Systems Modeling of Brazilian Sustainability with Emergy Flows Diagrams[1,2]

Paul Safonov*, Vito Comar**, and Enrique Ortega*

* Institute of Control Sciences, Russian Academy of Sciences, Moscow
E-mail: Paul.Safonov@ipu.rssi.ru

** Laboratory of Ecological Engineering and Applied Informatics,
School of Food Engineering, State University of Campinas, Brazil
E-mail: ortega@fea.unicamp.br

Rapid and uncontrolled population growth, low average income per capita, industrial development dependent on external market, and extensive degradation of natural resources - this is Brazil in the end of the 20th century. The country, known to be the "lungs" of the planet, is loosing its Amazonian tropical forests at an extremely high rate, up to almost 30.000 square km per year as in 1994/1995[3]. Deforestation, and erosion of agricultural lands becomes a danger already for the living generation. From another side, very heterogeneous income distribution, prevailing of young people in the age structure of Brazilian population, and low educational level of more than 50% of them, are respectively the factors of escalating severe socio-economic problems.

Awareness of these problems urges elaboration and adoption of environmental policies which might lead to sustainability at regional and national scale, as a consequence of global changes in attitudes to the world's future. The adoption of a systemic view of the relationship between ecological and economical factors can best assist in the definition and analysis of such policies.

The approach used deals with macromodeling at country level, based on systems diagrams of e*m*ergy[4] flows (Odum, 1994). Emergy analysis (Odum, 1996) is a valuation method, which provides a general category - emergy - for measurement of heterogeneous flows within the ecosystem, as well as an instrument to account for interactions between physical flows in nature and the economy and monetary flows within internal and external markets of natural resources and goods. This paper presents a summary of the study (Safonov, Ortega, Comar, 1999), which tackles the urgent environmental economic problems of Brazil at federal and international level, and attempts to find some general policy recommendations for sustainable development based on systems macro models.

Earlier developed models for Brazil (Odum, 1986; Comar, 1994) and for its Amazon region (Brown, 1986) were used as a reference for our model specification. Brazil can be viewed geographically in terms of two large regions: North-West, and the South. The former is the

---

[1] A chapter in "*Implementing Ecological Integrity: Restoring Regional and Global Environmental and Human Health*" (Philippe Crabbé, Alan Holland, Lech Ryszkowski and Laura Westra, eds), Kluwer, NATO Science Series, Environmental Security, 2000

[2] This work was made possible through the financial support of FAPESP, São Paulo, Brazil.

[3] Brazilian National Institute for Space Research - INPE: www.inpe.br).

[4] E*m*ergy, spelled with an "*m*", is defined as all the available energy that was used in the work of making a product expressed in units of one type of energy. The unit of e*m*ergy is the emjoule. If the type of e*m*ergy is solar , the unit of solar e*m*ergy is the solar emjoule. The concept was first used in 1967 and renamed in 1983 (Odum, 1986; Scienceman, 1987).

Amazon basin with majority of rural population and vast forests and other natural resources, most of which are still untouched. The South is more agriculturally and industrially developed, with many urban centers with rather high population level and density. The importance of the Andes mountains for the Amazon Basin should be emphasized as they supply headwaters to maintain the net water balance of the river and net sediment balance, ultimately contributing to long range land fertility in many areas (Odum, 1986).

Following the above mentioned experience, a modification of the ecological economic model of Brazil was designed as a research and educational tool, in order to study the problems of natural resources degradation, population growth, economic development, and money circulation. The model is driven in part by internal storages of energy and resources, and partly by the world economic system. External energy sources include sunlight and rain. The renewable resources are forests, when non-renewables are basically fossil fuels, partly exported from the world market.

The emergy diagram (Figure 1) gives the structure and main pathways of emergy in the model. It is mainly based on the model for Amazon basin (Brown, 1986), adding population (N) and money (M) state variables, with their respective interrelations in the overall system. Population modeling accounts for fertility and mortality rates, and migration processes influenced partly by the availability of food and assets. An additional state variable of the country's "image" is to be included as an integrated indicator of accumulated behavioral aspects of population, determining future development patterns.

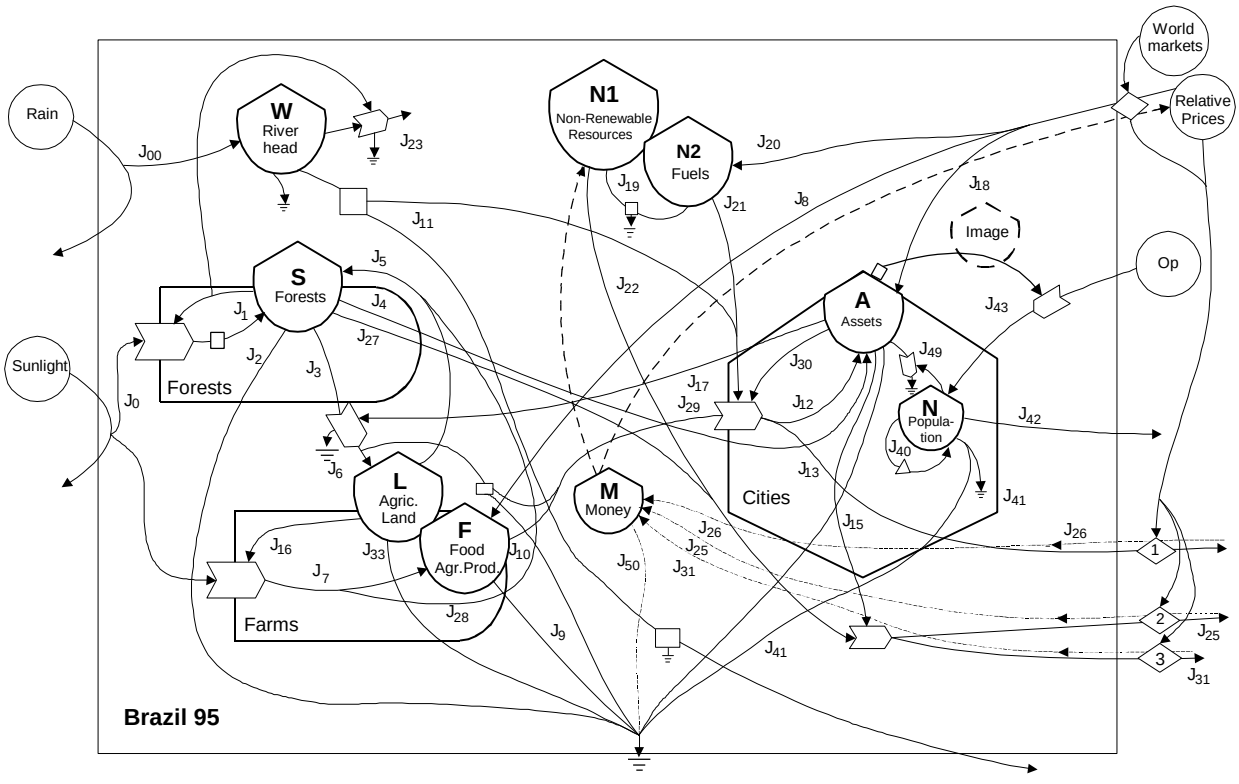

Figure 1. *Emergy flows diagram of the ecological-economic development model of Brazil*

The available statistical data for Brazil, along with results of emergy analysis for 1995 (Coelho, Comar, Ortega, 1999) were used for model's calibration, which is described in detail in (Safonov, Ortega, Comar, 1999), where the *Basic* program used for modeling is also given.

Several scenarios for a long time term (from 50 to 150 years) were simulated to analyze the features of the system and its sensitivity to different parameters in order to assess possible perspectives for sustainable development. For this purpose we tried to select relevant scenario considerations, having in mind "ecologically sustainable socio-economic development". Depending on definition and concept of "*sustainability"* different results could be obtained, so we should mention that here we would focus here mainly on achieving stabilization of the Brazilian population growth and stopping degradation of Amazonian rain forests at reasonably acceptable levels. Such targets, though, should be put in the perspective of sustaining and possibly developing the national economic wealth, including rational use of non-renewable natural resources. The model was appropriately adjusted in its demographic component, where population dynamics was modeled using several control variables: birth and mortality rates, emigration and immigration rates, consumption rate of assets by population, and decrease overpopulation factor.

Reference scenario: The parameters estimated were used for the modeling period of 100 years. Population grows exponentially with "business as usual" rates from 1995 Census. Land rotation rate is low, and extensive use of forests continues. As a result, substantial economic development (assets, food and agricultural lands) is characteristic for the first 50 years of the modeling term, but it is leveling down and even turns into decline in the course of the forests and non renewable fossil fuels exhaustive exploitation. Here, even with growing land use, food stocks decrease.

Scenario 1 tests a possible step to a more stable development in two directions: restricted population growth and recovery of rain forests. A consequence of this land rotation is a decline in agriculture and its products (food and fiber). Assets accumulation respectively slows down, which would mean lower standard of living for the population.

Scenario 2 advises a more "socially oriented" policy: a moderate land rotation, and at the same time more demanding patterns of consumption along with intensive population control, thus providing it a higher standard of living. The outcome is rather different from Scenario 1, namely in growth of economic indicators. But this requires a more substantial load on natural resources and higher use of lands for agriculture.

Scenario 3 models rather a hypothetical situation when the total population growth has almost stopped. The consumption rate is set at sufficiency level within a moderate economic output. Time horizon of 150 years is used for this scenario to demonstrate the leveling tendency. As a result, the overall development is stabilizing at the recent level, which can be interpreted that the quality of life would not improve with time. Such a self-sufficient ecological economic development could be foreseen as one of the scenarios of sustainability for the future, if the society is ready to sacrifice the technical change and level of services. Many researchers working on sustainable development argue though that such a perspective should be seriously considered in order to prevent ecological catastrophe, as an alternative to oscillating development with periods of rapid growth and deep stagnation.

In the ecosystem health and ecological integrity debate context, these results would rather argue for a conservation approach, when preservation of the balance in the ecological-economic system is given the highest priority. On the other hand, in order to study policy mechanisms, such instruments as environmental services pricing and taxation are to be further analyzed, to help assess economic background and feasibility of possible scenarios for sustainable development.

References

Anuário Estatístico do Brasil, 1996 (Statistical Yearbook of Brasil, 1996), Instituto Brasileiro de Geografia e Estatística - IBGE, Rio de Janeiro, p. 1-1 – 8-32.

BROWN M.T. (1986) Spatial Simulation of Economic Development in the Amazon Basin, in *Energy Systems Overview of the Amazon Basin*, Odum H.T., Brown M.T., Christianson R.A., Center for Wetlands, University of Florida, Gainesville, 1886, pp. 64-81

COELHO O., COMAR V., ORTEGA E. (1999), Emergy Balance of Brazil for 1995, in *Introduction to Ecological Engineering with Brazilian Case Studies*, Ortega E., Safonov P., Comar V. (eds), UNICAMP, Campinas.

COMAR, V. (1994) *An Emergy Evaluation of the Central Amazon Town of Itacoatiara, its Plywood and Veneer Industry and the Foodplain of Madeira River Basin*. 146 pg. Dissertação (Mestrado em Ecologia) INPA - Universidade do Amazonas (FUAM).

ODUM, H.T. (1986) Energy Analysis Overview of Brazil, in *Energy Systems Overview of the Amazon Basin*, Odum H.T., Brown M.T., Christianson R.A., Center for Wetlands, Univ. of Florida, Gainesville, pp. 64-81

ODUM, H.T. (1994) *Ecological and General Systems*: an introduction to systems ecology. Colorado. University Press of Colorado. 644 p.

ODUM, H.T. (1996) *Environmental Accounting: emergy and environmental decision making*. John Wiley & Sons, 370 p.

SAFONOV P., COMAR V., ORTEGA E. (1999), Energy and Emergy Based Dynamic Modeling of Brazil: Conceptual Considerations and Scenarios for Sustainable Development, in *Introduction to Ecological Engineering with Brazilian Case Studies*, Ortega E., Safonov P., Comar V. (eds), UNICAMP, Campinas.

Os Ecossistemas Brasileiros e os Principais Macrovetores de Desenvolvimento. Subsídios ao Planejamento de Gestão Ambiental. (1995), Ministério deo Meio Ambiente, dos Resursos Hídricos e da Amazônia Legal. PNMA, Brasilia, MMA, 108 p.