EMERGY SYNTHESIS 5:
Theory and Applications of the Emergy Methodology

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Emergy Methodology Improvement for a Proper Assessment of Sustainable Rural Systems

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ABSTRACT

The emergy assessment of rural systems was first developed in the Northern Hemisphere, where agricultural systems became over-simplified as result of using industrial chemicals and machinery in substitution of biological processes and labor. Because of that, the emergy assessment lost its inherent complexity. For a correct emergy assessment of ecological farming the excluded factors (labor and biological services) must be considered as well as new ones (climate change). This paper offer suggestions to overcome the identified methodological problems: (a) To use the renewability of each input in the calculation of renewable and non-renewable economy inputs and use these values in aggregated form (F_R and F_N) in Emergy Indices; (b) To consider as renewable those flows produced by local biodiversity, as soil minerals obtained by deep roots and micro-biota, chemicals obtained by symbiosis; (c) To measure productivity without considering top soil erosion as part of yield; (d) To develop indices for measuring internal flows (as local consumption, material cycling, internal services); (e) To develop indices to consider the quality of human labor; (f) To develop indices for measuring the loss of environmental services and negative externalities as well as the area needed for recovering; (g) To discuss the concept of transformity as indicator of feasibility; (h) To include in the Input-Output balance the Emissions, Effluents and Solid Wastes; (i) To consider the value of Information, both renewable and non-renewable, as input, stock and output; (j) To consider Natural Capital, Infra-structure, Financial and Human Resources and Organization.

INTRODUCTION

Research on Brazilian farming systems (Ortega et al., 2001, Ortega et al., 2002b, Ortega et al., 2005, Agostinho et al., 2008) revealed that farming can be grouped into two models: **Biological** (ecological and organic farming) and **Chemical** (inputs intensive and biotechnological farming). Ecological farms produce environmental services and chemical farms produce deleterious externalities. The family-managed ecological farms use intensively local labor, preserve native vegetation, use regional renewable inputs, show reasonable productivity, low profitability and do not receive subsidies. An important research advance was the use of farm typology, a novelty in emergy analysis (Ortega 2001). The suggestion of using input's specific renewability was presented at the 4th International Biennial Workshop Advances in Energy Studies (2002) and the concept that information could be the key input for Brazilian soybean system was presented at the 4th Emergy Conference (2006). In this paper the main contributions are new emergy indices, impact absorption area calculation in farm diagnosis and the proposal to study biosphere's stocks flows from for future use.

METHODOLOGY HISTORY

The first reference to emergy methodology applied to agriculture was a chapter of the book Energy in Agriculture (Odum, 1984). In Emergy Folio #4, Brandt-Williams & Odum (2002) presented a very similar approach. Figure 1 shows Agriculture of Florida systems diagram.

Brandt-Williams and Odum wrote a text on agriculture emergy assessment in 1997, that became part of a book (Ortega et al., 2002). Figures 2 and 3 show diagrams that belong to that book.

Nevertheless, these approaches didn't consider: (a) the environmental services provided by farm's preserved areas; (b) nitrogen and soil minerals mobilized by micro-biota; (c) local consumption; (d) recycling; (e) co-products; (f) waste, emissions, rural exodus, toxic substances and health problems, biodiversity loss, human culture degradation and other outputs. In order to solve part of this problem, Ortega et al. (2002a, 2002b) proposed the use of input's renewability and indices that consider renewable and non-renewable Feedback from Economy.

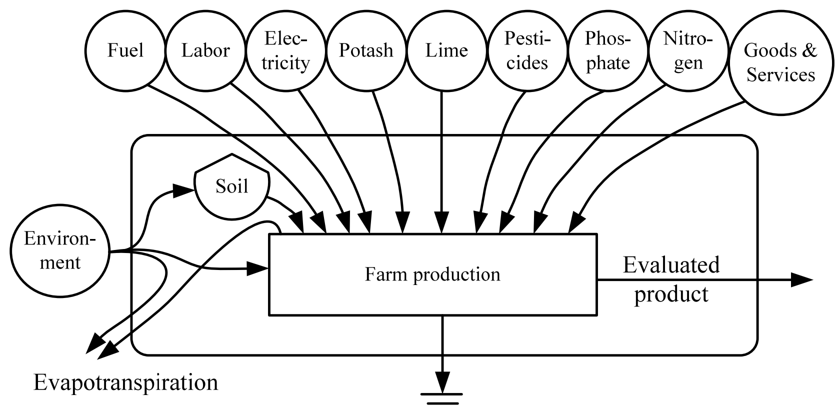

***Figure 1**. Systems diagram with 11 inputs and 1 output applied to 22 crops (Emergy Folio 4).*

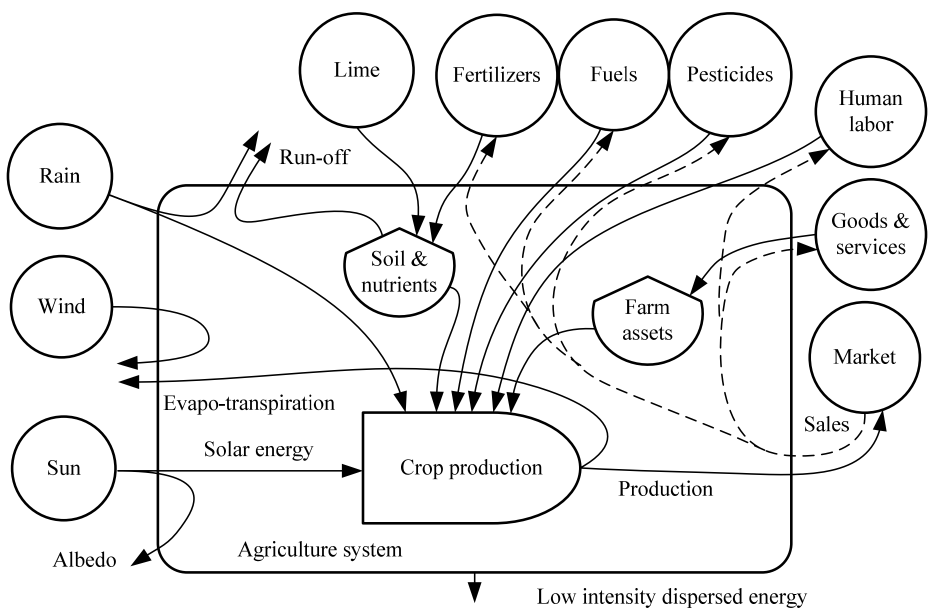

***Figure 2a.** Energy flows diagram of an agriculture system (Brandt-Williams, Odum, 1997).*

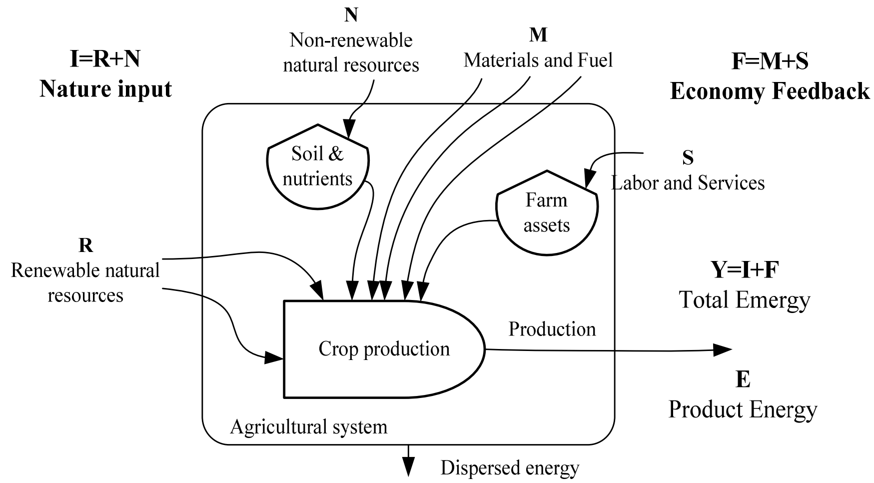

Figure 2b. *Nomenclature of aggregated flows in emergy analysis (Brandt-Williams & Odum, 1997).*

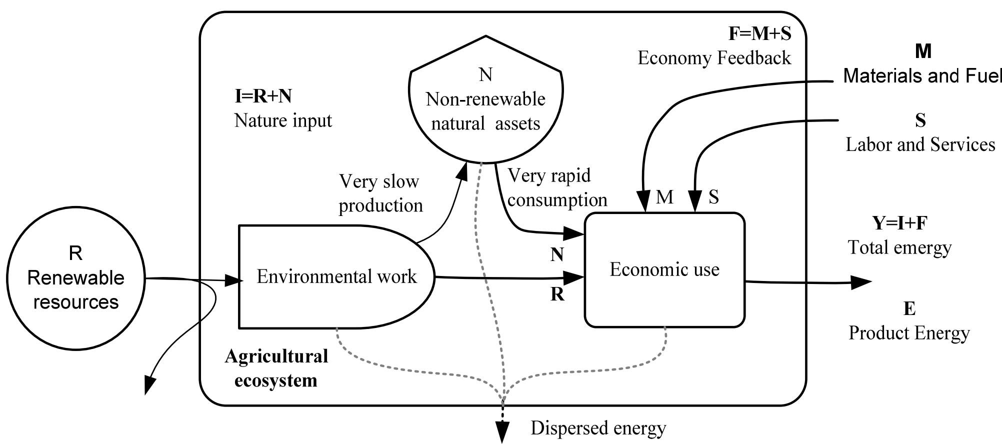

Figure 2c. *Soil as non-renewable resource (Brandt-Williams & Odum, 1997).*

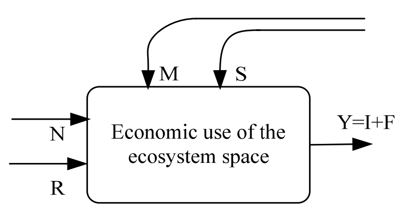

Figure 2d. *Resumed diagram showing aggregated flows (Odum, 1996).*

The Economic Feedback (F=M+S) is composed of renewable and non-renewable materials and services ($\mathbf{F = (M_R + S_R) + (M_N + S_N) = F_R + F_N}$).

$$M_R = \sum M_{iR} = \sum (Ren_i)(M_i) \qquad M_N = \sum M_{iN} = \sum (1-Ren_i)(M_i) \qquad \mathbf{M} = M_R + M_N$$
$$S_R = \sum S_{iR} = \sum (Ren_i)(S_i) \qquad S_N = \sum S_{iN} = \sum (1-Ren_i)(S_i) \qquad \mathbf{S} = S_R + S_N$$

Figure 3a shows an ecological farm producing environmental services and Figure 3b shows a modified agro-ecosystem that lost its natural stocks and its ability to produce environmental services.

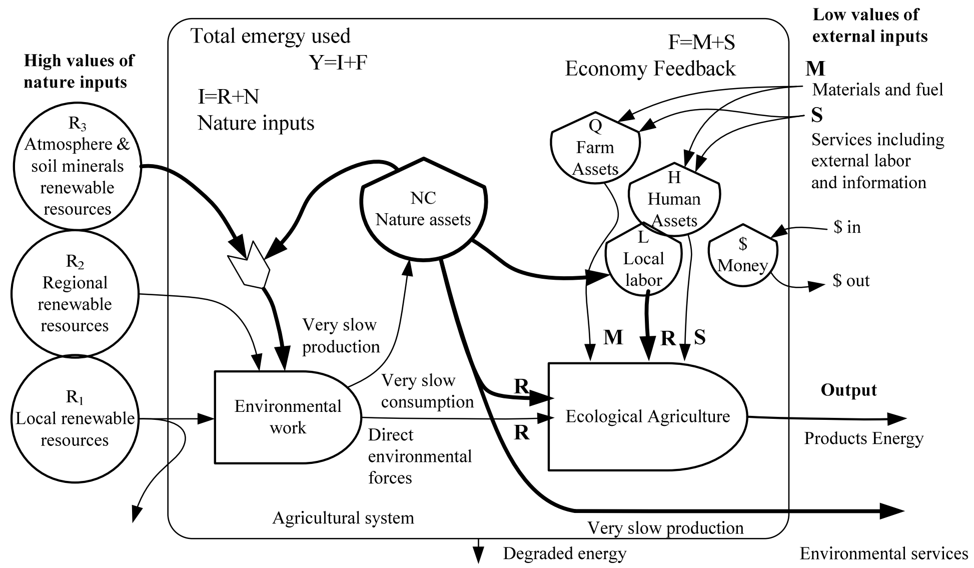

Figure 3a. *A broad vision of ecological agricultural system.*

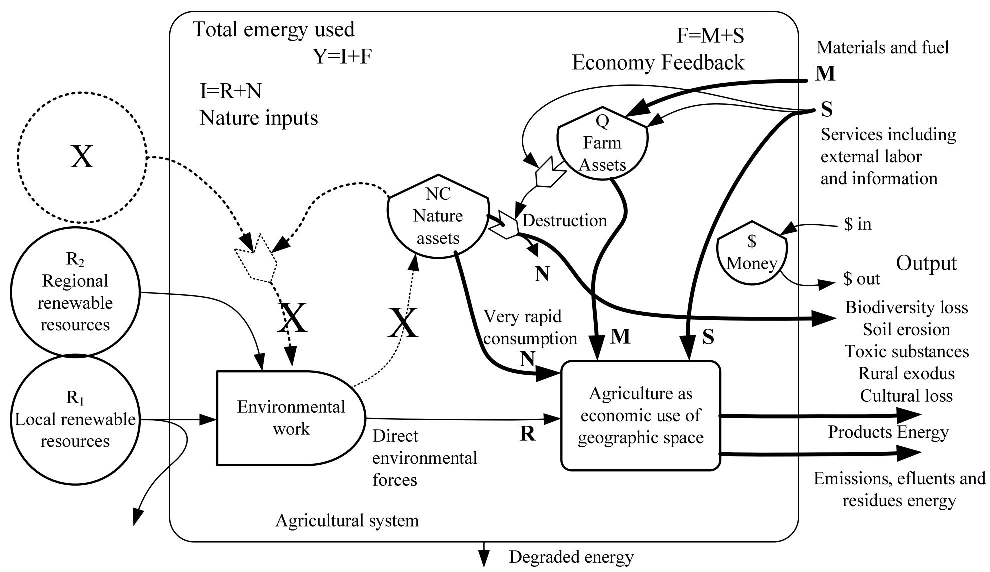

Figure 3b. *Systems vision of chemical agriculture.*

Figures 3a and 3b depict, in resumed form, the history of the modification that agriculture suffered in the last 150 years, after the introduction of chemical inputs and oil-based machinery. Figure 4 makes evident the difficulty in applying to the farm system the window used by Odum in Figures 2c and 2d, because the natural capital losses and environmental services are excluded, therefore the observation window has to be enlarged to consider them. Besides that, from Life Cycle Analysis, Ecological Footprint and Climate Change research (Cavalett, O., 2008; Pereira, C., 2007, Pereira, L., 2008; Ortega and Costa, 2008) emerged important interactions of farming with geological, biological and historical processes that should be considered in emergy analysis. These links are introduced in Figure 6, emergy research should identify and quantify these flows for future use.

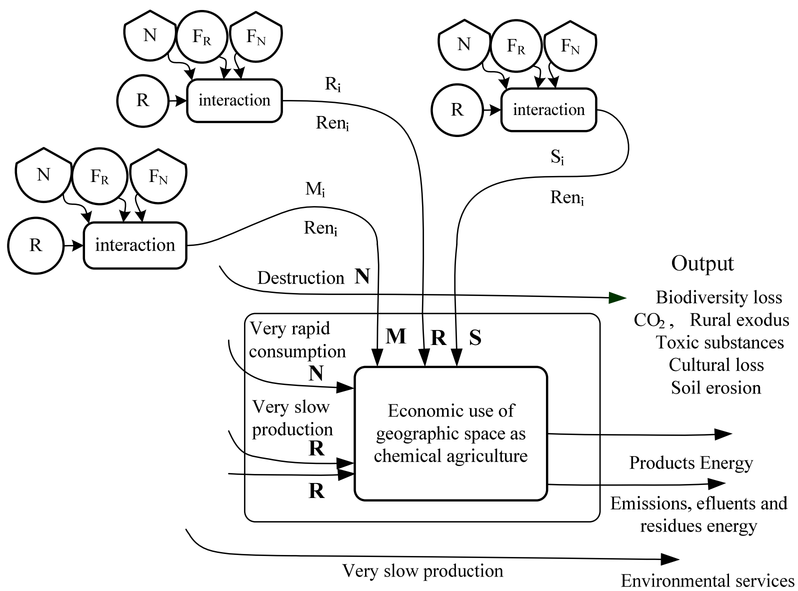

Figure 4. *Aggregated flows diagram. If only cropland is considered (the small window) then the output corresponding to remaining environmental services and system losses will be excluded.*

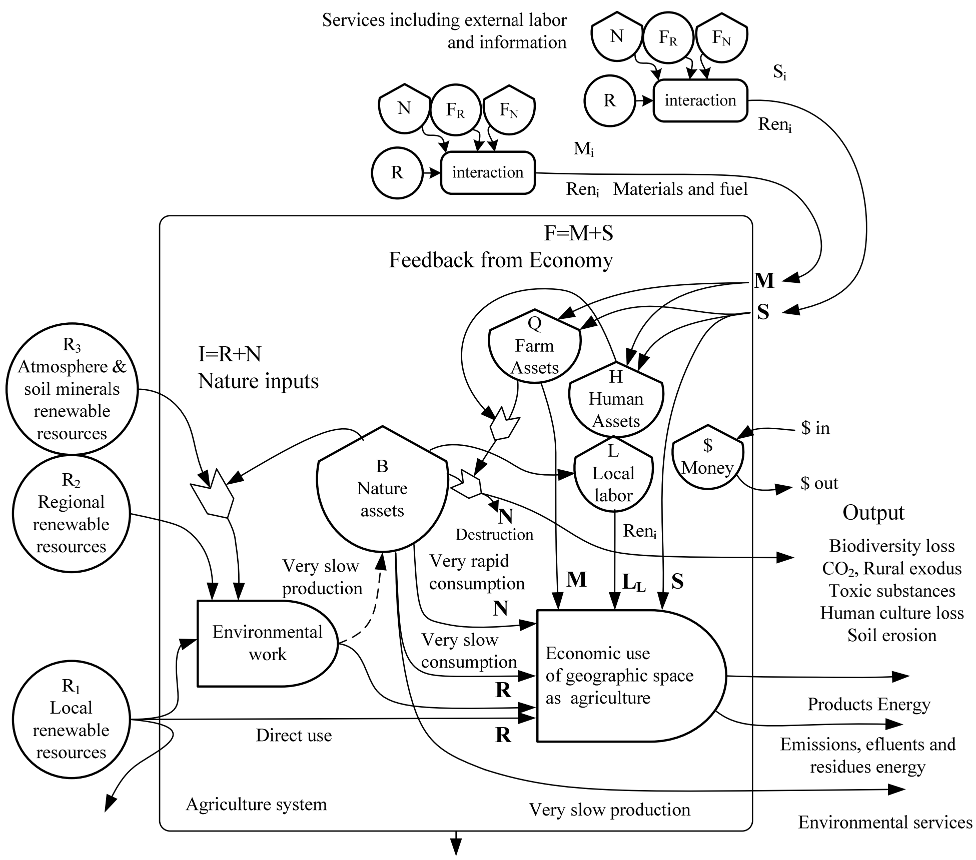

Figure 5. *A new diagram proposed to study agricultural systems.*

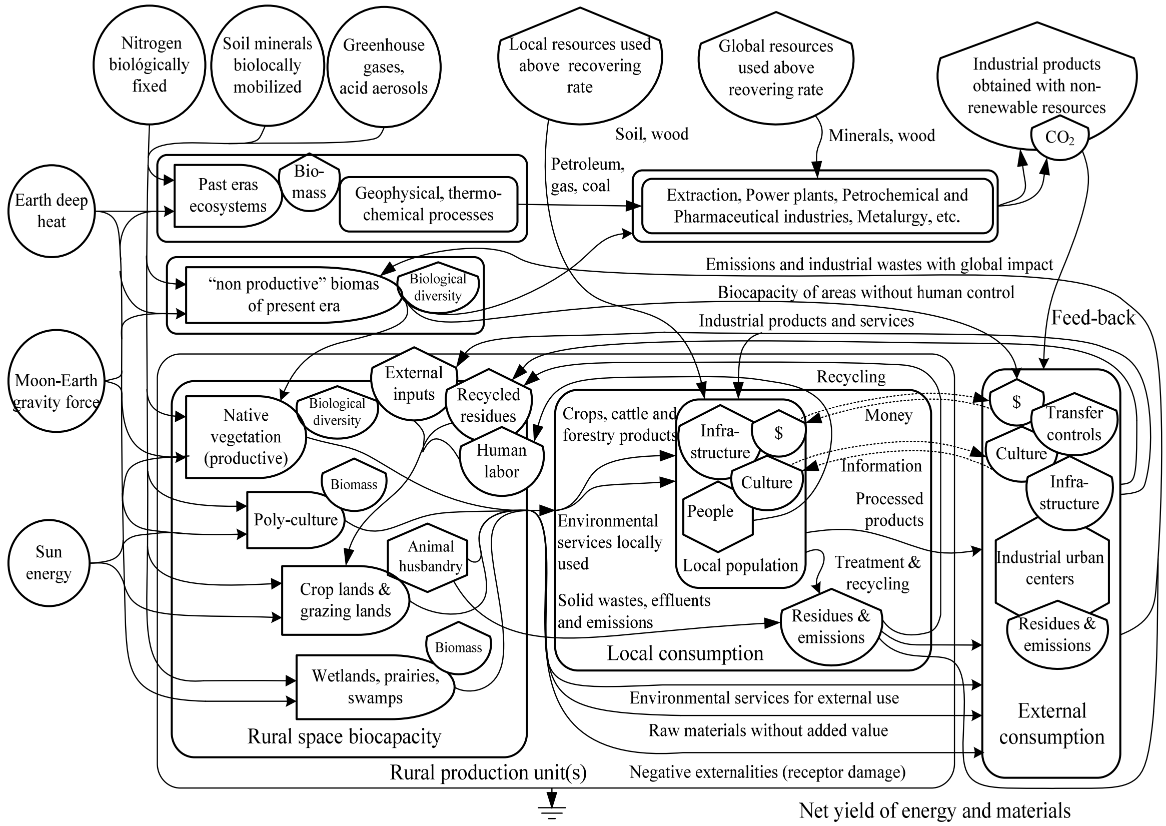

Figure 6. *A systems diagram that shows four critical relationships of agriculture: (a) with other Era's ecosystems areas (fossil fuel); (b) with present era "non productive biomes" whose preserved areas provide Biosphere functions (climate regulation); (c) clean development mechanism areas needed for CO_2 sequestering; (d) internal complexity of rural space biocapacity and local consumption.*

SUGGESTIONS FOR IMPROVEMENT

1. To use the renewability of each input in the Emergy Flows and Emergy Indices calculations;
2. To consider as additional renewable inputs those flows that are produced by biodiversity, such as soil minerals obtained by deep roots and micro-biota and chemicals produced by symbiotic biota (these additional resources are not shown in figures 1 and 2, they only begin to appear in figure 3);
3. To develop indicators to measure: (a) The real productivity (kg/ha/year) without the consideration of soil erosion and fossil fuel use as a positive fact (avoiding the use of EYR and ESI and using instead R/F and R/N); (b) Renewable and non-renewable capital; (d) Internal flows (local consumption, material recycling, internal services); (e) Environmental services loss and negative externalities;
4. To include Gas Emissions and Waste as new items in the Inputs-Output balance;
5. To discuss the value of Information as input, stock and output in order to include it in the calculations in the near future;
6. To discuss the use of Transformity as main indicator of public policy feasibility;
7. To consider impact absorption area in project appraisals.

RESULTS OF APPLICATION OF NEW EMERGY INDICES

A More Complete Diagram

Most part of suggestions listed before are implemented in Figure 7. As agriculture became an industrial activity that demands products obtained from fossil energy then every farm should have an area of native forest to absorb the impact derived from using non renewable resources: $(N+M_N+S_N)$. Up to now, all human systems (agriculture, industry, consumer centers) have been built without considering the impact absorption that could be made by native ecosystems or forested areas, as shown in Figure 8.

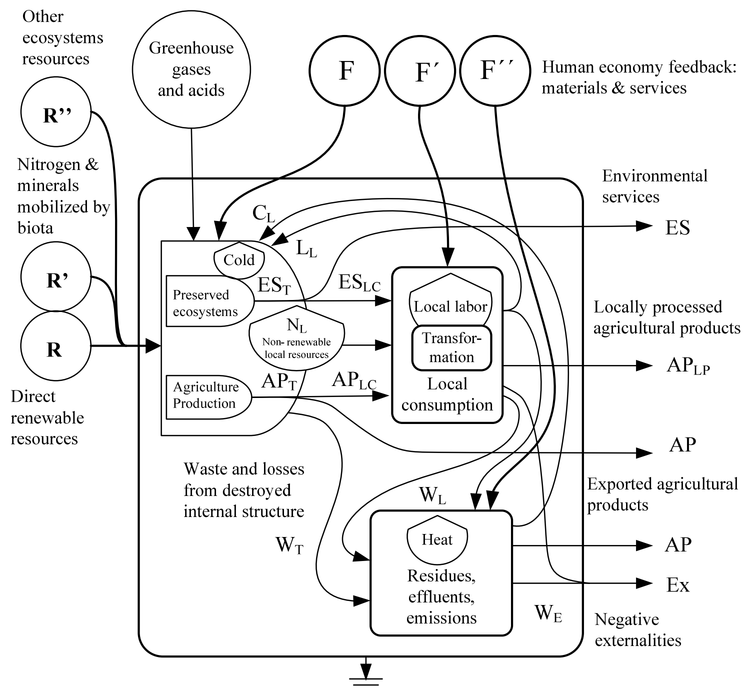

Figure 7a. *Agriculture and its impacts (negative externalities and less environmental services).*

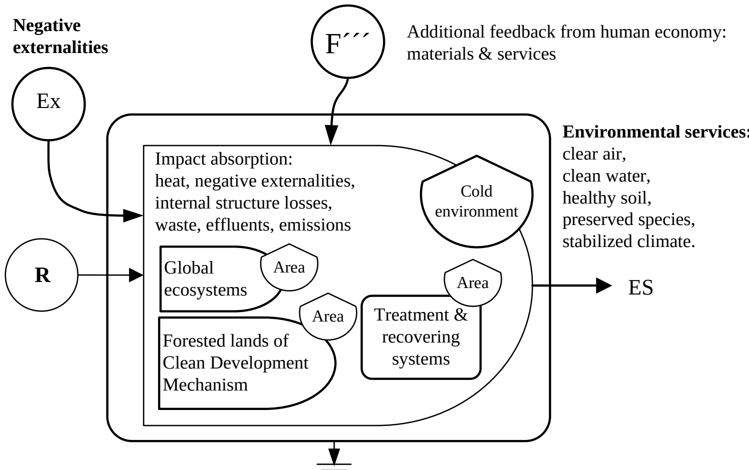

Figure 7b. *.The complete system of a generic diagram showing impact absorption area.*

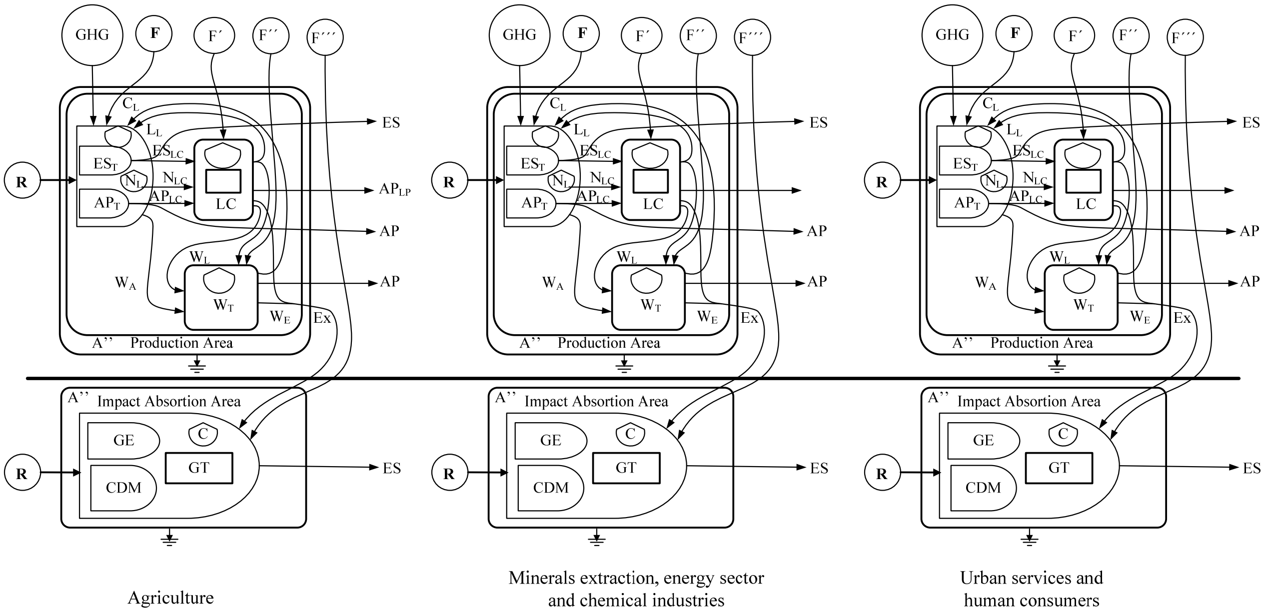

Figure 8*. Diagrams of agriculture, industry, consumer centers with their impact absorption areas.*

Impact Absorption Area in Agriculture

The impact area can be calculated (Brown and Ulgiati, 2001; Agostinho, 2008) converting the emergy of non-renewable resources in native forest area using the value of Net Primary Productivity.

$$SA_{NPP} = \frac{(M_N + S_N + N)}{\text{NPP forest x Biomass energy x Transformity}}$$

M_N, S_N and N = non-renewable resources used by process (seJ/yr);
NPP = Net Primary Productivity of native forest in kg/ha/year (Aber & Melillo, 2001)
BE = Biomass energy (J/kg) in J/kg (Prado-Jatar and Brown, 1997);
Tr = Native forest biomass transformity (seJ/J) in seJ/J (Agostinho et al., 2009)

In order to compare crop productivity (kg/ha/year) in a proper basis (as whole system), the area for environmental impact absorption should be considered. The Brazilian law (Código Florestal, 1965) establishes that in the Southwest region, the farms should maintain 20% of its area for native forest. The ecological farms usually obey this law. On the other hand as the chemical farms use many non-renewables (high impact) and due to its full conversion to crop land they lost many environmental services, therefore the environmental impact absorption area should included (than can be greater than the area that should be preserved following the law).

$$\text{Productivity} = \frac{\text{Production (kg/year)}}{\text{Crop area + Impact absorption area (ha)}}$$

An example of whole system comparison (data from Agostinho, 2007)

Corn production in an ecological farm:

$$\text{Productivity} = \frac{2000\ \text{kg/year}}{\text{Crop area (1 ha) + absorption area (1 ha)}} = \frac{1000\ \text{kg/year}}{\text{ha}}$$

Corn production in a chemical farm:

$$\text{Productivity} = \frac{6000\ \text{kg/year}}{\text{Crop area (1 ha) + absorption area (11 ha)}} = \frac{500\ \text{kg/year}}{\text{ha}}$$

In such a way, it is possible to understand and measure the productivity in a correct form. The ecological corn productivity has a greater value than chemical corn. The concept of complementary area needed to absorb environmental impact can help to explain the so called "Scale Economy" that really works in the opposite sense! The bigger the chemical farm the more mono-cropping, chemicals and fossil energy use and the less human labor and preserved native forest area. It means more impact and less native forest area to absorb it. Besides that, the productivity and income per unit of area decreases ($/ha/year) but the income per farm ($/farm/year) increases (just because the farm is bigger).

A Proposal for New Emergy Indices

First of all, it is necessary to list the aggregated emergy flows and describe in short form the items they involve (Table 1). After that in Tables 2a and 2b describe modifications proposed and the new indices that can overcome present limitations.

The economy in the last 150 years behave as show in Figure 9, a set of emergy indices increased during the economic expansion (Tr, EIR, ELR, EER. N/F), from now on the same set of indices should show a decrease during the economic decline. For other set of emergy indices (Ren, R/F) the trend should be the opposite.

Table 1. Classification of Emergy flows.

Inputs and services	Description
I: Nature contribution	R + N
R = R1 + R2 +R3 Renewable resources from nature	Rain (usually the higher input from renewable forces); Materials and services from preserved areas; Nutrients from soil minerals and air.
N: Nature non-renewable inputs	Soil and diversity loss (including people).
F: Economy Feedback	F = M + S
M: Materials	$M = M_R + M_N$
M_R: Renewable Materials	Renewable materials from natural origin.
M_N: Non-renewable Materials	Minerals, Chemicals, Steel, Fuel, etc.
S: Services (total)	$S = S_R + S_N + S_A$
S_R: Labor Services (partially renewable)	Labor (family, local & external): $S_R = S_{RF} + S_{RL} + S_{RE}$
S_N: Other Services (non-renewable)	Taxes, money costs, insurance, etc.
S_A: Additional Services (non-renewable)	Externalities as effluents treatment, medical costs, etc.
Y: Total Emergy	Y = I + F

Table 2a. Proposals for modification of Emergy Indices.

Modified Emergy Indices	Formula	Concept
Renewability*	R* = (R + MR + SR) / Y	Renewable/Total
Environmental Loading ratio*	ELR* = (N+MN+SN) / (R+MR+SR)	Non-renewable/renewable

Table 2b. Proposals for new Emergy Indices.

New Emergy Indices	Formula	Concept
Labor Services Ratio	**$LSR = S_R / S$**	Labor/Services
Labor Empower Ratio	**$LER = S_R / Y$**	Labor/Empower
Family farming	**$LWR = S_{RF} / (S_{RL}+S_{NE})$**	Family labor/Others
Externalities Empower Ratio	**$ExER = S_A / Y$**	Externalities/Empower
Cycling ratio	**CR = C / F**	Cycling / Feedback
Natural Capital/Economy	**NC / (IE + FN)**	Natural Capital / Feedback
Renewable mobilization	**Benefit =R/F**	Renewable/Feedback
Non-renewable mobilization	**Cost =N/F**	Nonrenewable / Feedback
Systemic Benefit/Cost	**BC=R/N**	Renewables /Non-renewables
External resources dependence	**ED= F/R**	Feedback/Renewables
Natural Capital change rate	**CN / Time**	Natural capital change with time
Anthropic Capital change rate	**$(IE + F_N)$ / Time**	Human assets change with time

Timeline reference for new emergy indices

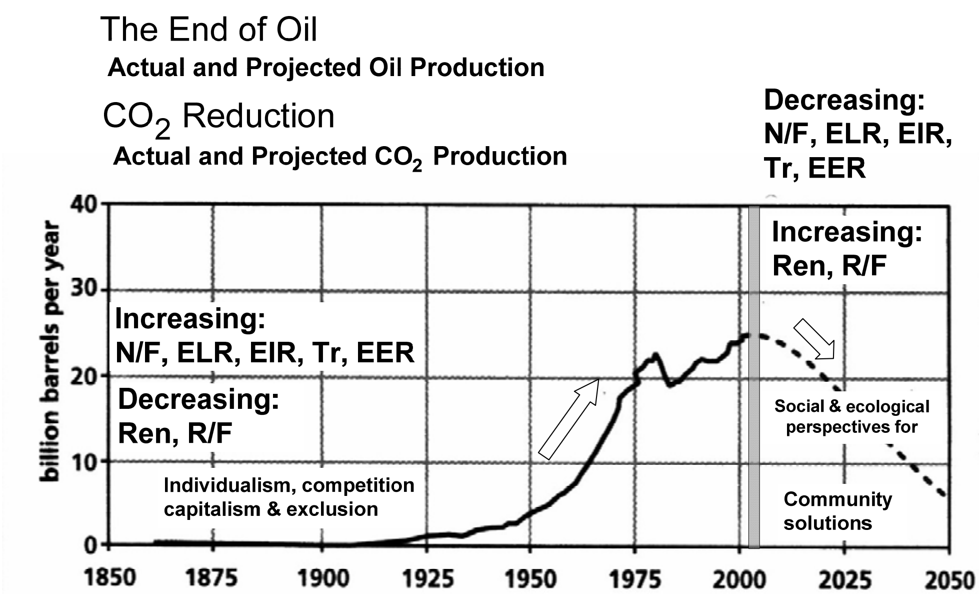

Figure 9*. Graph that express the urgency of improving emergy indices for systems analysis.*

Study Case: Comparison of Two Models of Egg Production

An application of the proposed improvement is shown below (Ortega et al, 2008). The first system is a conventional egg farm in Florida (USA), the second one (Figure 10) is an organic egg farm in São Paulo (Brazil). Table 3 shows the aggregated emergy flows. The emergy indices are shown in Table 4.

Table 3. Aggregated emergy flows (basis = 100 hens).

Aggregated flows (10^{13} seJ/year)	**Equation**	**Conventional**	**Organic**
Nature renewables	R	165	202
Nature non renewables	N	527	0
I =Inputs from nature	**I = R + N**	**692**	**202**
Materials	$M = M_R + M_N$	1191	1407
Renewable Materials	M_R	0	533.4
Non renewable Materials	M_N	1191	873.3
Services	$S = S_R + S_N$	7297	143.2
Renewable Services	S_R	0	72.7
Non renewable Services	S_N	7297	70.5
F = Feedback from Economy	***F = M + S***	***8489***	***1550***
F renewable	$F_R = M_R + S_R$	0	606.1
F non renewable	$F_N = M_N + S_N$	8489	943.9
Y = Emergy used	***Y = I + F***	***9181***	***1751***
E = Product Energy *(10^9 J/year)*	***E***	***8.64***	***11.0***

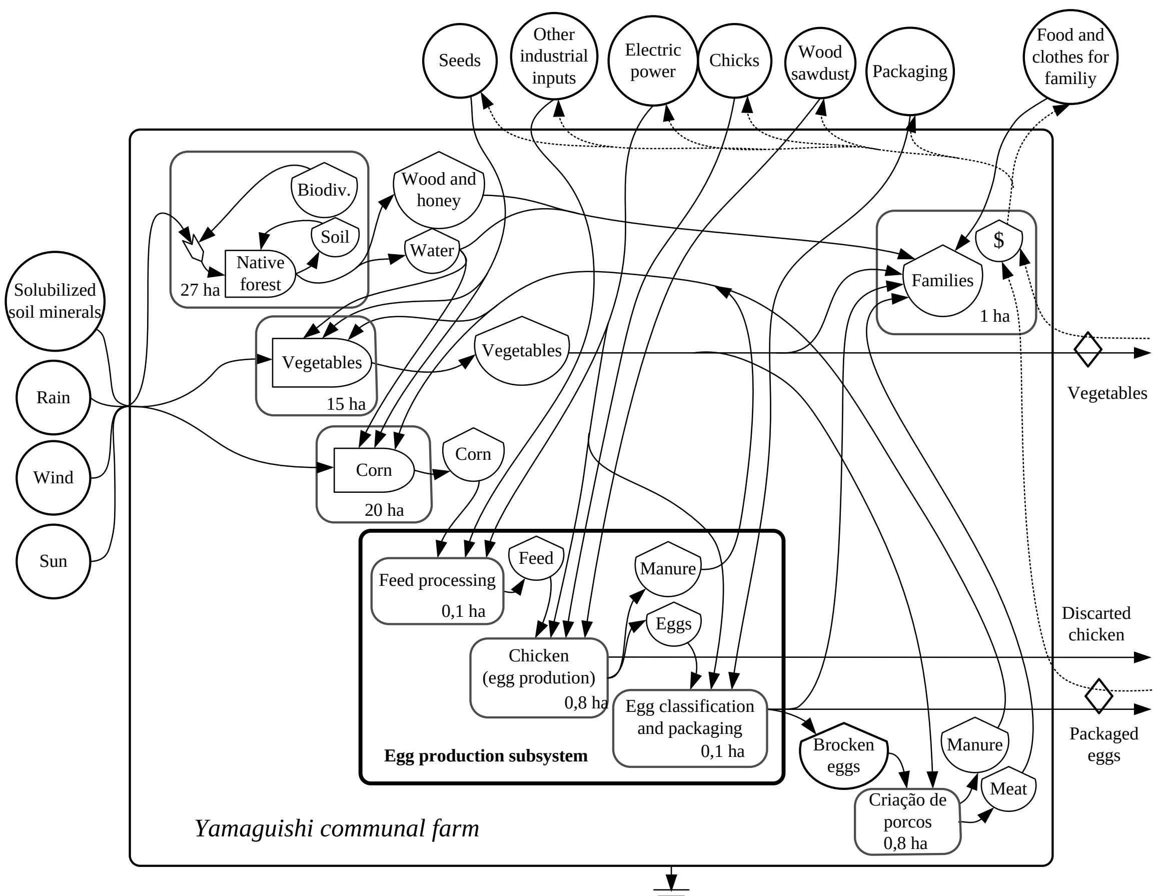

Figure 10. *Systems diagram of organic farm with egg production (9000 hens)*

Table 4. Comparison of emergy indices of poultry farms.

Emergy Indices	Equation	Conventional (USA)	Organic (Brazil)
Transformity (seJ/J)	Tr = Y/E	11.0 E6	1.6 E6
Transformity (seJ/kg)	Tr = Y/E	64.0 E12	9.5 E12
Renewability (%)	% Ren = 100*(R/Y)	1.8%	46.11%
Yield Ratio	EYR = Y/F	1.08	1.64
Investment Ratio	$EIR = F_N/(I+F_R)$	12.27	1.17
Environmental loading Ratio	$ELR= (F_N+N)/(R+F_R)$	47.31	1.17
Exchange Ratio	EER = Y/(US$ * sej/US$)	746	1.29
Renewables mobilization	Benefit=R/F	0.019	0.028
Support area per 100 hens	$SA_{NPP}= (N+FN)/(NPP*BE*Tr)$	3.0 ha	0.35 ha
Total support area (9000 hens)		270 ha	23 ha

DISCUSSION OF NEW EMERGY INDICES USE

The transformity (Tr) of conventional system is higher than organic: the emergy used in the conventional system is higher and the productivity of this system is lower. The renewability (Ren) of organic system is 25 times greater than the conventional: the organic system uses recycling and organic raw-materials that are partly renewable (corn, soy, wheat). The emergy yield ratio (EYR) shows is bigger because of natural resources use by the organic system. The emergy investment ratio (EIR) of conventional system is almost 11 times bigger than the organic and it indicates the great use of non-renewable materials and services from human economy. The environmental loading ratio (ELR) shows a great difference in favor of organic. The organic system shows more productivity and organic eggs have a higher price, and then it has a lower value for emergy exchange ratio (EER); the lower the value of EER the better for the farmer because the ratio (emergy transferred/ emergy received) gets close to unity (fair exchange). The renewable mobilization (R/F) shows that the organic system gets more resources from the local ecosystems and it degrades less. The benefit is bigger for the organic. Finally, the Support area (SA_{NPP}) shows the total absorption area for a system with 100 and 9000 hens. The area for the conventional system is much bigger than for the organic system.

CONCLUSIONS

The proposed new indices are a little more difficult to calculate but they seem adequate to measure: renewability, self-sufficiency, local labor and environmental impact absorption area that are important characteristics of sustainable farming systems. The organic farm partly analyzed in this study will provide better results when analyzed as a whole system including recycling. It was not possible to discuss in the example all the suggestions we made, therefore the study still demands additional effort. Finally, it is recommended to write a new Emergy Folio on Agriculture with a more open scope.

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