Energy and Emergy Based Dynamic Modeling of Brazil: Conceptual Considerations and Scenarios for Sustainable Development[1]

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Abstract

This paper tackles the urgent environmental economic problems of Brazil at federal and international level, and attempts to find some policy recommendations based on systems macromodeling using energy flow diagrams.

The previous emergy analysis and modeling studies for Brazil (Odum 1986) and for its Amazon region (Brown, 1986), are used as a reference, and a modification of a model is designed as a research and educational tool, in order to study the basic problems of natural resources degradation, population growth, economic development, and money circulation. The available statistical data for Brazil, along with results of emergy[2] analysis for 1995 (see the study of Coelho, Comar, Ortega, 1998) are used for model's calibration.

Several scenarios were simulated for a considerably long time term to analyze the features of the system and its sensitivity to different parameters in order to trace possible perspectives for sustainable development.

1. Introduction

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, which is known to be "lungs" of the planet, is loosing its Amazonian tropical forests at an extremely high rate, up to 29059 km^2 per year in 1994/1995[3]. Deforestation, and erosion of agricultural lands becomes a danger already for the living generation of Brazilians. From another side, very heterogeneous income distribution, prevailing of young people in the age structure of Brazil 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 of such policies.

This study deals with macromodeling at country level, based on systems diagrams of emergy 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.

1 This work was made possible through the financial support of FAPESP, São Paulo, Brazil.
2 EMergy, 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 EMergy is the emjoule. If the type of EMergy is solar , the unit of solar EMergy is the solar emjoule. The concept was used in 1967b and renamed in 1983 (Odum, 1986; Scienceman, 1987).
3 Brazilian National Institute for Space Research - INPE: www.inpe.br).

2. Dynamic Ecological-Economic Macromodeling of Brazil

This section gives an overview of the state-of-the-art in emergy-based modeling of Brazil and its main regions, describes the most important considerations which are taken into account for the model under development, and displays the systems diagram of the model and its dynamic equations.

2.1. Main Prerequisites and Considerations for Modeling of the Brazilian Development

The previous studies for Brazil (Odum 1986, Comar 1994) and for its Amazon region (Brown, 1986), are used as a reference for our further modification of a model, in order to study the basic problems of natural resources degradation, population growth, and economic development.

Brazil can be viewed geographically (Fig. 1) in terms of two large regions: North-West, and the South. The former is the Amazon basin with mostly rural population and vast forest and other natural resources, most of which are still undeveloped. The South is more agriculturally and industrially developed region with many urban centers with rather high population level and density.

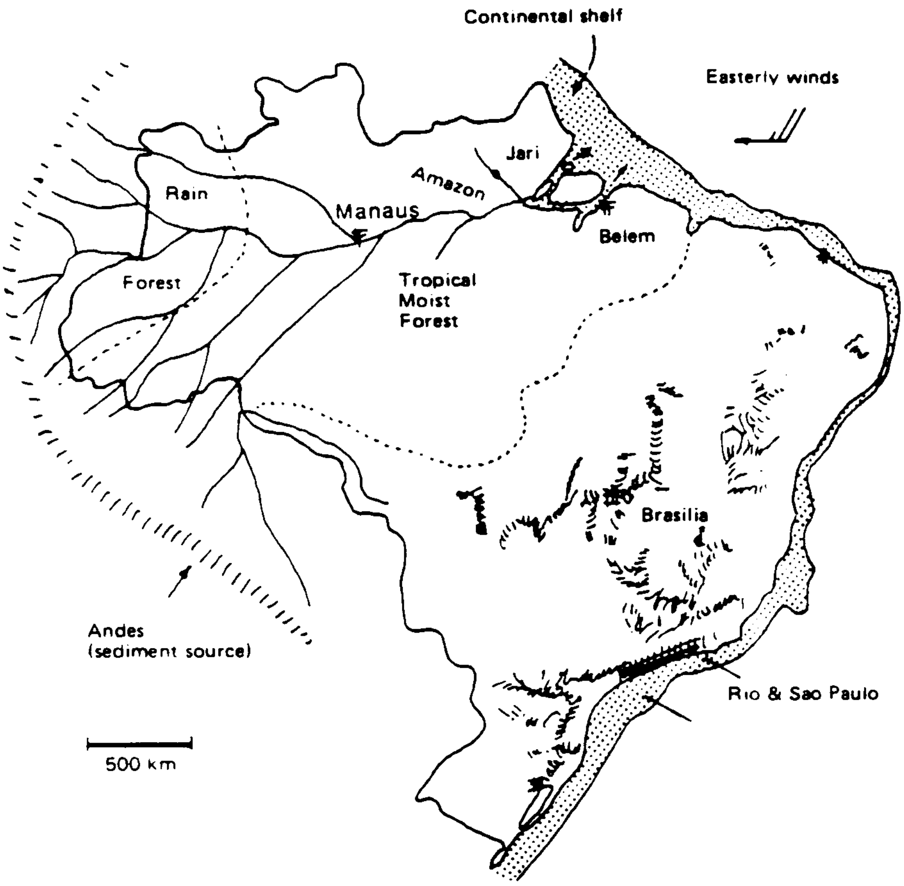

Figure 1. Overview map of Brazil (Odum, 1986)

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).

2.1.1. Demographic aspect of the development

The dynamics of the Brazilian population and its structure over its main five regions is summarized from several statistical sources and studies as presented at Table 1.

Table 1. Population dynamics of Brazil and its regions (mln. people)

Year	Brazil	Average annual growth rate (%)	South-East	North-East	South	Central West	North
1600	0.100						
1650	0.170	1.4%					
1700	0.350	2.1%					
1750	1.500	6.6%					
1800	3.300	2.4%					
1850	7.230	2.4%					
1900	17.400	2.8%	7.8	6.7	1.8	0.4	0.7
1920	30.600	3.8%	13.7	11.2	3.5	0.8	1.4
1940	41.200	3.5%	18.3	14.4	5.7	0.8	1.4
1950	51.900	2.6%					
1960	70.100	3.5%	30.6	22.2	11.8	2.9	2.6
1970	93.100	3.3%					
1980	119.000	2.8%	51.7	34.8	19.0	7.5	5.9
1991	146.800	2.1%	62.7	42.8	22.1	9.4	10.3
1995	152.347	0.9%	66.5	45.1	23.2	10.3	6.9

Sources: Anuário Estatístico do Brasil, 1996; Os Ecossistemas Brasileiros…, 1995; Buescu, 1970.

Figure 2 displays the chart of overall Brazilian population growth, and its exponential behavior can be clearly observed. The value for 2000 is extrapolated, and some significant decrease of the growth rate can be observed after 1990, as an indicator of probable leveling of this exponential tendency. In fact, as it can de seen from Table 1, the total growth rates start to decrease monotonously since 1965 and this is also proved by Figure 3, which explains this phenomena by decreased fertility rates as average per country. However, according to the region and family income, this indicator is varying a lot. Another peculiarity of population is migration from the poor North to southern parts of Brazil (see Table 1).

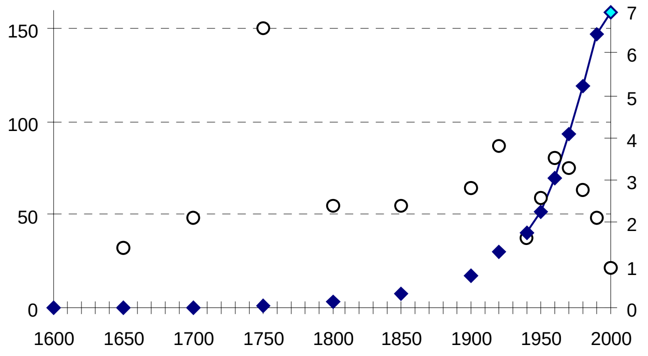

Figure 2. Population growth in Brazil.

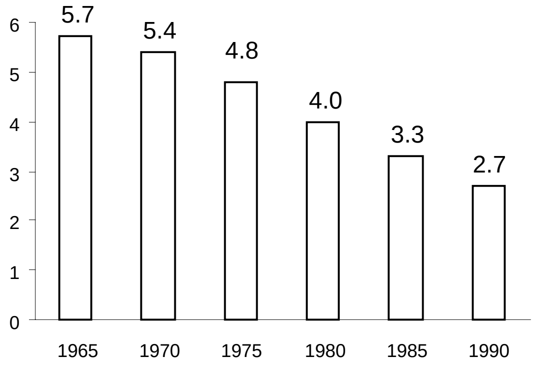

Figure 3. Average number of children per Brazilian family. (Os Ecossistemas Brasileiros…, 1995 p.7)

2.1.2. State-of-the-Art in Emergy Analysis and Modeling for Brazil and its Regions.

The emergy analyses and modeling for Brazil (Odum, 1986) and Amazon region (Brown, 1986) are described here to bridge these former experiences to the up-to-date information and recent situation in the World and Brazilian development.

Brazil, 1980

Perspectives on Brazil were analyzed (Odum, 1986) with overview systems diagram given in Figure 4. On the left, the forest sector is shown, largely of the Amazon. Pathways of development of these lands into croplands and pastures partly under rotation and shifting cultivation are pictured. The diagram shows the rural people based on and controlling the rural sectors. Included are also important marine ecosystems on the continental shelf at the Amazon mouth (see also Figure 1).

The large urban population on the right of the diagram (Figure 4) is shown with its resource base from the rural sectors increasingly based on food, fiber, fuels, mining, and electricity (at that time almost no hydroelectric power plants existed in the Amazon region). Feedback loops from the right to the left are the liquid fuels, fertilizers, technological inputs, labor and rural land uses. A more integrated coupling of rural and urban sectors facilitated by new transportation infrastructures maximizes the power of the region with consumption of resources exceeding the environmental production of these resources. On the far right are shown the trade balances and other fiscal exchanges such as international loans. This diagram, developed by H.T. Odum during his work at IIASA, Laxenburg, Austria, in 1983, aimed also to "help show the way Amazon destiny is part of accelerating national organization, ultimately based on excess consumption crescendo of the western world" at that time (Odum, 1986). Though there exists opinion that the recent situation is shifting to recognition of the Brazilian international debt having been already paid several times indirectly that, perhaps, will be followed by respective political consequences in the future), still the issue of loans is of importance for further development considerations, as the debt remains a substantial burden on the economy and population of Brazil.

Odum's 1986 analysis showed that the most important contributors to the combined economy of environment and humanity of the national economy are the rain and the inflowing river from the Andes including the sediments transported from the Andes. These drive many other flows evaluated separately such as food production, hydroelectric power, and coffee. The analysis showed the importance of preserving the water, sediment, forest regeneration system, finding ways to couple it to agricultural, forestry, and other economic yield systems without losing the environmental service, especially the sources of high embodied energy, a measure of their relevant role in the system.

In Figure 5 the separated flows are aggregated further to show the high fraction of renewable sources. This suggests that Brazil's economic development could be much more permanent than the fossil fuel-based developments in much of the world's present economic centers that are fossil fuel based (Odum, 1986). The estimation of the ratio of the emergy to dollars circulating in the gross national product was calculated in (Odum, 1986) to be of 2.5 times higher than of the USA, so that the real standard of living in Brazil could be estimated as 2.5 higher than from the comparison of incomes would indicate. The emergy per person is large when environmental resources are included.

Either on a money or an emergy basis, the exports and imports are a small proportion to the total system (imports are only 9%), such that Brazil could be considered to have a high degree of self-sufficiency.

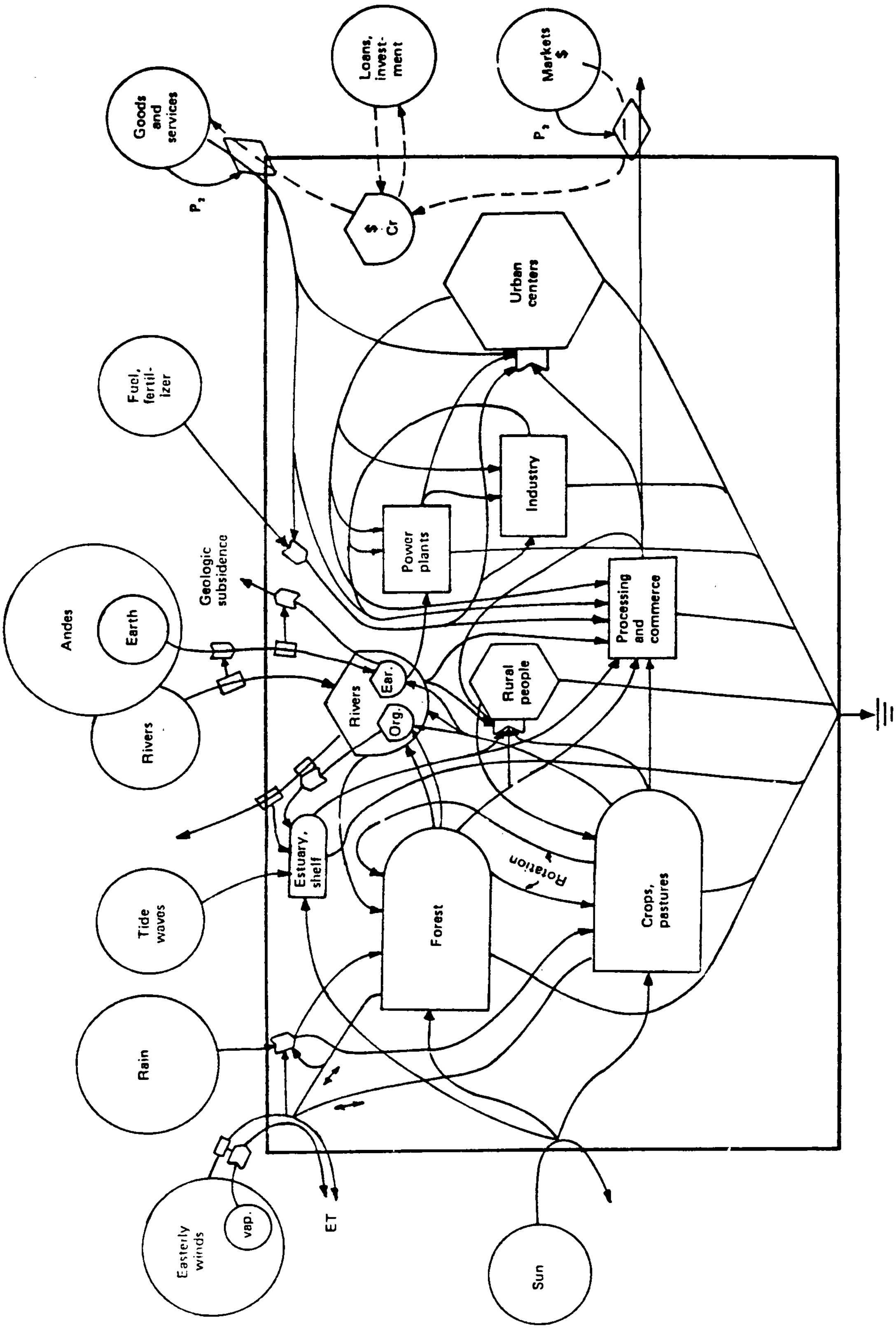

Figure 4. Systems diagram of the model of Brazil (Odum, 1986)

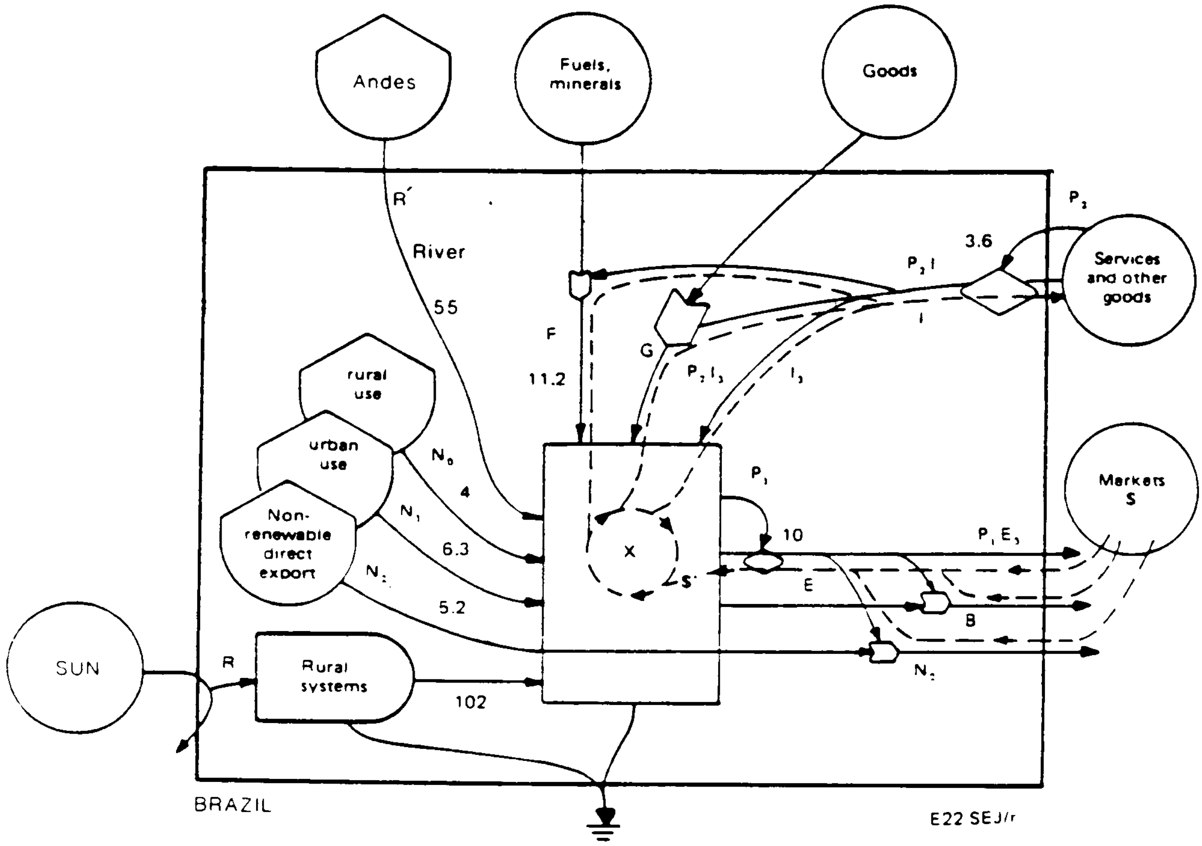

Figure 5. Summary of the embodied energy in Brazil (Odum, 1986).

The ratio of exports to imports was 1.025, indicating little imbalance in emergy flows. The imbalance of payments in money terms often concerns economic planners, but the imbalance in emergy in many undeveloped countries is often many times greater with much of the value of raw resources going unrecognized to stimulate other economies. In the 1980 analysis this was not the case for Brazil (Odum, 1986).

The rapid economic growth of Brazil's economy was almost unaffected by the OPEC oil price jump in 1972 because the economic basis of Brazil's development was internal. Only when the large foreign loans were added the economy underwent severe problems (Odum, 1986). The author suggested that the solution could be to recognize the embodied energy basis for foreign exchange rather than the international dollar and restructure payments, which could help restore Brazil to economic viability and readily generate the means to repay the loans. A sensible development of the Amazon requires a healthy Brazilian economy. This could follow a better understanding the real internal basis of its economic growth (Odum, 1986).

Amazon Basin, 1980

M. T. Brown (1986) had analyzed the interplay of the main components the Amazon Basin. A model (Figure 6) was developed that synthesized the main features of economy and nature of the basin. Diagram shows the rain forest, developed lands that are drawn from the forest lands and the storage of urban assets. The river is included as a storage of potential energy in its head waters. Two storages of resources are introduced: mineral resources, having long turnover time, and fuel resources having a relatively short turnover time.

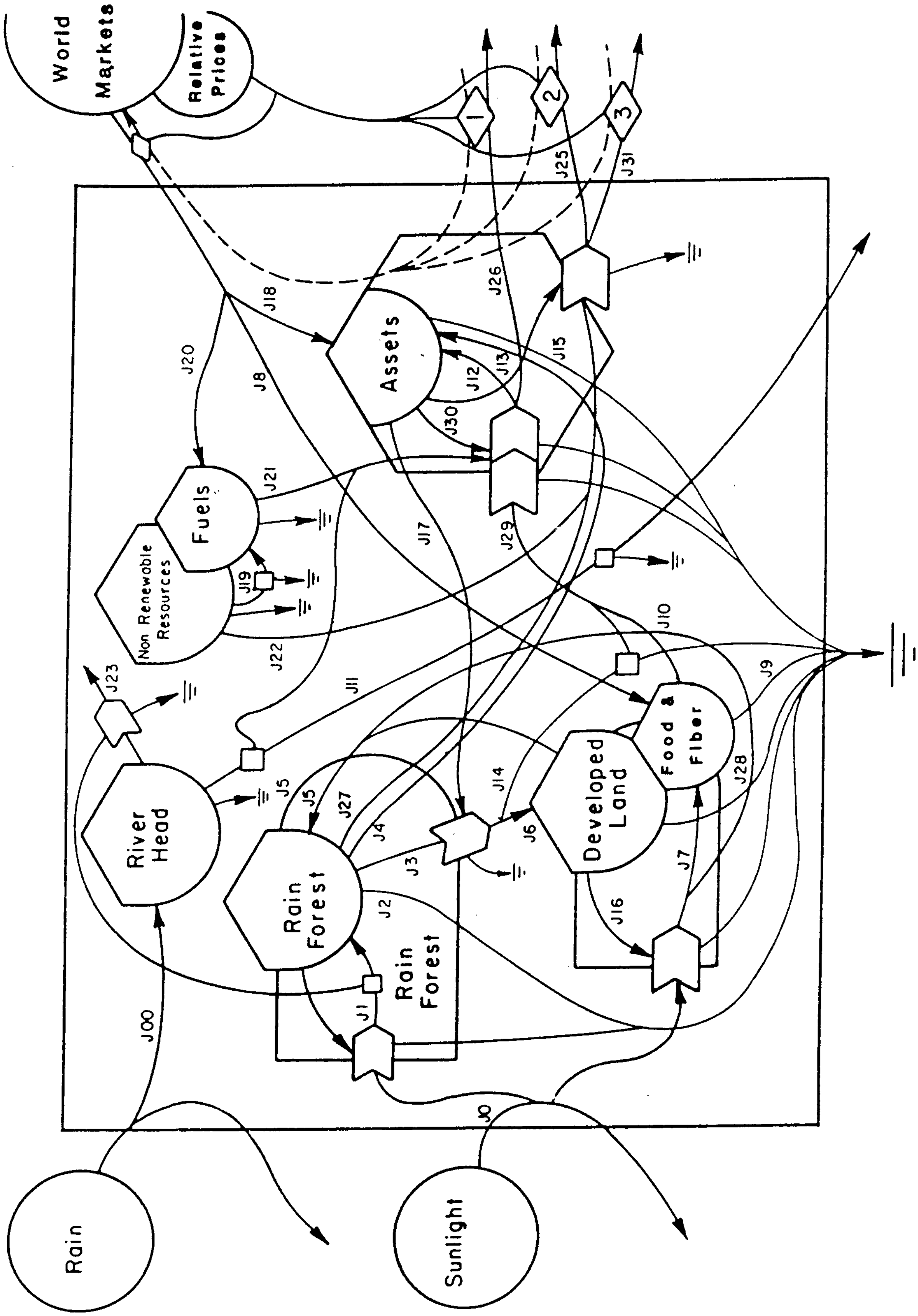

Figure 6. Simulation model of economic development in the Amazon Basin (Brown, 1986).

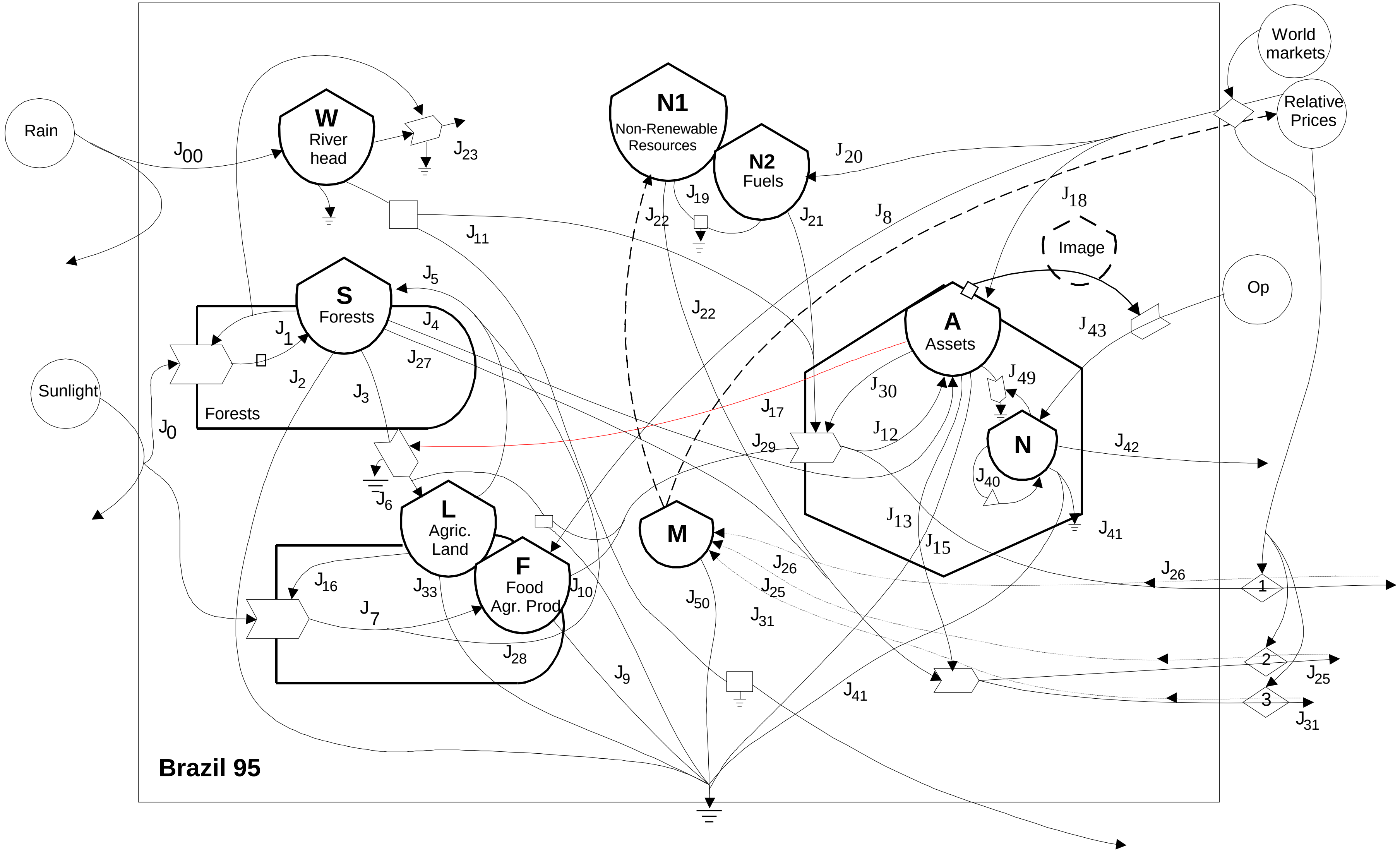

Figure 7. Energy diagram of the ecological-economic development model of Brazil

Native forests are removed turning into developed land areas through the interaction of assets. And developed lands return as successional forest areas when abandoned. Their river head is tapped and utilized as an energy source in the productive processes of the urbanized areas. Exports include:

1) manufactured goods,
2) minerals and other unrefined materials, and
3) lumber and other forestry products.

Moneys received from their sale is utilized to purchase goods, fuels and services from world markets. In this way availability of imports is directly related to the sale of exports. (Brown, 1986). The study of Brown gives a comparison of several computational, as well as it further details the analysis using spatial simulations, which are not considered in our paper.

2.2. Energy Diagram of the Brazil Model Based on 1995 Data

Following the above described experience, the model of the ecological economic development of Brazil was modified as presented in this paper. It 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 mainly fossil fuels, partly exported from the world market.

An energy diagram (Figure 7) gives the structure and main pathways of emergy in the model. It is mainly based on the model for Amazon Basin (Brown, 1986) - Figure 6, adding population (N) and money (M) state variables, with their respective interrelations in the overall system.

Population is modeled, accounting 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 planned to be included as an integrated indicator of accumulated behavioral aspects of population, determining future development patterns.

3. Statistical Information and Calibration of the Model

In this section the available statistical data for Brazil is used to identify the energy flows in the above specified model. Basic source of the information is the Brazilian emergy analysis for 1995 (Coelho, Comar, Ortega, 1998). The model's calibration is done according with this information and several assumptions are made on the behavior of the overall ecological-economic system.

Table 2 below gives the procedure for the estimation of parameters and coefficients derived from the energy flows in the system. *Excel* spreadsheets were used for calculations and the names of sources, stocks, and flows, correspond to the energy diagram on Figure 7 above, as well as to the *Basic* program used for modeling (see Appendix). It should be noted that most of the data from Table 2 was scaled by factor 1E+10.

The calibration of the model was made by heuristic adjustment of these parameters (mind difference of parameters values between their "original" estimations in Table 2 based on statistical sources, and their calibrated values as used in the *Basic* program, see Appendix).

Table 2. Spreadsheet for calculating and calibrating coefficients for Brazil's Model based on 1995 Census data (IBGE, 1996)

<u>SOURCES AND STOCKS</u> **(initial values =1995)**	**Symbol**	**Value**	**Unit**
Assets	A =	5.40E+05	Cal
Developed Land	L =	2.32E+02	m2
Food and Fibre	F =	2.22E+04	Cal
Non Renewable Resources	N1 =	1.72E+11	Cal
Fuels	N2 =	5.16E+04	Cal
Rain forest	S =	4.00E+07	g
River Head	W =	1	
Rain Input	A1 =	0.85	
Solar Energy Input	A2 =	0.85	
Non Renewable Resources	R1 =	1.00E-05	
Fuels	R2 =	4010	
World Market Price	P0 =	3.71176E+12	
Price 1	F1 =	0.053	
Price 2	F2 =	0.017	
Price 3	F3 =	0.92	
Goods and Services	G =	100	

<u>COEFFICIENTS</u>

Flux Equation	**Value**	**Coefficient**	**Value**	**Formula**
J00 = A1 =	0.85			
A2 =	0.85			
K0 =	4.769E-11			
L0 =	6.78E-03			
S1 = A1*(1+K0*S)	8.52E-01			
S2 = A2*(1+L0*L)	2.19E+00			
J1 = K1*A1*S =	1.07E+05	K1=	3.15E-03	K1 = J1/(A1*S)
J2 = K2*S =	4.00E+05	K2=	1.00E-02	K2 = J2/S
J3 = K3*S*A =	6.60E+04	K3=	3.06E-09	K3 = J3/(S*A)
J4 = K4*S =	3.18E-01	K4=	7.95E-09	K4 = J4/S
J5 = K5*(L + A2*L) =	1.80E-01	K5=	4.19E-04	K5 = J5/(L +
J6 = K6*S*A =	1.82E+00	K6=	8.43E-14	K6 = J6/(S*A)
J7 = K7*A2*L =	4.48E+03	K7=	2.27E+01	K7 = J7/(A2*L)
J8 = K8*I*F1 =	4.58E+03	K8=	2.06E+01	K8 = J8/(I*F1)
J9 = K9*F*F =	8.96E+02	K9=	1.82E-06	K9 = J9/(F*F)
J10 = B0 = G0*PO =	2.22E+04	G0=	5.98E-09	G0 = B0/P0
J11 = B1 = G1*W =	4.70E+07	G1=	4.70E+07	G1 = B1/W
J12 = B2 = G2*PO =	2.19E+04	G2=	5.90E-09	G2 = B2/P0
J13 = B3 = G3*S =	3.11E+04	G3=	7.78E-04	G3 = B3/S
J14 = B4 = G4*S*A =	1.09E+03	G4=	5.05E-11	G4 = B4/(S*A)
J15 = B5 = G5*A*A =	5.40E+03	G5=	1.85E-08	G5 = B5/(A*A)
J16 = B6 = G6*L*A2 =	1.16E+01	G6=	5.88E-02	G6 = B6/(L*A2)
J17 = B7 = G7*A*S =	5.40E+03	G7=	2.50E-10	G7 = B7/(A*S)
J18 = B8 = G8*I*F2 =	5.72E+03	G8=	8.01E+01	G8 = B8/(I*F2)
J19 = B9 = G9*R1 =	3.39E+04	G9=	3.39E+09	G9 = B9/R1
J20 = C0 = H0*I*F3 =	5.16E+04	H0=	1.33E+01	H0 = C0/(I*F3)
J21 = C1 = H1*P0 =	8.55E+04	H1=	2.30E-08	H1 = C1/P0
J22 = C2 = H2*A*R1 =	8.95E+08	H2=	1.66E+08	H2 = C2/(A*R1)
J23 = C3 = H3*W =	1.24E+06	H3=	1.24E+06	H3 = C3/W
J24 = C4 = H4*P0 =	4.44E+01	H4=	1.20E-11	H4 = C4/P0
J25 = C5 = H5*A*S =	8.14E+08	H5=	3.77E-05	H5 = C5/(A*S)
J26 = C6 = H6*P0 =	1.46E+04	H6=	3.93E-09	H6 = C6/P0
J27 = C7 = H7*A*S =	7.70E+01	H7=	3.56E-12	H7 = C7/(A*S)
J28 = C8 = H8*A2*L =	2.32E+00	H8=	1.18E-02	H8 = C8/(A2*L)
J29 = C9 = H9*P0 =	2.36E+04	H9=	6.36E-09	H9 = C9/P0
J30 = D0 = N0*A*R1 =	5.40E+00	N0=	1.00E+00	N0 = D0/(A*R1)
J31 = D1 = N1*A*R1 =	1.11E+03	N1=	2.06E+02	N1 = D1/(A*R1)

4. Modeling Scenarios for Sustainable Development

In this version of the paper we present some preliminary results of computer modeling using the above constructed model. Several scenarios were simulated for a considerably long time term (from 50 to 200 years), to analyze the numerical features of the system and its sensitivity to different parameters.

In order to figure out possible perspectives for sustainable development, we tried to focus on relevant scenario prerequisites, having in mind "ecologically sustainable socio-economic development". It should be noted that, naturally, according with various definitions and concepts of "*sustainability"* - radically different results can be obtained.

Here we would focus mainly on achieving a stabilization of the Brazilian population growth and degradation of Amazonian rain forests at reasonably acceptable levels. Such targets 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 mainly in providing a demographic component, where population dynamics (N) is determined by several parameters, which we would use as control variables in simulation modeling. These controls are as follows[4]:

K40 - birth rate,
K41 - mortality rate,
K42 - emigration rate from the country (inversely proportional to the Assets),
K43 - immigration rate inside the country (proportional to the Assets) ,
K44 - rate of consumption of Assets by population N,
K45 - decrease rate of population due to its high density ("overpopulation") -
(inversely proportional to the Assets availability for consumption)

Some other parameters were additionally adjusted, such as world market prices and rotation between agricultural lands and forest, but these would not be detailed herewith.

Reference scenario:

Figure 8 presents an output chart of a simulation run for a "reference scenario", where the parameters estimated are used for the full modeling period of 100 years. Population is growing exponentially with the "business as usual" rates from of 1995 Census data (K40 = 0.02014, K41 = 0.00687, with emigration/immigration parameters K42, K43 set as 0.001), extrapolated for the full modeling period. Land rotation rate is low, and extensive use of forests is observed. As a result of this, substantial economic development (Assets, Food and Agricultural Lands) is characteristic for the first 50 years of the modeling time, but it is leveling down and even turns into decline in the course of the forests and non renewable fossil fuels are exhaustively exploited. Here, even with growing land use, food stocks decline.

In fact if we look further at such mode of development (taking an assumption that all parameters stay unchanged - which is rather unrealistic), we would observe a leveling and further very slow but smooth decline of all variables, with unconstrained population growth. This scenario could hardly be accepted for further consideration, that is why other parameters, regulating population dynamics need to be introduced.

[4] For more details of the population dynamics component refer to the *Basic* text of the model in Appendix.

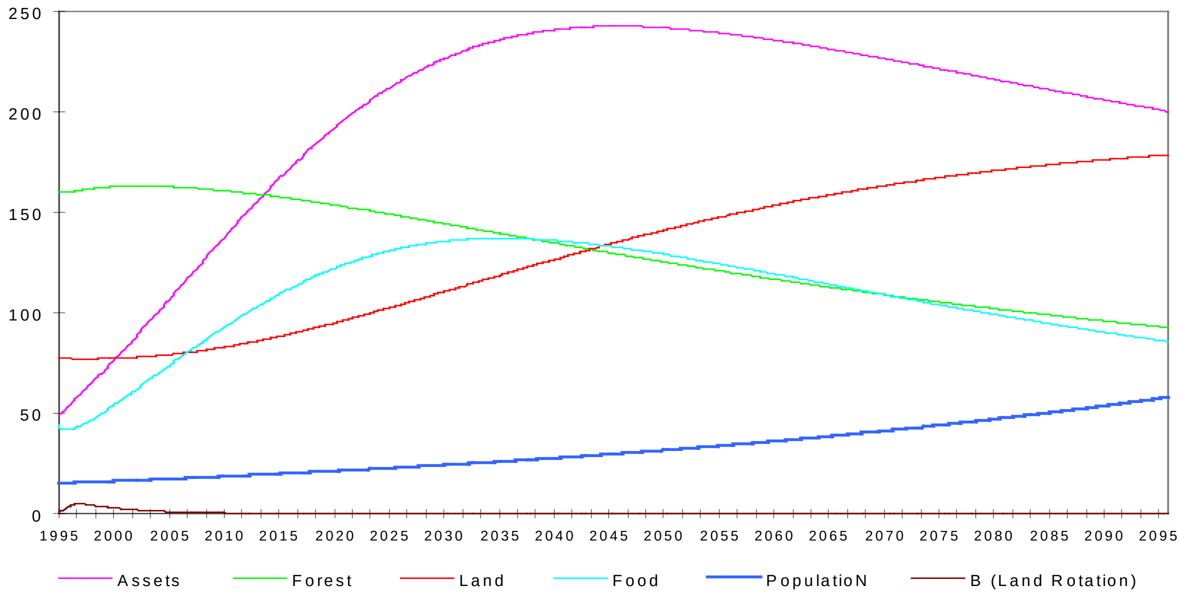

Figure 8. Reference scenario (0): unconstrained population growth.[5]

Scenario 1

Next Figure 9 plots a modification of the reference Scenario, which makes a step to a more stable type of development in two directions: restricted population growth and recovery of rain forests. To do so, respectively, K42, K43, K44, and K45 are equally set to 0.001, and appropriate parameters are adjusted to force agricultural land rotation into forests.

The consequences of this recovery of forests is a decline in agriculture and its products (food and fiber) and respective slow down of the assets accumulation, which would mean lower standard of living for the population, whose dynamics stays about the same (with further leveling of the exponential tendency - which is reached outside the modeling period).

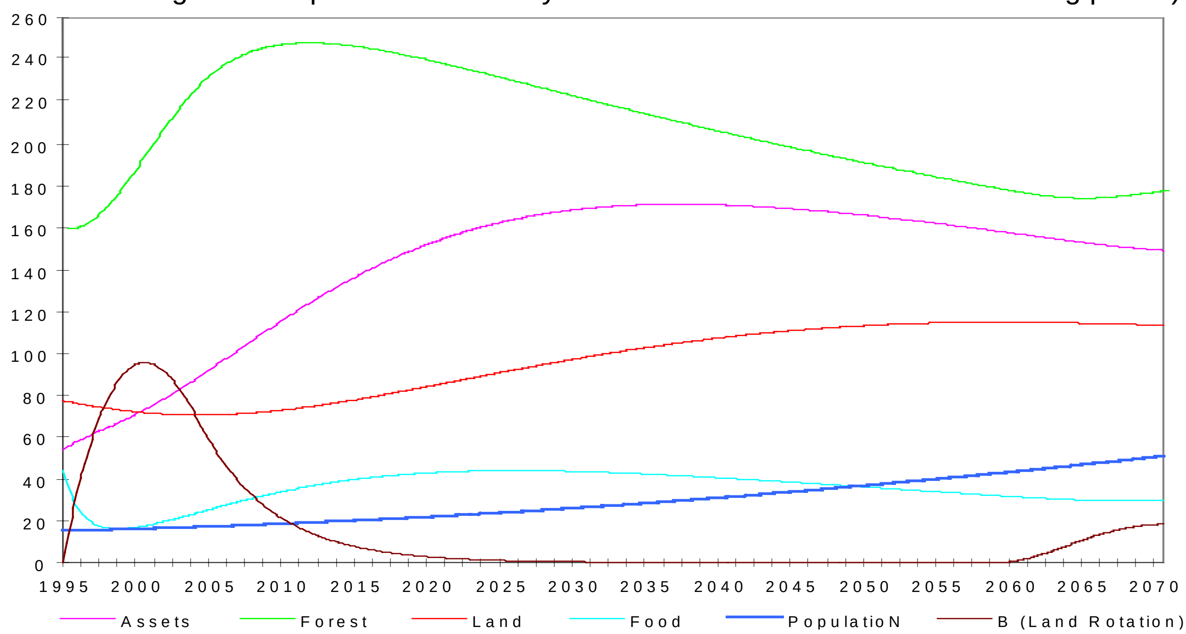

Figure 9. Scenario (1): Land rotation is enforced.

[5] Hereinafter, in all Figures, the axes Y of charts are represented in relative automatically scaled coordinates.

Scenario 2

Another scenario (Figure 10) models a more "socially oriented" policy: a moderate land rotation with at the same time more demanding patterns of population consumption: *K42 = 0.001, K43 = 0.001,* same as in previous scenarios, but consumption rate is 10 times higher: *K44 = 0.01,* with respective stronger population leveling parameter *K45 = 0.003.*

The former can be understood as a policy highly oriented to intensive population control with providing it a higher standard of living. The outcome is rather different from Scenario 1, namely in economic indicators, but this requires a more substantial load on natural resources and higher use of lands for agriculture.

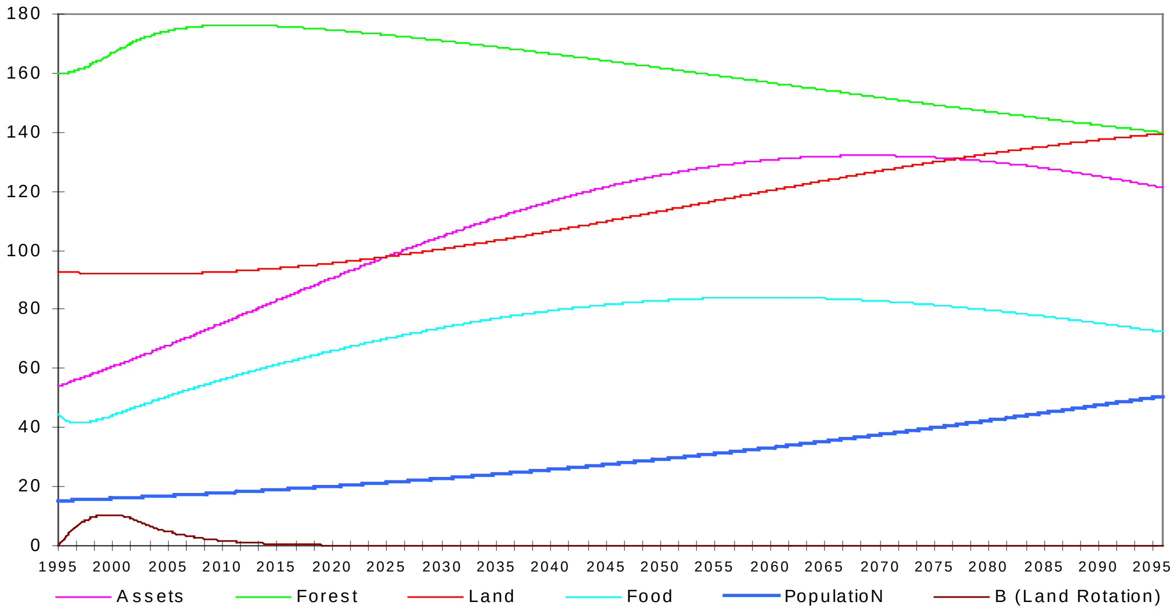

Figure 10. Scenario (2): A milder land rotation with more stable agriculture.

Scenario 3

Different idea is the basic of Scenario 3 (Figure 11), were situation is modeled with very high rates of economic development and extensive population growth (up 1 billion in 2100). It has been achieved by setting parameters: *K43 = 0.002, K44 = 0.001, K45 = 0.0001.* High value of K43 indicates an extra flow of immigration into Brazil from people outside the country, attracted by its growing potential. Though Assets grow higher than in the Scenario 2, but standard of living is lower as well as Assets/Population index. Also a more substantial load on the environment is observed.

Scenario 4

The last scenario (Figure 12) models a rather hypothetical situation when the total population growth is almost stopped: *K45 = 0.01.* The level of consumption is set to *K44 = 0.03,* which is very high. Time horizon of 150 years is used for this scenario to demonstrate the leveling tendency.

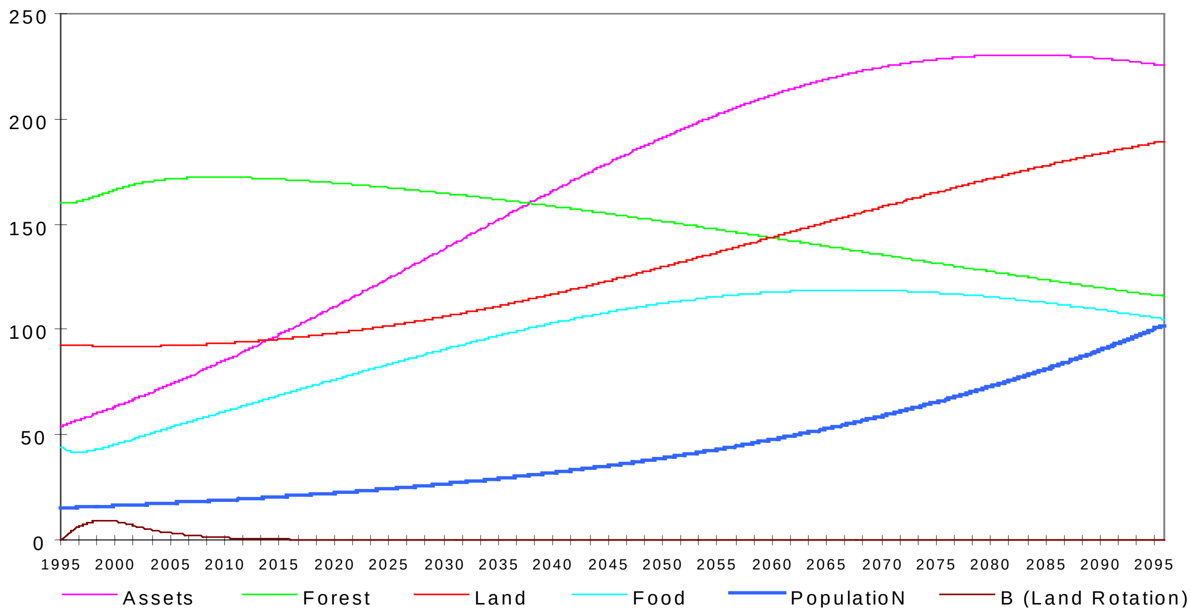

Figure 11. Scenario (3): High economy and population growth

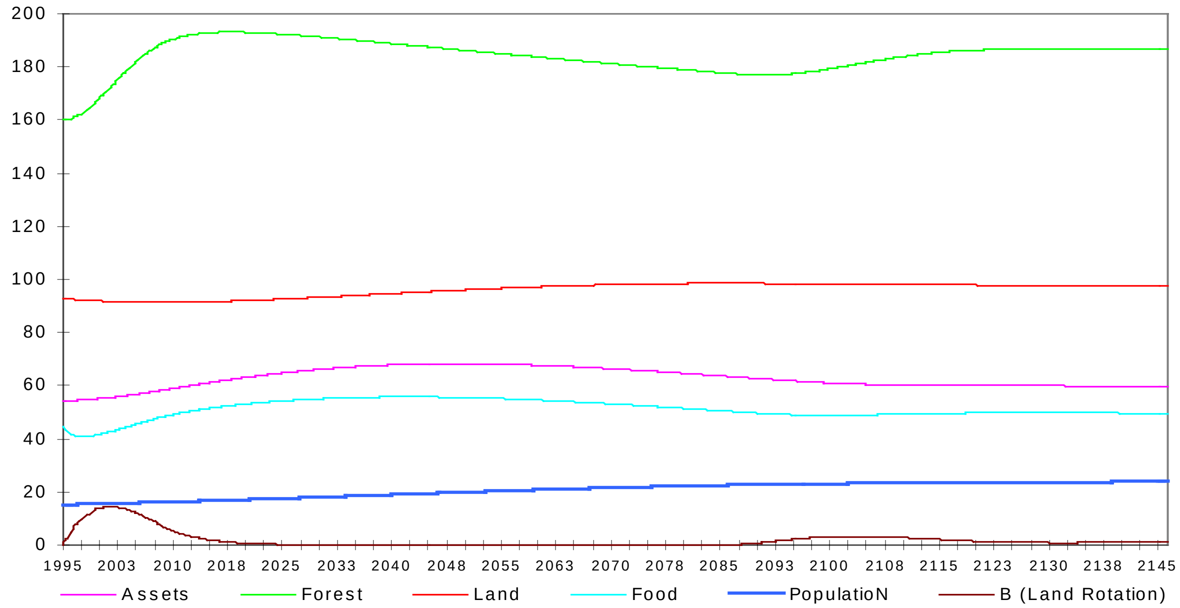

Figure 12. Scenario (4): "back to the future"

Thus we can see that 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 are arguing that such a perspective should be seriously considered in order to prevent ecological catastrophe. As an alternative to oscillating development with high growth and stagnation periods, it could be advised to decrease the amplitude of such oscillations (you can see some parts of them on Figure 12) so that it would be possible to preserve society from sharp fluctuations in the economic sphere and population dynamics.

5. Conclusions and Further Recommendations

A modification of the model (Brown, 1986) was developed for analysis of the ecological economic development of Brazil, and it was calibrated using 1996 Brazil Census data. Several scenarios of development were calculated for the perspective of 100 years in order to verify which policy alternatives at a macro level could assist to achieve goals which are sustainable.

Important policy instruments, which would be analyzed at the more advanced stages of this study, are prices and taxation, which would require development of a financial component in the model. It is also recommended to introduce links between labor productivity, agricultural and industrial production. The latter should be considered separately from the other Assets, such that the influence of different categories of values could be analyzed on the overall development.

The next version of the model would be also redefined in emergy terms, using transformities of different types of energy in the system applying to Brazil. The basic values of transformities are given in the Appendix of the book (Ortega, Safonov, Comar, 1998), can be used as a reference and changed appropriately for the Brazilian case studies.

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Appendix: BASIC text of the ecological-economic development model of Brazil

```
DIM Version AS STRING:        Version = "MS DOS, July 22, 1998"

OneStep = 1                   ' =1 start as step-by-step calculations, = 0 otherwise.
TraceEachStep = 1             ' =1 trace variables for each, even fractional time step, =0 otherwise.
dt = 1 / 8                    ' calculation step - can be less than 1 year if needed.
t9 = 1 / 8                    ' modeling time horizon: 75 years (in fractions of a 600 years time unit)

ScaleA = 10000                ' scaling parameters for chart output
ScaleS = 450000
ScaleL = 3
ScaleF = 500
ScaleB = .1#
ScaleW = 100000!
ScaleN = 10

CLS
SCREEN 12
LINE (0, 0)-(600, 200), 8, B
LOCATE 14, 1: PRINT "Ecological-Economic Development Model of Brazil. Version: "; Version;

t = 0

OP = 1            ' - Outside population attracted to Brazil
N = 152.347       ' - Brazil’s population, mln.  (1995)

B = 0
x8 = .2
X7 = 530000
M = 0
L0 = .00678
K0 = 4.769E-11        ' 1.8 E13 Cal/yr: exports of forest products
S = 40000000#
L = 232#              'REM 26 E10m2; 260,000 km2 converted forest lands
W = 1000000!
R1 = 0.01
r2 = 4010
F = 22200#           'REM original value p.55: 2030 E10 Cal
A = 540000#          'REM original value p.55: 27160 E10 Cal

I = 100000      '4203
P0 = 3711760000000#  'World Market Price : same as Amazon?
R = 10000000#
S1 = 1
S2 = 1
A1 = 0.85           'REM river head
A2 = 0.85
P1 = 6              '6 - original Amazon
P2 = 0.0004         '.0859 - original Amazon
P3 = 0.001406       '- original Amazon
Q1 = 3.9
Q2 = 1724           'REM 1724 E18 Cal: proven storage of mineral & oil resources
X1 = 142
X2 = 39000
X3 = 189000000#

j1 = 107000#        'REM 1.84 E15 g/yr: gross production = 261 g/m2/yr
```

```
j2 = 100000#         'REM 1.25 E15 g/yr: respiration 1% of storage
j3 = 63600#          'REM 6.3  E14 g/yr: rate of cutting forest (1.8 E10m2/yr)(3.5E4g/m2)=6.3E14g/yr
j4 = 0.318           'REM 3200 E10 g/yr: assume 5% of forest wood harvested used as lumber
j5 = 0.18            'REM 2300 E10 g/yr: return of lands to successional forest (2.6E9m2 * 3.5E4g/m2 * 25%)
j6 = 1.82            'REM 1.8 E10 m2/yr: conversion of forest to developed land
m5 = 0.26            'REM
j7 = 4480#           'REM 2710 E10 Cal/yr: Gross Primary Production of agriculture & forestry lands
j8 = 4580#           'REM 138 E10 Cal/yr: actual energy in imported goods
j9 = 896#            'REM 540 E10 Cal/yr: loss due to respiration, insects
B0 = 22200#          'REM 2030 E10 Cal/yr: consumption of food and fibre
b1 = 470000!         'REM 4.7 E15 l/yr: river discharge = 26% rainfall
b2 = 21900#          'REM 1110 E10 Cal/yr: average growth rate of assets equal to 4.07% from 1858 to 1979
b3 = 31100#          'REM 1300 E10 Cal/yr: wood used for construction of assets
b4 = 1090#           'REM 1200 E10 Cal/yr: fuelwood and charcoal use adjusted for popul.on basin
b5 = 5400#           'REM 270 E10 Cal/yr: depreciation of assets, assume 1% /yr
b6 = 4.5 '11.6       'REM 1.3 E10 m2/yr: utilization of lands and abandonment, assume 20 year rotation time
b7 = 5400#           'altered REM 340 E10 Cal/yr: use of assets for conversion of forest lands to dev.lands (2%)
b8 = 5720#           'REM 140 E10 Cal/yr: actual energy in imported goods b8=0
B9 = 33900#          'REM 700 E10 Cal/yr: fuels derived from internal storages
c0 = 51600#          'REM 4000 E10 Cal/yr: fuels imported
c1 = 85500#          'REM 4700 E10 Cal/yr: fuels consumed
C2 = 895000000#      'REM 4.3 E18 Cal/yr: mineral extraction
c3 = 1240000         'REM 1.3 E16 l/yr: evapotranspiration: 74% of rainfall
c4 = 44.4            'REM 3.9 E10 Cal/yr: hydroelectricity generated
c5 = 814000000#      'REM 3.9 E18 Cal/yr: export of minerals. 90% of yearly extractable mineral ore
c6 = 14600#          'REM 140 E10 Cal/yr: actual energy in exported goods
c7 = 77#             'REM 1800 E10 g/yr: wood products cut for export
c8 = 2.32            'REM 2.6 E9 m2/yr: active loss of lands through utilization (1% developed land)
c9 = 23600#          'REM 1200 E10 Cal/yr: fuelwood and charcoal use
D0 = 5400#           'REM 270 E10 Cal/yr: use of assets for exports of forest products and minerals: 1%
D1 = 1110#           'REM 1.8 E13 Cal/yr: exports of forest products
N0 = D0 / (A * R1)
N1 = D1 / (A * R1)
F1 = .053
F2 = .017
f3 = .92
z = 0
K1 = j1 / (A1 * S)    'K1 related to J1: 1.84 E15 g/yr: gross production = 261 g/m2/yr
K2 = j2 / S           ' K2 related to J2: 1.25 E15 g/yr: respiration 1% of storage
K3 = j3 / (S * A)
K4 = j4 / S
K5 = j5 / (L + A2 * L)
K6 = j6 / (S * A)
N3 = m5 / L
K7 = j7 / (A2 * L)
K8 = j8 / (i * F1)
K9 = j9 / (F * F)
G0 = B0 / P0          ' G0 related to J10: 2030 E10 Cal/yr: consumption of food and fiber
G1 = b1 / W
G2 = b2 / P0
G3 = b3 / S
G4 = b4 / (S * A)
G5 = b5 / (A * A)
G6 = b6 / (L * A2)
G7 = b7 / (A * S)
G8 = b8 / (i * F2)
h0 = c0 / (i * f3)    ' H0 related to J20: 4000 E10 Cal/yr: fuels imported
h1 = c1 / P0
H3 = c3 / W
```

```
h4 = c4 / P0
H5 = c5 / (A * S)
H6 = c6 / P0
H7 = c7 / (A * S)
H8 = c8 / (A2 * L)
H9 = c9 / P0

'Population dynamics parameters:
K40 = .02014          ' Population birth rate (1995)
K41 = .00687          ' Population death rate (1995)
K42 = .001 * A        ' Emigration rate
K43 = .002 / A        ' Immigration rate
K44 = .001 / N        ' Consumption of assets rate
K45 = .003 / N * A  ' Over-population decrease factor (quadratic drain), scaled to availability of Assets.

DO
    LOCATE 29, 1: COLOR 11: PRINT "Press any key to pause calculation                              ";
    icount = icount + 1
    IF t = 0 OR icount >= 1 / dt OR TraceEachStep = 1 OR OneStep = 1 THEN
            COLOR 7: LOCATE 15, 60: PRINT "Year T ="; t,
            COLOR 5: PRINT "Assets          A ="; A / ScaleA
            COLOR 2: PRINT "Rain Forest     S ="; S / ScaleS
            COLOR 3: PRINT "Developed Land  L ="; L / ScaleL
            COLOR 4: PRINT "Food and Fiber  F ="; F / ScaleF
            COLOR 6: PRINT "Success.Forest  B ="; B / ScaleB
            COLOR 7: PRINT "River Head      W ="; W / ScaleW
            COLOR 9: PRINT "Population      N ="; N / ScaleN
            COLOR 1: PRINT "I ="; I, "R1="; R1,”R2="; R2
            icount = 0
    END IF
    PSET (t / t9, 200 - A / ScaleA), 5
    PSET (t / t9, 200 - S / ScaleS), 2
    PSET (t / t9, 200 - L / ScaleL), 3
    PSET (t / t9, 200 - F / ScaleF), 4
    PSET (t / t9, 200 - B / ScaleB), 6
    PSET (t / t9, 200 - N / ScaleN), 9

    A1 = S1 / (1 + K0 * S)
    A2 = S2 / (1 + L0 * L)
    X1 = H6 * P0
    X2 = H5 * A * S
    X3 = N1 * A * R1
    i = (X1 * P1) + (X2 * P2) + (X3 * P3)
    Q1 = ((G1 * W) - (h4 * (Q2 + F) * A * R2)) / (1 + (h4 * (Q2 + F) * A))
    Q2 = ((G4 * S * A) - (H9 * F * (Q1 + R2) * A)) / (1 + (H9 * (Q1 + R2) * A))
    P0 = (Q2 + F) * (Q1 + R2) * A

    S9 = K1 * A1 * S - K2 * S - K3 * S * A - K4 * S + K5 * L + H8 * A2 * L - H7 * A * S + X7 * B
    L9 = K6 * S * A - N3 * L - G6 * L * A2
    F9 = K7 * A2 * L + K8 * i * F1 - K9 * F * F - G0 * P0
    W9 = R - G1 * W - H3 * W
    N9 = K40 * N - K41 * N - K42 * N / A + K43 * N * A - K45 * N * N / A
    A9 = G2 * P0 + G3 * S + G8 * i * F2 - G5 * A * A - G7 * A * S - N0 * A * R1 - K44 * A * N
    Z9 = -H2 * A * R1 - G9 * R1
    X9 = h0 * i * f3 + G9 * R1

    IF L9 < 0 THEN
        m9 = L9 * -1
    ELSE
```

```
        m9=0
    END IF
    M = m9 - x8 * B
    B = B + M * dt
    S = S + S9 * dt
    IF S > 3.7E9 THEN S = 3.7E9  'higher constraint on rain forests stock  - value of 1980 (Brown, 1986)
    L = L + L9 * dt
    IF L > 705 THEN L = 705        ' higher constraint on agricultural lands
    F = F + F9 * dt
    W = W + W9 * dt
    A = A + A9 * dt
    N = N + N9 * dt
    R1 = R1 + Z9 * dt
    R2 = X9

    'Interactive control of computation process

    IF INKEY$ > CHR$(0) OR OneStep = 1 THEN
      LOCATE 29, 1: COLOR 14: PRINT "Press <ESC> - exit, 1 - one step, other - continue calculation";
      DO
          OneStep = -1
          SELECT CASE INKEY$
          CASE IS = CHR$(27) 'Key Esc pressed
                LOCATE 29, 1: COLOR 12: PRINT "Calculation aborted                                        ";
                END
          CASE IS = CHR$(49)  ' Key 1 pressed
                OneStep = 1
          CASE IS > CHR$(0)    ' Other key pressed
                OneStep = 2
          CASE IS = CHR$(0)    ' waiting for the key to be pressed
                OneStep = 0
          END SELECT
      LOOP UNTIL OneStep > 0
    END IF

    t = t + dt

LOOP WHILE t <= 600 * t9            ' 600 is width of the screen in pixels

LOCATE 29, 1: COLOR 12: PRINT "Calculation completed                                  ";

END
```