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Conference Paper · January 2010

DOI: 10.13140/2.1.3854.1763

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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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Fábio Takahashi, Sandra Santos, Urbano Abreu and Enrique Ortega

ABSTRACT

Emergy allows the sustainability of agricultural and livestock systems to be evaluated. This methodology was applied to analyze livestock systems on traditional farms located in the Pantanal Watershed in Brazil. The goals were to evaluate the sustainability of the system and to show the importance of the presence of native fauna and cattle in maintaining the region's ecological quality. The results showed that the traditional livestock management in the Pantanal is composed of a high percentage of renewable resources, approximately 98% of the total emergy used. Cattle have the important function of controlling the fires in the region and thus cattle production preserves the local fauna and flora, which produce 7687 kg of biomass/ha/year. The value of this biomass was estimated by the emergy methodology to have a yearly value of US$ 367.80 per hectare of preserved landscape. Even though a large amount of renewable resources are used, thereby preserving the environment, the cost for maintaining this system is very expensive, mainly due to the cost of bringing materials into this isolated region.. Thus, alternatives must be discussed, such as certification seals for environmental preservation, to add value to these products, encouraging the continuation of this activity in the region and consequently preserving the ecological balance.

INTRODUCTION

The Pantanal is a tropical wetland and the world's largest wetland of any kind. It lies mostly within the Brazilian state of Mato Grosso do Sul but extends into Mato Grosso as well as into portions of Bolivia and Paraguay, sprawling over an area estimated at between 140,000 km^2 and 195,000 km^2 as shown in Figure 1. Various sub-regional ecosystems exist, each with distinct hydrological, geological and ecological characteristics. The region is influenced by rivers that drain the Alto Paraguai River and by four biomes: Amazon, Cerrado, Chaco and Atlantic Forest.

The part of Pantanal located in Mato Grosso State is considered to be one of the best preserved ecosystems in Brazil, with the highest percentage of native vegetation (88.78%) and lowest area of human action (11.7%). According to Seidel et al. (2001), 95% of the region is private property of which 80% has been used for beef cattle for over 250 years. The beef cattle in the Pantanal are developed in breeding sites with extensive natural features of the management system guided by the flooding cycle (Pott et al., 1989).

The objective of this study was to evaluate the traditional cattle ranching of the Pantanal in terms of sustainability through analysis using the emergy methodology.

METHODS

The traditional farm livestock production system (Alegria Farm) selected to be evaluated is located in the Nhecolândia sub-region, Corumbá-MS, Brazil. The farm has an area of 20,838.8 ha. To perform the emergy evaluation it was necessary to survey all the natural and economic resources used by the system. Data were obtained through interviews with the owners of farms and from geo-

Figure 1. *Map of Brazilian Pantanal.*

referenced maps. However, some important data were estimated including the amount of sediment and flood water. These variables are very dynamic and have marked seasonal differences.

The emergy indices were calculated considering the renewability fraction of material and services (Ulgiati et al., 1994; Ortega et al., 2002; Ortega et al., 2005; Agostinho et al., 2008). The classification of emergy flows are shown in Table 1.

Beef cattle and vegetal biomass were considered the products of the system. The energy of biomass production was calculated using the NPP of each type of vegetation. The vegetation was classified as shown in Table 2 and the areas were estimated from satellite images as show in Figure 2. The total plant biomass produced annually by the system is consumed by cattle, used by man, and the remaining biomass leaves the system by two ways: a) consumption by local fauna and b) wash-out in the period of floods. The value of the remaining biomass that can be consumed by local fauna or leave the system in the flood water was calculated in emDollars. The biomass produced annually by each vegetation classes was calculated using the NPP value. This quantity of biomass (kg/ha/yr) was transformed to energy (J/ha/yr) and multiplied by the appropriate transformity (found in this study) to obtain the emergy flow of plant biomass (seJ /ha/yr). This emergy flow was multiplied by the emergy per money ratio (seJ/US$) for Brazil in 2008. All values of unit emergy values used in this work were adjusted to the 15.83 E24 seJ/y baseline. The value of the biomass that leaves the system was calculated by the difference between total biomass and the estimated consumption by cattle and man.

Table 1. Emergy flow classification.

Inputs classification	Equation / Symbol	Description
Renewable resources from nature	R	Sun, rain, wind.
Non-Renewable resources from nature	N	Soil, biodiversity, people exclusion.
Resources from Nature	I = R + N	
Materials	$M = M_R + M_N$	
Renewable Materials	M_R	Seeds, wood.
Non-renewable Materials	M_N	Fuels, chemicals.
Services	$S = S_R + S_N$	
Renewable Services	S_R	Manpower supported by renewable
Non-renewable Services	S_N	Services such as external services,
Feedback from economy	F = M+S	
Total Emergy	Y = I + F	

Table 2. Area and Net Primary Production (NPP) of vegetation classes on Alegria farm in the Pantanal.

Vegetation	Area	NPP*
Forested areas of Pantanal	3661.99	1500
Savanna areas of Pantanal	3661.99	700
Native grassland with areas of dry land	6255.83	600
Native grassland with seasonal areas of land	4894.81	600
Native grassland with humid areas of land	974.38	1200
Ponds	104.56	1000

*Estimated from Begon et al. 2005

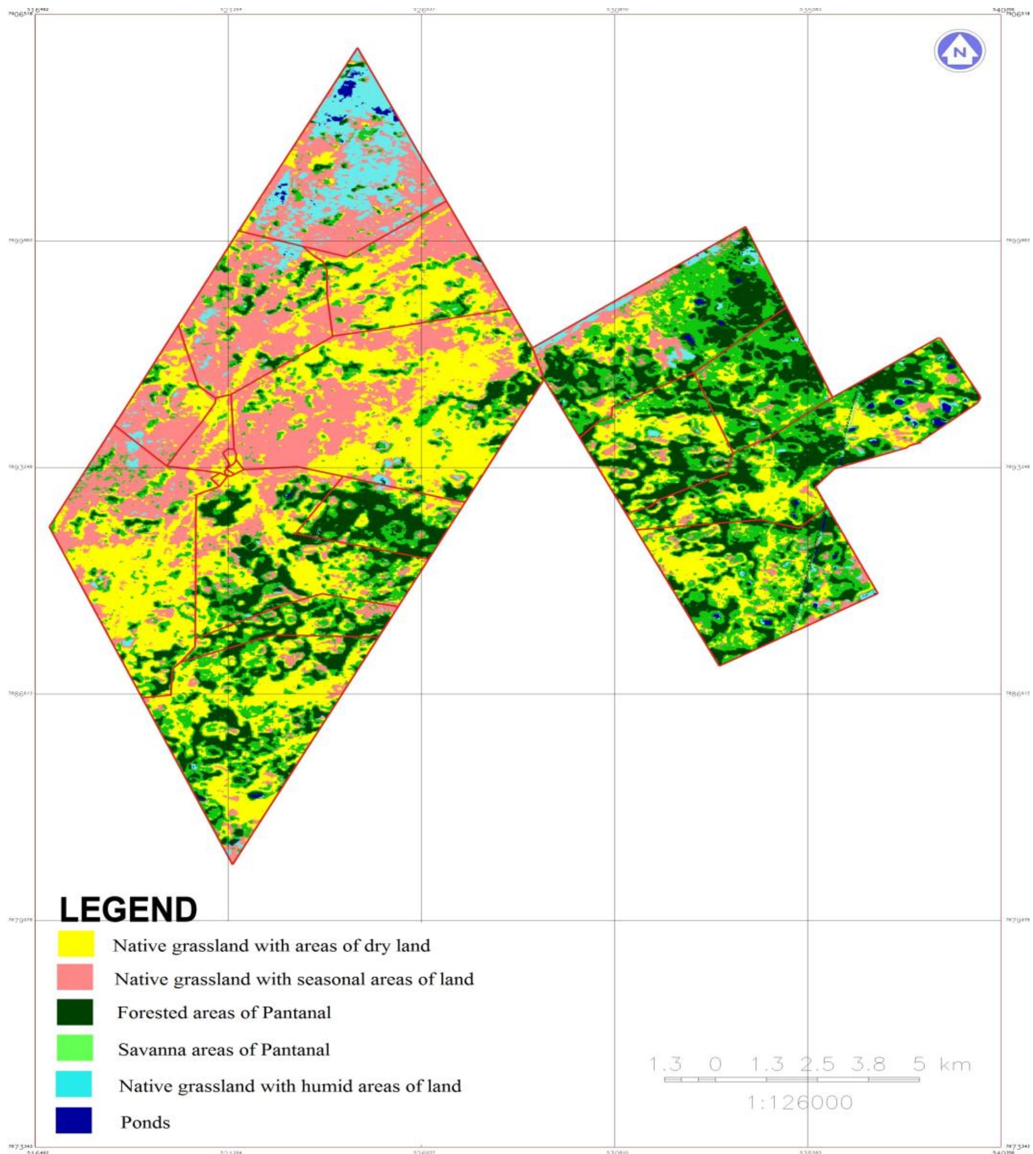

Figure 2. *Map of Alegria Farm showing land use classes.*

RESULTS AND DISCUSSION

Figure 3 shows the simplified emergy diagram for Alegria farms. There is a small area for agricultural products but these products are consumed almost totally within in the system. The current state of native biomass and consequently the production of environmental services are totally dependent on the presence of the cattle in the system. Cattle control the storage of biomass (grass), mainly in the dry season by keeping combustible fuel at a low level, and thereby avoid the destruction of all native vegetation by burning. Without cattle in the system, the storage of plant biomass increases in the dry season and fire caused by natural forces, such as lightning during thunder storms, can destroy the whole vegetation, as happened in many systems that are no longer used to raise cattle. The remaining plant biomass is like a co-product in the sense that it needs the same emergy as the cattle. This is a special case where the feedback loop from cattle grazing suppressing fire results in increasing the emergy required for the remaining biomass.

Table 3 shows the emergy evaluation of Alegria Farm and Table 4 shows the emergy of the aggregated flows. The rain emergy flow is notable compared with the other non-renewable flows. The comparably high renewable emergy flow of rain caused the traditional cattle system in Pantanal to have high emergy indices of sustainability, (see Table 5).

The solar transformity (Tr) can be defined as the amount of solar energy required to produce a unit of available energy of a product. The transformity of old cows, steers for fattening and vegetal biomass were estimated in 5.37E7 seJ/J, 3.38E7 seJ/J, and 2.97E4 seJ/J. This index assesses the system's efficiency and quality of energy flow and allows comparisons with other forms of energy from other systems. The Pantanal system is sustainable due to the high % of renewable emergy and

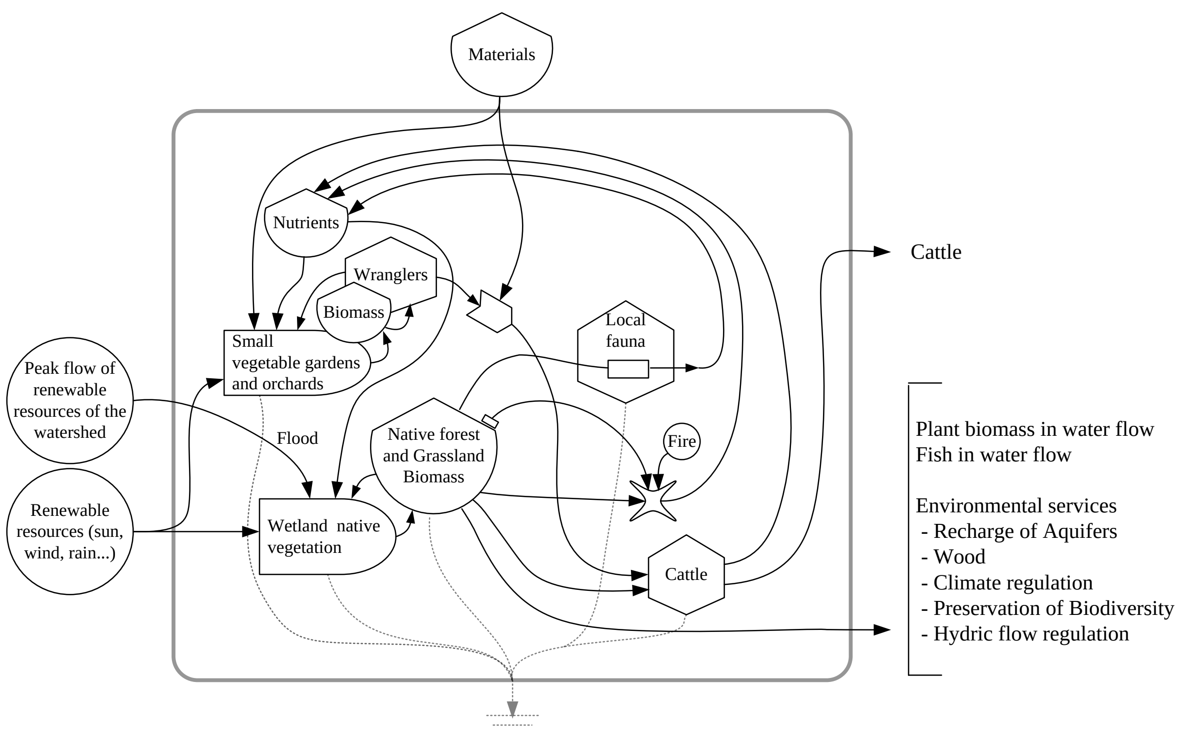

***Figure 3**. Simplified diagram of Alegria farm.*

Table 3. Emergy evaluation of Alegria Farm.

Code	Item	Renov. Parc.	Quantity	Unit (/ha/yr)	Transfor- (sej/unit)	Renew. E12	Non E12	Total Flow E12
R1	Sun	1	1.90E+1	J	1	1.90E+11	0.00E+00	1.90E+11
R2	Rain	1	6.00E+1	J	3.10E+04	1.86E+15	0.00E+00	1.86E+15
R3	Sediments	1	3.65E+0	kg	1.24E+05	4.53E+14	0.00E+00	4.53E+14
R4	Solubilized calcium	1	1	kg	1.68E+12	1.68E+12	0.00E+00	1.68E+12
R5	Solubilized	1	1	kg	2.92E+12	2.92E+12	0.00E+00	2.92E+12
R6	Atmosf. Nitrogen	1	1	kg	7.73E+12	7.73E+12	0.00E+00	7.73E+12
N1	Net topsoil loss	0	4.52E+0	J	1.24E+05	0.00E+00	5.60E+10	5.60E+10
N2	Loss of Biodiversity	0	1	J	7.38E+04	0.00E+00	7.38E+04	7.38E+04
N3	Loss of people	0	1.17E+0	J	1.68E+06	0.00E+00	1.93E+11	1.93E+11
M1	Salt	0.80	5.14	kg	1.00E+12	4.11E+12	1.03E+12	5.14E+12
M2	Vaccines and	0	0.48	US$	5.22E+12	0.00E+00	2.51E+12	2.51E+12
M3	Gasoline	0	0.0001	L	3.25E+12	0.00E+00	3.25E+08	3.25E+08
M4	Diesel	0	0.571	L	5.58E+12	0.00E+00	3.19E+12	3.19E+12
M5	Another materials	0	3.341	US$	5.22E+12	0.00E+00	1.75E+13	1.75E+13
S1	Temporary labor	0.6	0.35	US$	5.22E+12	1.10E+12	7.31E+11	1.83E+12
S2	Labor	0.6	1.38	US$	5.22E+12	4.33E+12	2.88E+12	7.21E+12
S3	Maintenance	0.6	0.26	US$	5.22E+12	8.15E+11	5.43E+11	1.36E+12
S4	Maintenance of	0.9	0.71	US$	5.22E+12	3.34E+12	3.71E+11	3.71E+12
S5	Administration	0.2	0.18	US$	5.22E+12	1.88E+11	7.52E+11	9.40E+11
S6	Transportation	0.3	0.39	US$	5.22E+12	6.11E+11	1.43E+12	2.04E+12
S7	Taxes	0	0.13	US$	5.22E+12	0.00E+00	6.79E+11	6.79E+11
S8	Telephone	0	0.10	US$	5.22E+12	0.00E+00	5.22E+11	5.22E+11
S9	Association	0	0.01	US$	5.22E+12	0.00E+00	5.22E+10	5.22E+10
outputs								
	Calves		7.02E+0	J	3.38E+07			2.37E+15
	Old cows		4.42E+0	J	5.37E+07			2.37E+15
	Plant biomass		7.98E+1	J	2.97E+04			2.37E+15

* unit emergy values references in appendix A

high value of ESI (3673.8). The Renewability Index (%R) was estimated at 98.63%. Nearly all the emergy used in the system is derived from renewable resources.

The indices Emergy Investment Ratio (EIR), Emergy Exchange Ratio (EER) and Emergy Loading Ratio (ELR) were estimated at 0.02, 11.29 and 0.014, respectively. The EIR evaluates the ratio of feedback emergy from the economy in relation to environmental emergy, which indicates how economical the process is when it uses investments of the economy in comparison with other alternatives. The small value (0.02) indicates that the system of the Pantanal is not so dependent on economic resources. This makes the system competitive and allows it to thrive in the market and attract additional investment.

The emergy exchange rate (EER) is the relation between the emergy used by the system to produce products and the emergy that can be purchased by the money received in an economic exchange for those products. This indicator provides a measure of who ‘‘wins’’ and who ‘‘loses’’ in economic trade. Raw materials, such as minerals and products from agriculture, fishing and forestry tend to have a high value of EER (between 5 and 10) when they are purchased at the market price, because usually only the monetary value for human services is paid for and not the work done by nature (Cavalett et al., 2006). The value 11.29 for the conventional production system of Pantanal indicates that the system provides 11.29 times more emergy to purchasers of the product than is returned in dollars paid. The environmental load average (ELR) calculated was practically zero (0.014), showing the low environmental impact and low use of nonrenewable resources.

Table 4. Aggregated flow of Alegria Farm.

Aggregated flow	**Equations**	**Emergy flow E13 sej/ha/yr**
Renewable resources from nature	R=R1+R2+...+Ri	232.49
Non-renewable resources from nature	N=N1+N2+...+Ni	0.02
	I = R + N	232.52
Materials from economy	M=M1+M2+...+Mi	2.83
Materials from economy (renewable)	Mr=Mr1+Mr2+...+Mri	0.41
Materials from economy (non-renewable)	Mn=Mn1+Mn2+...+Mni	2.42
Services from economy	S=S1+S2+...+Si	1.83
Services from economy (renewable)	Sr=Sr1+Sr2+...+Sri	1.04
Services from economy (non-renewable)	Sn=Sn1+Sn2+...+Sni	0.80
	F = M + S	4.66
	Fr = Mr + Sr	1.45
	Fn = Mn + Sn	3.21
Total emergy	Y= I + F	237.18

Table 5 Emergy Índices of Alegria Farm.

Emergy indices	Equation	Value
% Renewable	Ren=(100)*((R+Mr+Sr)/Y)	98.63%
Emergy Yield Ratio	EYR=Y/(M+ S)	50.86
Emergy Investment Ratio	EIR=(M+S)/(R + N_0)	0.02
Emergy Exchange Ratio	EER=Y/EmS	11.29
Environmental Loading Ratio	ELR=(N+Mn+Sn)/(R+Mr+Sr)	0.014
Emergy Sustainability Index	ESI = EYR / ELR	3673.8

Table 6. Production of plant biomass and estimated value.

Yype of vegetation	**Total biomass**			
	kg/year	**J/ha year**	**seJ/ha year**	**US$/ha year**
Forested areas of Pantanal	54929850	3.98E+10	1.18E+15	226.26
Savanna areas of Pantanal	25633930	1.86E+10	5.52E+14	105.59
Native grassland with areas of dry land	37534980	2.72E+10	8.08E+14	154.61
Native grassland with areas of seasonal land	29368860	2.13E+10	6.32E+14	120.97
Native grassland with humid areas of land	11692560	8.47E+09	2.52E+14	48.16
Ponds	1045600	7.58E+08	2.25E+13	4.31
Total	160205780			659.90

Table 6 shows the total production of plant biomass and its value in emdollars was estimated to be US$ 659.90 per hectare year. The consumption of plant biomass by cattle and man was estimated in US$ 194.90 and US$ 11.40 per hectare years respectively. Thus, the value of plant biomass, which is available for the local fauna and to maintain the balance of the system, was estimated as US$ 453.59 per hectare year. This shows the importance of the cattle in the region to preserve and maintain the system balance.

It is possible to observe throughout this analysis that the system of traditional livestock production in Pantanal is one of the most sustainable cattle systems described using the emergy methodology. The renewability index calculated for a system on the pampas of Argentina was 65% (Rotolo, et al., 2007). It is interesting to compare the traditional system with more intensified systems that have been deployed in the Pantanal and thereby encourage more sustainable management.

CONCLUSION

The emergy methodology proved to be useful tool for the study of livestock systems in the Pantanal, providing summaries for important decision making and development of sustainable policies. The results indicate that the traditional system of producing beef cattle in the Pantanal is a highly sustainable system. It is very important to compare this result with other management strategies that have been deployed in the Pantanal to stimulate the traditional farmers to maintain traditional management practices and to implement public policies that encourage more sustainable management.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial support of CNPq

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Appendix A. Unit Emergy Values references.

R1: Sun
Unit emergy value: 1 seJ/J (definition)
Quantity = 5.29 kWh/m^2/yr
Quantity = 5.29 kWh/m^2/yr x 356 days/yr x 3.6E6J/kWh x 10000 m^2/ha = 1.90E11 J/ha/yr

R2: Rain
Unit emergy value: 3,06E4 seJ/J (Odum 1996)
Quantity = 1.2 m^3/m^2
Quantity = 1.2 m^3/m^2 x 1000kg/m^3 x 5000 J/kg x 10000m^2/ha = 6.00E10 J/ha/yr

R3: Sediments
Unit emergy value: 1,24E5 seJ/J (Brown and Ulgiati 2004)
Quantity= 3.65E9 kg/ha/yr (estimated)

R4:Solubilized calcium
Unit emergy value: 1,68E12 seJ/kg (Ortega 1998)
Quantity= 1 kg/ha/yr (estimated)

R5:Solubilized Potassium
Unit emergy value: 2,92E12 seJ/kg (Ortega 1998)
Quantity = 1kg/ha/yr (estimated)

R6: Atmosf. Nitrogen
Unit emergy value: 7,73E12 seJ/kg (Brandt-Williams 2002)
Quantity = 1kg/ha/yr (estimated)
N1:Net topsoil loss
Unit emergy value: 1,24E5 seJ/J (Brown and Ulgiati 2004)
Quantity = 0.50 kg/ha/yr (estimated)
Quantity = 0.50 kg/ha/yr x 0.04kg o.m./kg soil x 5400 kcal/kg o.m. x 4186J/kcal = 5.52E5 J/ha/yr

N2: Loss of Biodiversity
Unit emergy value: 7,38E4 seJ/J (Odum 1996)
Quantity = 1 J/ha/yr (estimated)

N3:Loss of people
Unit emergy value: 6,72E5seJ/J (Ortega 1998)
Quantity = 0,80 people/ha/yr (estimated)
Quantity = 0.80 people/ha/yr x 8400kJ/people/day x 365 days/yr =1.17 E5 J/ha/yr

M1: Salt
Unit emergy value: 1,0E12 seJ/kg (Castellini et. al 2006)
Quantity = 5.14kg/ha/yr

M2: Vaccines and medicine
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity = 0.48 US$/ha/yr

M3 Gasoline
Unit emergy value: 3,25E12 seJ/L (Odum 1996)
Quantity = 0.0001L/ha/yr

M4: Diesel
Unit emergy value: 5,58E12 seJ/L (Odum 1996)
Quantity = 0.571L/ha/yr

M5: Another materials
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity = 3.341 US$/ha/yr

S1: Temporary Labor
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.35 US$/ha/yr

S2: Labor
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 1.38 US$/ha/yr

S3: Maintenance
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.26 US$/ha/yr

S4: Maintenance of local fauna and flora
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.71 US$/ha/yr

S5: Administration
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.18 US$/ha/yr

S6: Transportation
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.39 US$/ha/yr

S7: Taxes
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.13 US$/ha/yr

S8: Telephone
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.10 US$/ha/yr

S9: Association
Unit emergy value: 5,22E12 seJ/US$ (Coelho et. al 2003)
Quantity 0.01 US$/ha/yr