence of fossil fuels and minerals, while high level of agricultural management means an ecological management and consequent reduction of fossil fuels and minerals dependence.

The model showed in Figure 2 was replaced in a mathematical-computational model using Simile® environment (Figure 3) allowing the simulation procedure according to specific scenarios assumed. The calibration procedure was made considering the available data about watershed's land use from 1983 to 2002, and the validation was made considering the time period from 2002 to 2008. Appendix A shows the calibration and validation results.

Figure 4 shows the final results of watershed's emergy indices dynamics. Renewability index dynamics indicates a small increase from 29.9% to 34.7% for baseline. Scenario #5 showed better performance of all scenarios, reaching 47.0% in 2033. Scenarios #2 and #3 also obtained better performance than baseline (41.6% and %37.1 respectively) due to their lower dependence of non-renewable resources or respect of environmental law, achieving renewability values close to Brazilian's ecological agriculture (from 56% to 73%; Ortega et al., 2005; Francescatto et al., 2008). Scenarios #4 and #1 obtained worst performance (28.3% and %27.7 respectively) due exclusively to its large dependency of non-renewable resources, close to values found for Brazilian's chemical agriculture (from 20% to 42%; Ortega et al., 2005; Cavalett et al., 2006; Pereira and Ortega, 2009; Francescatto et al., 2008; Cavalett and Ortega, 2009).

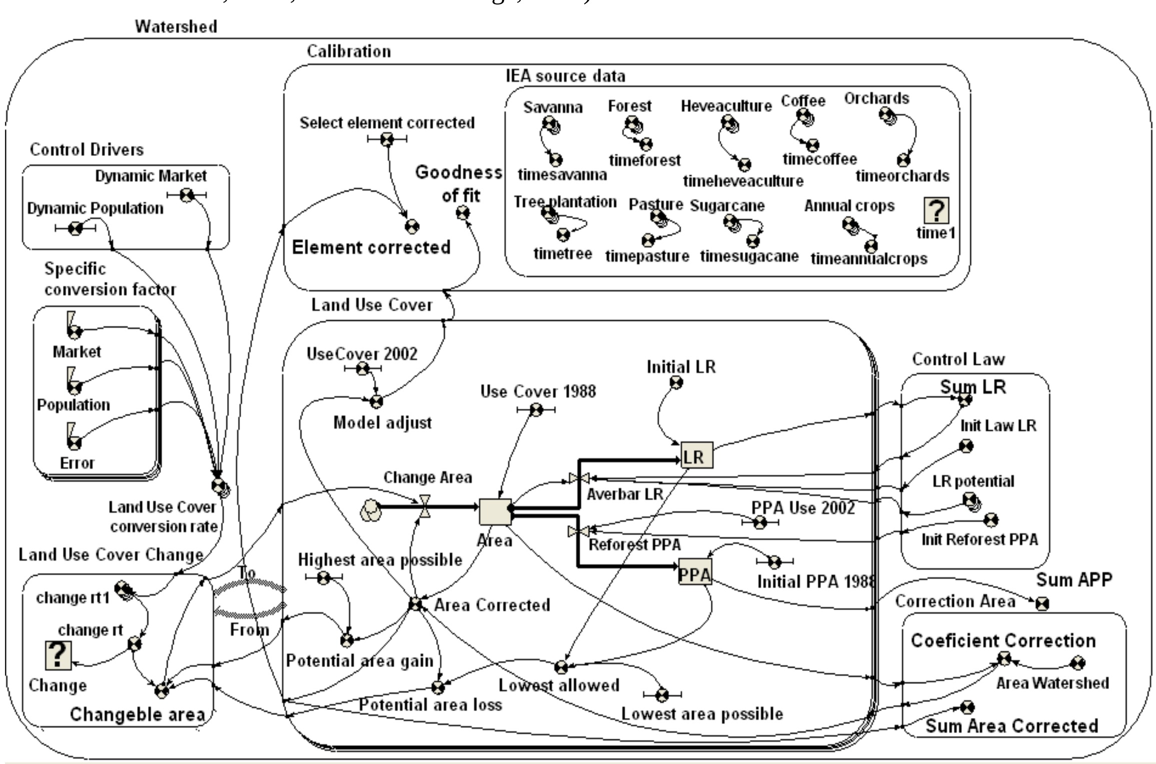

Figure 3. *Land Use Cover Change (LUCC) model of Mogi-Guaçu and Pardo watershed in Simile® environment.*

It is important to note that, considering only the respect of Brazilian environmental law, it resulted in little increase (only 4.1 in average) in the performance for those scenarios that considerer it: scenario #3 better than baseline, scenario #4 better than #1 and scenario #5 better than #2. Assuming Renewability index as a strong indicator of sustainability, if the agricultural production in the watershed follow the scenarios #2, #3 and #5, the watershed will improve its sustainability. Considering the baseline as parameter, a reduction of 20% in the dependence of non-renewable resources and increase of 20% in the use of renewable ones contributed strongly for a good performance of scenarios #5 and #2.

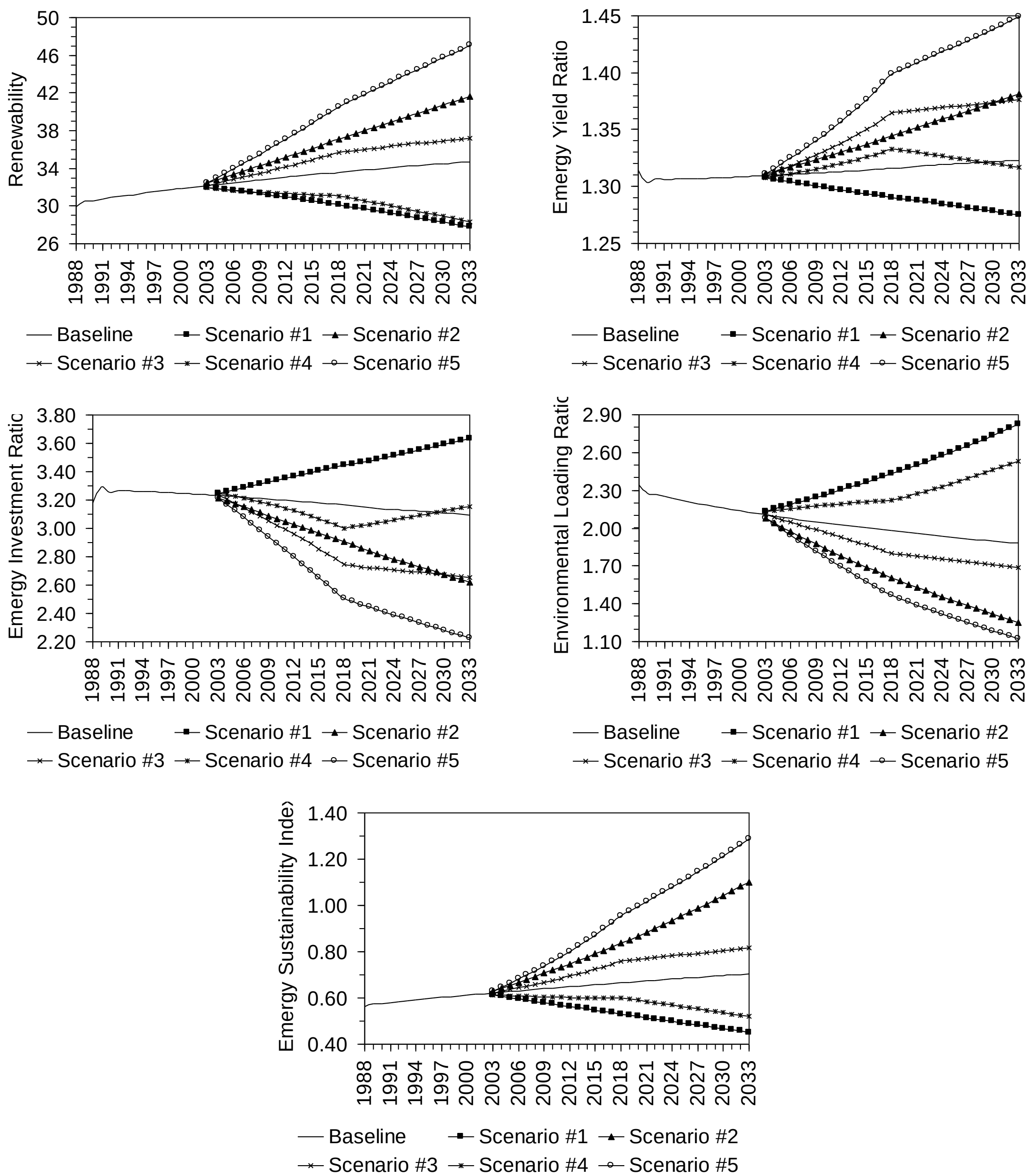

Figure 4. *Emergy indices dynamics on Mogi-Guaçu and Pardo watershed from 1988 to 2050.*

Emergy Yield Ratio (EYR) dynamics for watershed indicates a constant behavior for baseline, from 1.31 in 1988 to 1.32 in 2033, indicating that 75% of its total emergy comes from economic resources. Scenario #4, which respects the Brazilian environmental law and assumes an increase in non-renewable resources use, it shows a little better performance than baseline until 2025, but in 2033, it has almost the same performance. Scenario #1 showed worst performance than all scenarios, reaching an EYR of 1.28; this indicates that 78% of its total emergy comes economic resources. Scenario #5 obtained better performance than all scenarios with EYR of 1.45, indicating a dependence of 69% from economic resources. Scenarios #2 and #3 obtained both an intermediary performance with 1.38 (dependence of 72% of economic resources). Neither a reduction of 20% of current non-renewable resources dependence (Scenarios #2 and #5) was able to reach good values of EYR, which at least should be bigger than 2.0 indicating a dependence of 50% from economic resources. Emergy Investment Ratio (EIR) index reinforces the EYR results: the baseline and scenario #4 use about 3.12 times more emergy from economy than environmental; scenario #5 showed better performance of all scenarios, but it uses 2.23 times more emergy from economy than environmental; scenario #1 has the worst performance with EIR of 3.64, while scenarios #2 and #3 have 2.64 aproximately. For comparison, EYR for Brazilian's chemical agriculture ranges from 1.34 to 2.17, while EIR ranges from 0.85 to 2.95 (Ortega et al., 2005; Cavalett et al., 2006; Pereira and Ortega, 2009; Francescatto et al., 2008; Cavalett and Ortega, 2009); Brazilian ecological agriculture has EYR ranging from 2.24 to 3.69, while EIR ranges from 0.37 to 0.80 (Ortega et al., 2005; Francescatto et al., 2008).

The Environmental Loading Ratio (ELR) for baseline showed a small reduction, ranging from 2.34 in 1988 to 1.88 in 2033, but sufficient to improve its performance from a moderate to a small load on the environment (in accordance to ELR range defined by Brown and Ulgiati, 2004). Scenarios #5, #2 and #3 also obtained good performance, causing small load on the environment with ELR of 1.13, 1.25 and 1.69 respectively. On the another hand, scenarios #1 and #4 showed worst performance, causing a moderate load on the environment with ELR of 2.82 and 2.53 respectively. ELR for Brazilian's chemical agriculture ranges from 1.40 to 4.18 (Ortega et al., 2005; Cavalett et al., 2006; Pereira and Ortega, 2009; Francescatto et al., 2008; Cavalett and Ortega, 2009); Brazilian's ecological agriculture has ELR ranging from 0.37 to 0.84 (Ortega et al., 2005; Francescatto et al., 2008).

According to Brown and Ulgiati (2004), Emergy Sustainability Index (ESI) indicates the system sustainability, but we consider that ESI (ESI=EYR/ELR) shows a kind of benefit-cost relationship, in which it is evaluated the benefit provided to society (through buying materials) in relation to load on the environment (cost) made to reach that benefit. The ESI dynamic for watershed shows that baseline had low variation and low performance (from 0.56 in 1988 to 0.70 in 2033) indicating low benefit to society through high load on the environment. Increasing the dependency of non-renewable resources in 20% and the same percentage for reduction of renewable ones, it resulted for scenarios #1 and #4 the worst performance of all scenarios with ESI of 0.45 and 0.52 respectively. The respect of Brazilian environmental law assumed in scenario #4 showed better performance for ESI than scenario #1, but still not sufficiently to achieve a good performance (at least bigger than 1.00); this is reinforced by scenario #3, that even assuming current emergy flows and respect to Brazilian environmental law, it was not able to obtain an ESI bigger than 1.00 (scenario #3 with ESI of 0.82). Scenarios #2 and #5, which reduced their dependence on non-renewable resources, achieved ESI of 1.10 and 1.29 respectively and can be considered as good benefit-cost relationship.

Considering the dynamics of all emergy indices, we could say that if the current trends pursue, the watershed can not be considered sustainable. Worst situation occurs when the dependence of non-renewable resources increase, resulting in a scenario of absolute un-sustainability; this happened with scenarios #1 and #4. Scenarios #2 and #5 assume a reduction of non-renewable resources in 20% and also an increase of renewable ones of 20%, resulting in a better emergy performance compared to all others scenarios, but still far to be considered with good performance due to their low renewability (lower than 47%), low EYR (lower than 1.45) and high EIR (bigger than 2.23). Scenarios #3, #4 and #5 showed that, considering only the respect of Brazilian environmental law, it is not sufficient to reach good emergy performance for watershed. Besides a respect of environmental law, it is needed a strong reduction (bigger than 20%) of dependence on non-renewable resources compared to nowadays.

CONCLUSION

If the current trends of watershed pursue, the baseline showed that the watershed will remain unsustainable in 2033 due to its low renewability (34.7%), high dependence of economic resources (76%; EYR of 1.32) and low benefit-cost relationship (ESI of 0.70). Worst situation occurred when the dependence of non-renewable resources increased in 20% (for scenarios #1 and #4) in relation to baseline, resulting in a renewability index of 28.0% approximately. Even reducing the dependence of non-renewable resources in 20% compared to baseline, scenarios #2 and #5 were not able to reach good emergy performance: 41.6% and 47.0% of Renewability; 1.38 and 1.45 of EYR.

Considering only the respect to Brazilian environmental law, scenario #3 showed that it is not sufficient to achieve good emergy performance: 37.1% of Renewability; 1.38 of EYR; 1.69 of ELR; and 0.82 of ESI. It is evident that to become more sustainable, high effort by stake holders and decision makers should be realized aiming the performance of scenario #5, which assumes a reduction of 20% in the dependence of non-renewable resources and the respect to Brazilian environmental law. This goal is considered a huge advance compared to current performance (baseline), but it is still not sufficiently to achieve an excellent performance and alternatives for agricultural production must be envisioned. Public policies must aim lesser dependence of non-renewable resources from fossil fuels and minerals (reduction bigger than 20% of current values), increase of renewable resources dependence, better relation with human-labor and recognizing the importance of preserved natural areas as supplier of environmental services.

Acknowledgement

The authors are grateful to the ECOAGRI Project (FAPESP, process number 2002/06685-0) for the raw data. Acknowledgments to Support Alfa Project (*http://www.e-science.unicamp.br/support/*) due to scholarship provided to Feni Agostinho during his Ph.D. studies in Italy. This work had financial support from CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico). Special thanks to International Society for the Advancement of Emergy Research (ISAER) which sponsored the presentation of this work at 6th Emergy Conference.

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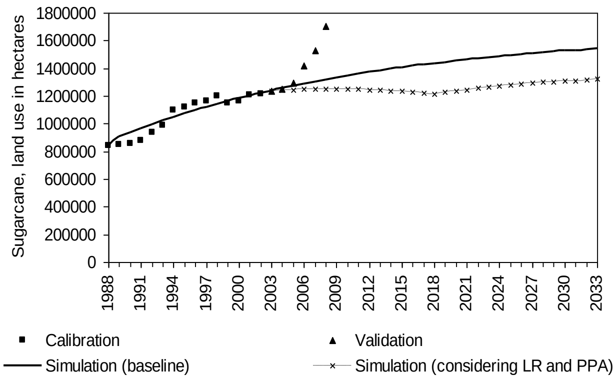
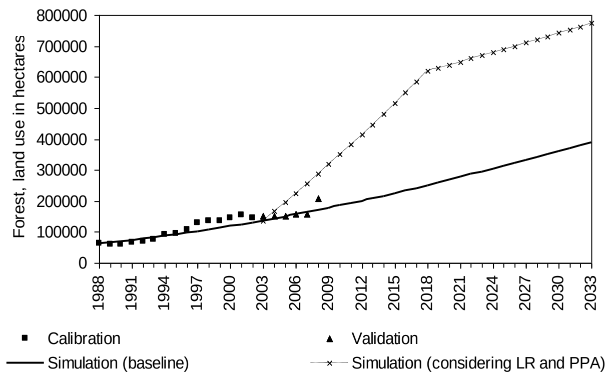
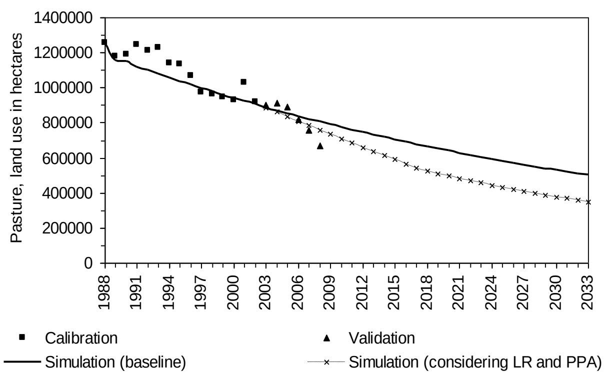
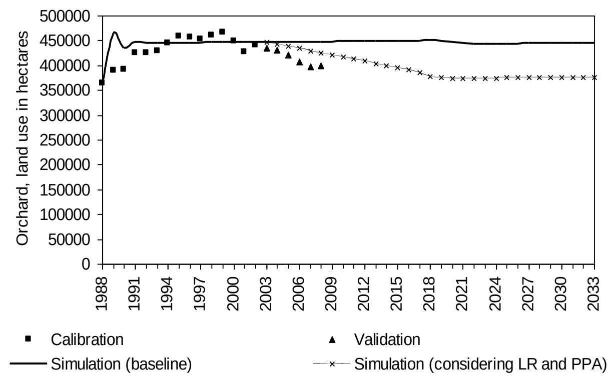
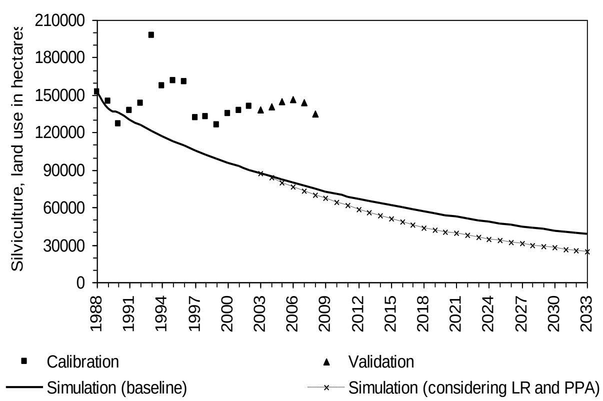
Appendix A. Calibration, validation and simulation of watershed's land use cover change (LUCC) model

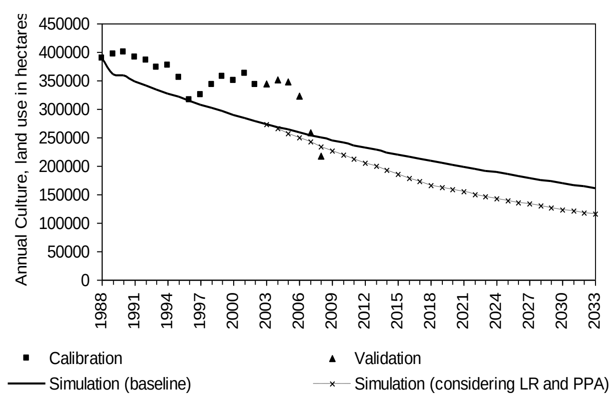












Appendix A. Continued.