SAMEFRAME – SUSTAINABILITY ASSESSMENT METHODOLOGY FRAMEWORK

Geraldo Stachetti Rodrigues[*1], *Mark T. Brown*[2], *Howard T. Odum*[2]

[1] *Embrapa Environment, CP 069, Jaguariúna (SP), Brasil, CEP 13820-000*
[2] *Department of Environmental Engineering Sciences, Box 116350, University of Florida, Gainesville, FL 32611-6350*

ABSTRACT

SAMeFrame is a cross-scale sustainability assessment methodology framework directed at agricultural technology innovation performance evaluation. The system comprises a set of integrated spreadsheets for accounting the emergy balances from the agricultural and livestock production activities at three scales: 1) the farm, 2) the region, and 3) the nation. Data needed to fulfil the requirements of SAMeFrame at the macro scales (country through county) are obtained from the national, regional, and agricultural censuses, while micro-scale data are obtained directly from the farm records. Based on integrated emergy accounting, several performance indices are calculated at all three levels of analysis and displayed numerically and graphically in the assessment spreadsheets. The spreadsheets are used to evaluate impacts of changes in agricultural technology on emergy indices of sustainability. Data from a farm (or other rural activity) are entered into the "farm-scale" spreadsheet and indices are automatically calculated. Comparisons can be made "before and after" technological innovation, or between different technologies. The spreadsheet analysis methodology is demonstrated using data for the USA, Florida, and average conditions for six crops grown in Florida. Spreadsheets may be downloaded from the following URL: http://www.ees.ufl.edu/homepp/brown/eep/. When updated with national and regional data from other regions, they can be used to evaluate agricultural technology innovation in other parts of the world.

1. INTRODUCTION

It is a common practice to decide on the development of plans, projects, and even technology research programs according to economic, technical, and political criteria. Environmental quality, sustainable natural resource use, and socio-cultural impacts seldom receive the required consideration, and when included, they are often considered only from an economic perspective that offers a poor basis for devising alternative, more appropriate development options.

The introduction of sustainability criteria into the decision making process brings about complex conceptual and policy orientation problems. It introduces not only questions concerning the definition of sustainable use of natural resources and the regenerative capacity of ecosystems, but also questions concerning the trade-offs between improvement and growth of economic activities, environmental conservation, and the fair sharing of wealth among the social groups involved.

If sustainability is to be understood, incorporated into decision making, and planned for, it must be quantitatively evaluated. The "Sustainability Assessment Methodology Framework" (SAMeFrame) presented in this paper offers a systemic approach based on the energy flows associated with all change processes brought about by the introduction of new agricultural activities in a rural establishment, especially those associated with technological innovations.

* Telephone: +55 19-38678735, Fax +55 19-38678740, e-mail: stacheti@cnpma.embrapa.br

The system comprises a template for the gathering, documentation, and synthesis of information on sustainable development.

2. ENVIRONMENTAL ACCOUNTING WITH SAMEFRAME

Agro-ecosystems use environmental energies directly and indirectly from both renewable energy flows and from storages of materials and energies that resulted from past biosphere production. Accounting for all inputs to agro-ecosystems, renewable, slow renewable, and non-renewable alike, is imperative if sustainability is to be understood in an environmental context. Farming systems and forest extraction involve both monied and non-monied flows of materials and energy, the totals of which determine sustainability (Brown[1], Rodrigues *et al.*[2]).

Using methods of environmental accounting (Odum[3,4,5]), the flows of both monied and non-monied materials and energy within agro-production systems can be evaluated. The use of materials, energy, labor, and machinery as well as environmental services as both an input and a sink for by-products are evaluated in their appropriate units such as tons, cubic meters, human-hours, joules, etc. and integrated into a common basis using techniques of emergy analysis. Using this common emergy unit, costs, impacts, and changes in natural capital can be summed to evaluate total environmental sustainability (Ulgiati *et al.*[6]).

SAMeFrame is a cross-scale sustainability assessment methodology framework directed at agricultural technology innovation performance evaluation. The system comprises a set of integrated spreadsheets (MS Excel® platform) for accounting the emergy balances from the agricultural and livestock production activities at the farm level, the regional insertion of the farm at the county or State level, and the systemic evaluation of the country and national agriculture (Figure 1).

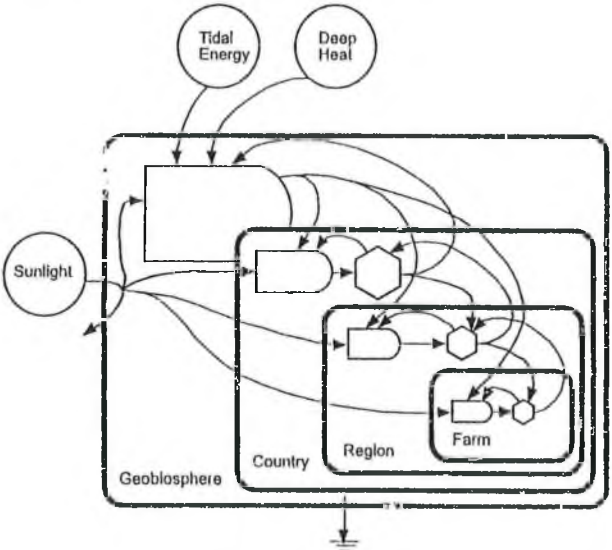
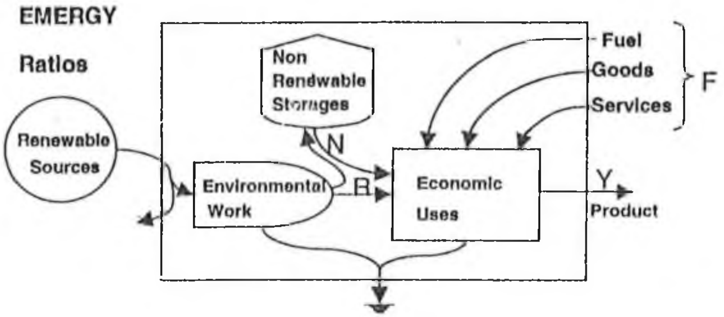


Figure 1. System diagram of the energy flows and transformations at various scales, considered for the assessment of sustainability of rural activities with SAMeFrame

Data needed to fulfil the requirements of SAMeFrame at the macro scales (country through county) are obtained from the national, regional, and agricultural censuses, while micro-scale data are obtained directly from the farm records.

Based on this integrated emergy accounting, a series of performance indices is obtained for all scales and expressed in numeric and graphic format in the spreadsheets, facilitating a circumstantiated assessment of sustainability. Each scale considered in the assessment is described in a general diagram constructed with energy systems language, and some diagrams are used to express summary results of the assessment. Assessing the contributions of an agricultural technology innovation or a rural activity with SAMeFrame involves filling out all required data on input use and production (marked cells in the spreadsheets – download available from http://www.enveng.ufl.edu/homepp/brown/syseco/). All appropriate data from one scale spreadsheet are automatically transported to the next scale, converging to compose the "farm results" spreadsheet. The resulting emergy flows are composed into a series of indices concerning the sustainability of the systems (Figure 2), that can be combined and compared to address issues of concern to public policy.



Product (Yield, Y) = R + N + F

% Renewable = R / (R + N + F)

Nonrenewable to Renewable Ratio = (N + F) / R

EMERGY Yield Ratio = Y / F

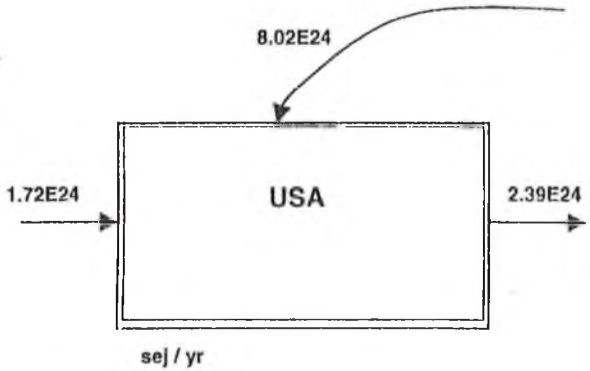
EMERGY Investment Ratio = F / (R + N)

Environmental Loading Ratio = (F + N) / R

Figure 2. Some of the emergy indices composed into SAMeFrame for the assessment of sustainability of rural activities (after Brown et al., 2000).

2.1. Country level assessment

The emergy evaluation of the country establishes the large-scale resource base and economic setting for all productive activities developed in the smaller scales, and must be the first step in the sustainability assessment. A summary diagram of the main energy pathways of the USA constructed with SAMeFrame is presented in Figure 3. The overall energy use and emergy evaluation of the country are combined with the market values of imports, exports, and money flows to define the emergy/money ratio for the national economy. This emergy/money ratio influences all production activities within the country, as well as the exchanges of goods and services between countries.



$$\text{Solar Emergy / Money} = \frac{1.18E25 \text{ sej / yr}}{9.94E12 \text{ \$ / yr}} = 1.19E12 \text{ sej / \$}$$

Figure 3. Summary results of the overall energy use and emergy/money ratio of the USA (after Odum, 1996).

Essential indication of the sustainability of a country is given by the share of emergy that is obtained from the environment, or from nonrenewable sources and storages. The emergy signature constructed with SAMeFrame for the USA is shown in Figure 4.

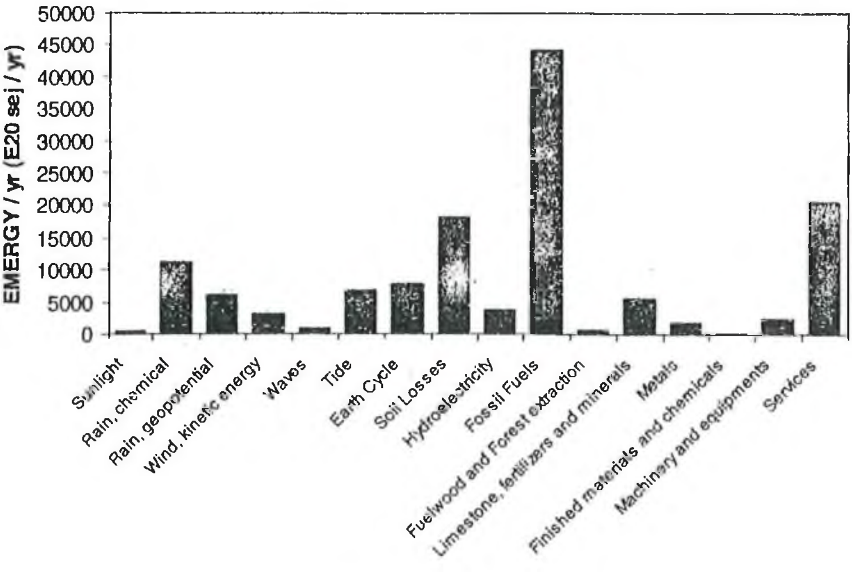


Figure 4. Emergy signature of environment and economy of the USA.

2.2. National agriculture level assessment

The general emergy analysis of the country offers the basis for assessing the National Agriculture and Livestock Production System, which sets the economic and the resources environment for the insertion of the farm. This large scale structuring of rural productive activities determines how the local production of the farm can match the emergy investments characteristic of the whole country, and better rely on special local conditions to improve sustainability. The summary emergy flows comparing natural sources and purchased inputs of the US National Agriculture and Livestock Production System is shown in Figure 5.

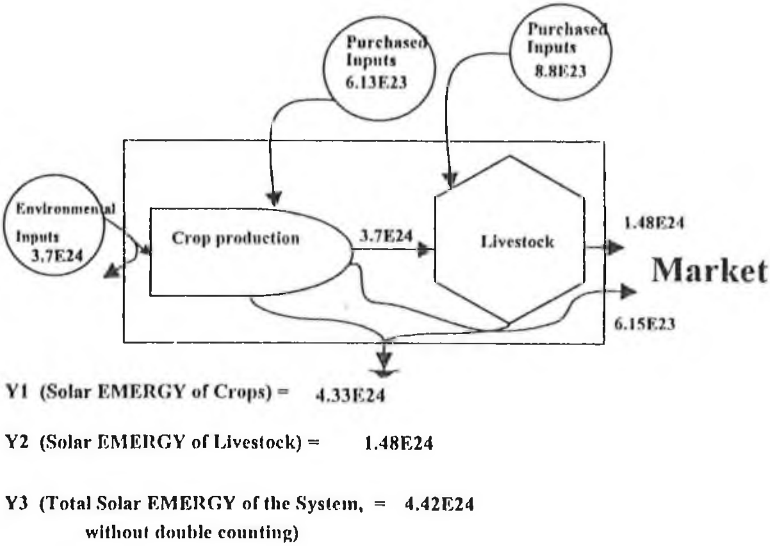


Figure 5. Summary emergy flows of the US national agriculture and livestock production systems (after Ulgiati et al., 1993).

2.3. Crops in national agriculture spreadsheet

The ten most important products in the National Agriculture and Livestock Production System are analyzed in this spreadsheet and the summary results, emergy signature of production and emergy ratios, as well as transformity values are shown in dedicated tables and diagrams. All these large-scale assessments set the basis for comparison with the local production at the farm level (evaluated in specific spreadsheets). Each spreadsheet displays complete tables with emergy ratios and diagrams to facilitate such comparisons.

2.4. County level spreadsheet

The emergy evaluation of the county (as inserted within the larger scale of the country and national agriculture) establishes the local resource base and economic setting for the productive activities developed at the individual farm scale. The overall energy use and emergy evaluation of the county are combined with the market values of imports, exports, and money flows to define the emergy/money ratio for the local economy. This emergy/money ratio influences all production activities within the county, as well as the exchanges of goods and services between the county and the national economy. Essential indication of the sustainability of a county is given by the share of emergy that is obtained from the environment, or from nonrenewable sources and storages. In the presently available construction of SAMeFrame, the county level is represented by the State of Florida, which emergy signature is shown in Figure 6.

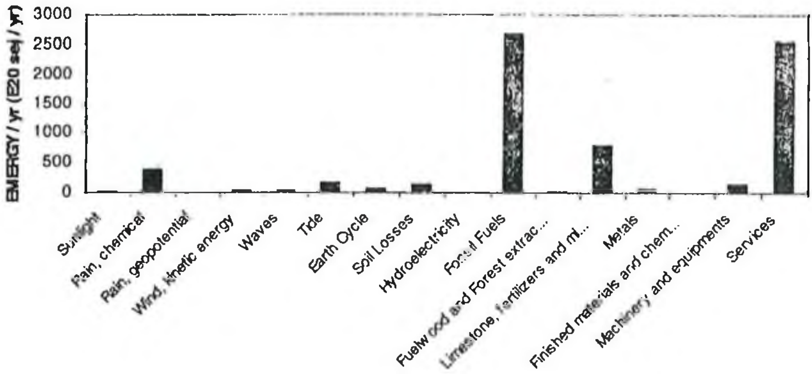


Figure 6. Emergy signature of environment and economy of Florida.

2.5. Farm results spreadsheet

The specific objective of SAMeFrame is the assessment of the contribution brought about by any given technological innovation or rural productive activity to the sustainability of the farm. The procedure involves the cross-scale emergy evaluation of the farm, as affected by the technological innovation or productive activity, and its effects on the insertion of the farm into the local market and the national economy. The contribution of any given technological innovation or rural productive activity to the sustainability of the farm depends on how it influences the local emergy allocation and the matching of sources relative to the larger scale emergy investments characteristic of the county (at the local level) and the whole country.

Technological innovations and productive activities that take advantage of local emergy sources and storages, or favor feedback flows that improve emergy use efficiency, will increase the overall sustainability of the farm. The final assessment of a technological innovation or a productive activity is obtained by comparing the emergy ratios and sustainability indices of the farm, before and after technology adoption or activity introduction, as well as how these changes influence the farm performance relative to the larger scales presented in the respective country and county spreadsheets.

2.6. Farm crops and livestock spreadsheets

The most important crops and livestock produced in the farm are analyzed in these two SAMeFrame spreadsheets, and the results are linked to compose the "farm results" spreadsheet. All the summary results, emergy signature of each production process, emergy ratios, as well as transformity values are shown in dedicated tables and diagrams in these farm crops and livestock spreadsheets.

3. RESULTS

The composition of SAMeFrame for the USA, the national agriculture and selected agricultural production systems (corn, soybean, wheat, sugarcane, cotton, oranges, and cattle), the State of Florida, and the main Floridian agricultural systems (the same selected for the national agriculture) representing a typical farm, resulted in a printed report with over seventy pages. The report offers a complete emergy database of the economy and resources use from the farm to the national level, contributing towards the assessment of sustainability of the agricultural production systems.

The report shows that the State of Florida provides important resource flows to the country, especially as mined phosphates. The emergy signature of the State of Florida, however, shows the dependence on imported fuels and services, which constitute most of the inputs for the State economy. In general, the transformities of agricultural production in Florida are considerably larger than those characteristic of the national agriculture, which indicates comparatively less sustainable production systems at the state level.

4. CONCLUSION

Contrasting with economic benefit-cost analyses normally carried out to assess the performance of agricultural activities and technology contribution toward sustainability of farm systems, which are highly influenced by transitory aspects of the market and do not account for environmental issues in general, the integrated emergy assessment made possible by SAMeFrame explicitly considers the cross-scale matching of environmental and purchased input uses. Accordingly, the results obtained with SAMeFrame point out that soil and water conservation practices are crucial for sustainability, and that these practices should be greatly stimulated. However, resources for such are difficult to come by, because the emergy/money ratio characteristic of rural areas imposes that both the farms and the national agriculture, function as net providers of large amounts of wealth to the urban markets.

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