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The Center for Environmental Policy
Department of Environmental Engineering Sciences
University of Florida
Gainesville, FL

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Emergy-Based Sustainability of the Peruvian Economy

Raúl Siche and Enrique Ortega

ABSTRACT

In this study, emergy evaluation was used to analyze the Peruvian ecological – economic system. The material and energy flows were evaluated in units of solar emergy. The performance of the Peruvian system was assessed through emergy-based indices. The main calculated indicators are the following: (a) Emergy/USD ratio = 1.01 E+13 sej/dollar; (b) Emergy Yield Ratio (EYR) = 9.69; and (c) Environmental Loading Ratio (ELR) = 2.17; which, when combined give the Emergy Sustainability Index (ESI) = 4.47. In order to obtain a general measure of ecological sustainability, the renewability was also calculated: %R = 32%. These values, as well as other data shown in the paper, indicate that the Peruvian system benefits from a great contribution of natural renewable energies to its economy with low environmental loading, but the country contributes to other economies by exporting high volumes of natural resources such as metals.

INTRODUCTION

Usually, economic analyses do not take into consideration the origin and quality of the energy used by an economic system and often ignore the interconnections between present and past ecosystems. As a result, sustainability is not calculated and is ignored. This is evident in the inadequacy of the national development project, social organization, and cultural values in relation to the use of renewable resources.

The concept of emergy allows expression of all the factors that contribute in the production of goods and services in the same numeraire: the energy of the solar radiation equivalent necessary for the whole production process (Odum 1996). Thus, the emergy methodology accounts for the solar energy "memory" of all the flows of energy and materials necessary to the processes, products, and services that characterize a region.

The objective of this paper is to analyze the resource basis of the economy of Peru with 2004 statistical data using emergy-based indices to describe the environmental performance of the system.

MATERIALS AND METHODS

Peru is the third largest country in South America, after Brazil and Argentina, with an area of 1.29 E+9 km^2. Peru is confined by the Pacific Ocean to the west and Brazil to the east. Its neighbor countries are Ecuador and Colombia to the north and Chile and Bolivia to the south. Peru, by its geographic location should be a tropical country, of warm and rainy climate; nevertheless, it is a country of varied subtropical and tropical climates due to the existence of two factors that modify its climatic conditions completely: the Andes mountain range and the sea currents of Humboldt and El Niño. According to these determining factors, Peru has almost all the climates that appear in the world.

Peru is a rich country in terms of water, but it transfers 98 percent of the water that falls on its surface to the Amazon jungle towards the Atlantic Ocean. Peru lives with only two percent of the rainfall water, which is also not easily accessible because it is far away from the cities.

The rainfall in the North Mountains is 900 mm/m^2/year, in the South Mountains is 300 mm/m^2/year. On the coast it is 58 mm/m^2/year and in the Peruvian Amazon it is 2,451 mm/m^2/year (MINAG 2005).

The Republic of Peru developed an economy based on agriculture, mining, and fishing. According to Banco Central de Reserva del Peru, the Gross National Product (GNP) in 2004 was 6.84 E+10 USD, equivalent to $2,450 per person per year (BCRP 2005).

The first step in the emergy analysis was collection of quantitative data from various sources including scientific, economic, and technical literature, as well as national statistical yearbooks and digital databases of the country.

After that, the basic data about resources used by the Peruvian system in 2004 were listed in terms of energy (J), mass (kg), or money (USD) flows in order to calculate the respective emergy flows (sej/year). The emergy analysis table allows multiplying all the items listed by their respective transformity in order to obtain the emergy flow. Transformities from previous studies were used for the calculations.

The aggregated emergy flows are used to calculate several emergy indices, the most important for this work are: Environmental Loading Ratio (ELR), Emergy Yield Ratio (EYR), Emergy Sustainability Index (ESI), and % Renewability (%R).

RESULTS

Table 1 gives detailed values of the emergy evaluation of Peru's economy. The most important indigenous production sectors are agricultural production and fisheries (Table 1, items 9 and 11) representing 42 and 38 percent, respectively, of the indigenous renewable emergy base of the country.

The most important indigenous non-renewable resource is soil loss (mineral + organic = 2519.7 E+20 sej/y; Table 1, items 19 and 20) representing 88 percent of the non-renewable resources. The emergy of imported fuels (Table 1, item 21) represents an important fraction of the emergy imported to the country (30%). Regarding exports, metals (copper, zinc, and gold were the principal metals) represent almost 82 percent of the total exported emergy (Table 1, item 36).

A summary of flows supporting Peru's economy is given in Table 2. The diagram shown in Figure 1 further summarizes Peru's economy by aggregating emergy flows from indigenous sources ($R + N_0 + N_1 + N_2$), imports ($F + G + P_2I$), and exports ($N_2 + B + P_1E$).

Total emergy use (U) is estimated at 6.88 E+23 sej/year (Table 3, item 5), representing 63 percent of the total emergy inflows to the country (Table 3, item 4).

The flow of imported emergy $F + G + P_2I$ (Table 3, item 3) represents 10 percent of the total emergy used. On the other hand, the flow of exported emergy without use (N_2 in Table 2) represents 85 percent of the exported total emergy. There is a deficit in the emergy trade (imports – exports) (Table 3, item 8). In addition, the ratio of exported emergy to imported emergy shows a relation of 6.6/1 (Table 3, item 9).

Exports from the economy are composed of three flows: direct export of non-renewable resources (N_2), exports of products transformed within Peru (B), and emergy value of the dollar income from exported goods and services (P_1E). P_1E (169 E+20 sej/yr; Table 2) is defined as emergy-to-money ratio for Peru (P_1 = 1.01 E+13 sej/USD, this paper; Table 3, item 19) multiplied by dollars received for exports (E = 1.68 E+09 USD; Table 2, item 10). P_2I is defined as the World Emergy-to-Money ratio (P_2 = 1.85 E+12 sej/USD; Brown 2003) multiplied by dollars paid for imported services and tourism (I = 3.69 E+09 USD, Table 2, item 8).

Table 1. Emergy evaluation of the resources base for Peru (2004).

Item (*)	Flows	Raw Units		Transformity (sej/unit)	Solar Emergy (E+20 sej)
RENEWABLE RESOURCES:					
1	Sunlight	8.28E+21	J	1	82.8
2	Rain, chemical	3.87E+18	J	30500	1178.8
3	Rain, geopotential	2.11E+18	J	47000	993.3
4	Wind, kinetic energy	4.61E+18	J	2450	112.8
5	Waves	6.09E+17	J	51000	310.8
6	Tide	2.93E+18	J	73900	2163.0
7	Earth Cycle	1.48E+18	J	58000	857.9
INDIGENOUS PRODUCTION SECTORS:					
8	Hydroelectricity	6.51E+16	J	2.67E+05	173.9
9	Agriculture Production	3.59E+17	J	3.36E+05	1206.1
10	Livestock Production	1.03E+16	J	3.36E+06	346.5
11	Fisheries Production	3.28E+16	J	3.36E+06	1101.6
12	Fuelwood Production	6.50E+16	J	2.21E+04	14.4
13	Forest Extraction	6.78E+16	J	2.21E+04	15.0
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:					
14	Natural Gas	4.28E+16	J	5.88E+04	25.1
15	Oil	2.96E+17	J	8.90E+04	263.9
16	Coal	2.23E+16	J	6.69E+04	14.9
17	Limestone and fertilizers	2.74E+11	g	1.35E+10	37.0
18	Metals	7.35E+11	g	1.28E+09	9.4
19	Soil, mineral fraction	1.46E+14	g	1.68E+09	2444.4
20	Soil, organic fraction	1.02E+17	J	7.40E+04	75.3
IMPORTS AND OUTSIDE SOURCES:					
21	Fuels	2.02E+17	J	1.05E+05	212.4
22	Metals	6.53E+11	g	3.67E+09	24.0
23	Minerals	7.99E+11	g	1.10E+10	88.1
24	Food & agric. products	4.92E+16	J	3.36E+05	165.3
25	Livestock, meat, fish	4.15E+14	J	3.36E+06	14.0
26	Plastics & rubber	1.70E+16	J	1.11E+05	18.9
27	Chemicals	5.30E+11	g	1.48E+10	78.5
28	Finished materials	5.52E+11	g	3.91E+09	21.6
29	Mach.& trans equip.	2.86E+11	g	6.70E+09	19.2
30	Service in imports	2.61E+09	$	1.85E+12	48.3
31	Tourism	1.08E+09	$	1.85E+12	19.9
EXPORTS:					
32	Food & agric. products	1.21E+16	J	3.36E+05	40.5
33	Livestock, meat, fish	1.38E+16	J	3.36E+06	464.2
34	Finished materials	2.34E+11	g	3.17E+09	7.4
35	Fuels	3.52E+16	J	1.11E+05	39.1
36	Metals	1.12E+13	g	3.46E+10	3879.8
37	Minerals	1.43E+12	g	1.00E+09	14.3
38	Chemicals	6.15E+11	g	1.48E+10	91.0
39	Mach. & trans equip.	3.80E+10	g	6.70E+09	2.5
40	Plastics & rubber	5.50E+14	J	1.11E+05	0.6
41	Service in exports	1.68E+09	$	1.01E+13	169.0

(*) Footnotes to Table 1 are found at end of chapter.

Table 2. Summary of Flows in Peru (2004).

Item	Aggregated Flows	Unit	Quantity (E+20 sej/unit)	Dollars
1	R, Renewable sources	yr	2172.18	
2	N, Nonrenewable resources	yr	8024.99	
3	N_0, Dispersed Rural Source	yr	3650.59	
4	N_1, Concentrated Use	yr	350.36	
5	N_2, Exported without Use	yr	4423.58	
6	F, Imported Fuels and Minerals	yr	324.43	
7	G, Imported Goods	yr	317.39	
8	I, Dollars Paid for Imports	USD		3.69 E+09
9	P_2I, Emergy of Services in Imported Goods & Fuels	yr	68.21	
10	E, Dollars Received for Exports	USD		1.68 E+09
11	P_1E, Emergy Value of Goods and Service Exports	yr	168.97	
12	B, Exported products transformed within Peru	yr	115.80	
13	X, Gross National Product	USD		6.84 E+10

1 R: Items 2, 3, Table 1
2 $N = N_0 + N_1 + N_2$
3 N_0: Items 11, 12, 13, 19, 20, Table 1
4 N_1: Items 14 through 18, Table 1
5 N_2: Items 32, 33, 35, 36, Table 1
6 F: Items 21, 22, 23, Table 1
7 G: Items 24 through 29, Table 1
8 I: Items 30, 31, Table 1
9 P_2I: where P_2 is World Emergy/dollar ratio used in imports (1.85 E+12 sej/USD; Brown, 2003)
10 E: Item 41, Table 1
11 P_1E: where P_1 is Peru Emergy/dollar ratio used in exports, Index 19, Table 3
12 B: Items, 34, 37 through 40
13 BCRP (2005)

A significant percentage (32%) of the emergy used in Peru's economy is derived from renewable sources within the country (Table 3, item 10). Almost 10 percent of the emergy basis of Peru's economy is purchased (Table 3, item 11). One percent of the country's emergy came from imported service (Table 3, item 12). Eighty-five percent of the emergy used in the country has no economic cost (Table 3, item 13).

Peru's emergy resource use per unit area (Table 3, item 15) is 5.36 E+15 sej/ha/year, while resource use per person (Table 3, item 16) is 2.46 E+16 sej/year. The renewable carrying capacity of the country (Table 3, item 17) is 8.81 million people, or around 32 percent of today's population of 28 million inhabitants. The developed carrying capacity (Table 3, item 18) is 17.6 million people (around 63% of today's population).

DISCUSSION

The ratio of internal to rural resources used (Table 3, item 14) is a ratio that relates the percent of emergy use that flows through urbanized areas to the renewable emergy that is derived primarily from the rural landscape (Brown and McClanahan 1996). In Peru, this ratio is 18 percent, suggesting that only about one fifth of the country's emergy use is derived from internal sources that flow through urban centers. This is a low value when compared to countries like Thailand where 85 percent of their emergy use is derived from internal sources (Brown and McClanahan 1996).

Table 3. Indices using emergy for overview of Peru (2004).

Index	Name of Index	Expression	Quantity
1	Renewable emergy flow	R	2.17E+23
2	Flow from indigenous nonrenewable reserves	N	8.42E+23
3	Flow of imported emergy	$F+G+P_2I$	7.10E+22
4	Total emergy inflows	$R+N+F+G+P_2I$	1.13E+24
5	Total emergy used, U	$N_0+N_1+R+F+G+P_2I$	6.88E+23
6	Total exported emergy	P_1E	4.71E+23
7	Fraction emergy use derived from local sources	$(N_O+N_1+R)/U$	0.90
8	Imports minus exports	$(F+G+P_2I)-(N_2+B+P_1E)$	-4.00E+23
9	Export to Imports	$(N_2+P_1E)/(F+G+P_2I)$	6.63
10	Fraction used, locally renewable	R/U	0.32
11	Fraction of use purchased	$(F+G+P_2I)/U$	0.10
12	Fraction imported service	P_2I/U	0.01
13	Fraction of use that is free	$(R+N_0)/U$	0.85
14	Ratio of concentrated to rural	$(F+G+P_2I+N_1)/(R+N_0)$	0.18
15	Use per unit area, Empower Density	U/(area ha)	5.36E+15
16	Use per person	U/population	2.46E+16
17	Renewable carrying capacity in 2004	Country population	2.79E+07
	at present living standard	(R/U) (population)	8.81E+06
18	Developed carrying capacity		
	at same living standard (*)	2(R/U)(population)	1.76E+07
19	Peru Emergy/dollar ratio	P_1=U/GNP	1.01E+13
20	Ratio of electricity to use	(el)/U	2.97%
21	Fuel import per person	fuel/population	7.61E+14
22	Environmental Loading Ratio (ELR)	$(F+G+P_2I+N)/R$	2.17
23	Emergy Yield Ratio (EYR)	$U/(F+G+P_2I)$	9.69
24	Environmental Sustainability Index (ESI)	NYR/ELR	4.47

(*) We found that the total emergy was two times larger than renewable emergy available.

The renewable carrying capacity of Peru (Table 3, item 17) is around 32 percent of today's population of 27 million inhabitants, representing the number of people that could be supported on renewable sources alone, if the present living standard is maintained. This is a measure of the long-term sustainable carrying capacity for humans of a country's landscape (Brown and McClanahan 1996).

Around 94 percent (44.2 E+22 sej/yr, Table 2) of the exported total emergy (47.1 E+22 sej/yr, Table 3, item 6) is exported without use. This is very high compared to countries like United States (Odum 1996), Nicaragua (Cuadra and Rydberg 2000), Sweden (Lagerberg 1999), Thailand (Brown and McClanahan 1996), and Italy (Ulgiati et al. 1994), which export 24, 16, seven, two, and one percent, respectively, of emergy without local use. It means there is a high release of natural resources without processing within the country. The ratio of exported emergy to imported emergy is 6.63, suggesting that Peru is exporting more emergy than it is importing and that it is losing emergy in international trade. The fact that the value of imports minus exports is negative reinforces the previous affirmation (Table 3, item 8). When observing Table 1, the export of emergy in metals (Au, Cu, Zn, Fe, etc), alone represents approximately 5.5 times the total of imported emergy. These results indicate that Peru could be classified as a raw-material exporter country, because the country's exports are composed mainly of unprocessed resources (metals, livestock, meat, and fish).

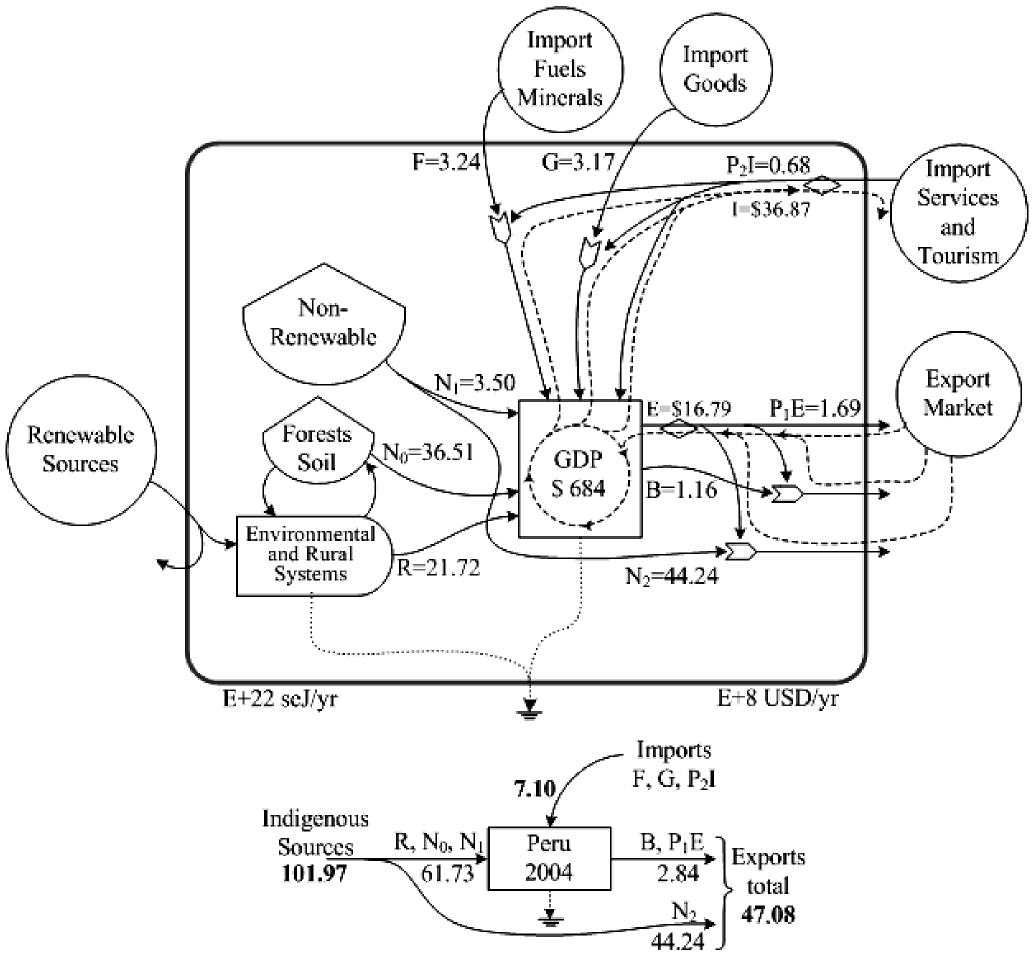

Figure 1. *Systems overview diagram summarizing all resource flows for the Peruvian economy for 2004.*

Peru's Emergy Yield Ratio (EYR) is 9.69 (Table 3, item 24) indicating a high ability of the economy to make use of the local resources. The Environmental Loading Ratio (ELR) for Peru is 2.17 (Table 3, item 23), indicating a moderate technological level, as well as moderate level of environmental stress.

When combined (EYR/ELR) in the Emergy Sustainability Index (ESI) the result is 4.47 (Table 3, item 27), which according to Ulgiati and Brown (1998), indicates that Peru has an undeveloped economy, but low environmental stress and environmental loading. This is opposite to what was found for countries like the United States (ESI = 0.48), Sweden (ESI = 0.19), Italy (ESI = 0.17), and Denmark (ESI = 0.14), which have more developed economies (Ulgiati and Brown 1998; Lagerberg 1999; and Haden 2003). Brown (2003) argues that values higher than four indicate countries with "sustaining" economies. Thus, Peru could be classified as a sustaining economy, but with a latent danger to become unsustainable if private management policies and public policy continue to ignore environmental and social aspects of country development.

CONCLUSIONS

Because of its rich availability of natural resources, Peru has become a raw materials supplier for the more industrialized countries. As a consequence, the economy has remained undeveloped and the standard of living is low compared with other Latin American countries. We think that, in order to develop its economy, many resources should be processed within the country and exported as processed or semi-processed products. In that sense, we consider that it is very important to calculate the emergy value of the natural resources and minerals of the country and, after that, to express that value in equivalent dollars (emdollar). This procedure can be offered as an alternative to PIB calculation.

The Peruvian national economy has to establish industries to process raw materials and to export resources with aggregate value. To support this strategy it will be necessary to establish new infrastructure to process local and imported oil. The country demands an up-grade of its industry. This conventional policy may improve the standard of living in Peru.

Besides that, Sustainability, Global Warming and Oil Peaking should be studied in order to discuss how the Peruvian Population will modify the political and cultural system to adjust to a new type of economy based on renewable resources. Under this perspective the local community approach and water shed planning using GIS and Emergy will be necessary. It is necessary that part of the benefits of mineral extraction can go to indigenous populations who live in the mountains near the mines. The implementation of this policy should take into consideration the local ecological culture.

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NOTES: FOOTNOTES TO TABLE 1

(Transformities before year 2000 were multiplied per 1.68)

1. SOLAR ENERGY: Cont shelf area=9.23E+11m^2 (at 200 m depth.); Land area = 1.29E+12m^2 (CIA, 2005); Insolation=1.28E+02kcal/cm^2/year; Albedo=0.30 (% given as decimal) (estimate); Energy(J)=(area incl. shelf in m^2) x (avg insolation in cal/cm^2/year) x (1-albedo) x (E+04 cm^2/m^2) x (1-albedo) x (4186 J/kcal)=8.28E+21J/year; Transformity=1sej/J by definition (Odum 1996).

2. RAIN, CHEMICAL POTENTIAL ENERGY: Land area=1.29E+12m^2; Cont shelf area = 9.23E+11m^2 (at 200 m depth.); Rain (land)=0.54 m/year (Minag 2005); Rain (shelf) = 0.24m/year (est. as 45% of tot. rain); Evapotrans. Rate =0.43m/year (est. as 80% of tot. rain); Energy (land) (J) = (area in m^2) x (evapotrans. in m)x(1000kg/m^3)x(Gibbs no. 4.94E+03J/kg)=2.75E+18J/year; Energy (shelf) (J) = (area of shelf) x (rainfall) x (Gibbs no.) = 1.11E+18 J/year; Total Energy (J)= 3.87E+18J/year; Transformity=3.05E+04sej/J (Odum et al. 2000; Folio #1).

3. RAIN, GEOPOTENTIAL ENERGY: Area=1.29E+12m^2; Rainfall=0.54m; Avg. elevation=1548m (Average elev. Coast, Andean mountain ranges and Amazon); Runoff rate=0.20% (percent. given as a decimal); Energy(J)=(area in m^2)x(rainfall in m) x (% runoff) x (avg elevation in m) x (gravity in m/s^2) x (1000kg/m^3)= 2.11E+18 J/year; Transformity = 4.70E+04 sej/J (Odum et al. 2000; Folio #1).

4. WIND ENERGY: Area=1.29E+12m^2; Density of air=1.30kg/m^3; Avg. annual wind velocity=4.00m/s (Senamhi 2004); Geostrophic wind=4.44m/s (estimate avg. annual wind velocity/0.9); Drag coeff.=0.001; Energy (J)=(area in m^2)x(air density. 1.3 kg/m^3) x (drag coefficient) x (velocity in m/s)^3 x (3.14E+07 s/year); Energy (J) = 4.61E+18 J/year; Transformity = 2.45E+03 sej/J (Odum et al. 2000; Folio #1).

5. WAVE ENERGY: Shore length=2.41E+06m (CIA, 2005); Wave height= 1.20m; Energy(J)=(shore length in m) x (1/8) x (density, 1.025E+03kg/m^3) x (gravity, 9.8 m/s^2) x (wave height in m)^2 x (velocity in m/s) x (3.14E+07s/year); Energy(J) = 6.09E+17 J/year; Transformity = 5.10E+04 sej/J (Odum et al. 2000; Folio #1).

6. TIDAL ENERGY: Cont shelf area=9.23E+11m^2; Avg tide range=0,93m (average of ten main ports; Osomarine, 2005); Density=1.03E+03kg/m^3; Tides/year= 7.30E+02 (estim. of 2 tides/day in 365 days); Energy(J)=(shelf in m^2)x(0.5)x (tides/year)x(mean tidal range)^{2}x(density of seawater in kg/m^3)(gravity, 9.8m/s^2)= 2.93E+18 J/year; Transformity=7.39E+04sej/J (Odum et al. 2000; Folio #1).

7. EARTH CYCLE: Land area=1.29E+12m^2; Heat flow=1.15E+06J/m^2=0.37W/m^2 (average value, Henry and Pollack, 1988); Energy (J) = (area in m^2) x (heat flow in J/m^2) = 1.48E+18 J/year; Transformity = 5.80E+04 sej/J (Odum 2000; Folio #2).

8. HYDROELECTRICITY: Kilowatt hr/year=1.81E+10kwh/year (Osinerg, 2005); Energy (J) = (Energy production in kwh/year)x(Energy content, 3.6E+06J/kwh) = 6.51E+16J/year; Transformity=2.67E+05sej/J (Odum 1996).

9. AGRICULTURAL PRODUCTION: Production = 2.68E+07 t (Dry mass, 20% humidity) (Minag 2005); Energy (J) = (total production in t) x (Energy content, 1E+06g/t) x (80%) x (4.0kcal/g) x (4186 J/kcal) = 3.59E+17J/year; Transformity= 3.36E+05sej/J (Brown and MacClanaham 1996).

10. LIVESTOCK PRODUCTION: Livestock production=2.46E+06t (80% humidity) (Faostat 2004); Energy (J) = (total production in t)x(Energy content, 1E+06g/t)x (20%) x (5.0kcal/g) x (4186J/kcal)=1.03E+16J/year; Transformity=3.36E+06sej/J (Brown and MacClanaham 1996).

11. FISHERIES PRODUCTION: Fish catch=7.83E+06t (80% humidity) (Inei 2005); Energy(J)=(total production in t)x(Energy content, 1E+06g/t)x(5.0 kcal/g)x(20%) x (4186 J/kcal) = 3.28E+16 J/year; Transformity = 3.36E+06 sej/J (Brown and MacClanaham 1996).

12. FUELWOOD PRODUCTION: Fuelwood prod = 9.29E+06 m^3 (Faostat 2004); Energy(J)=(total production in m^3)x(Energy content, 0.58E+06g/m^3)x(3.6kcal/g)x (80%)x(4186J/kcal)=6.50E+16J/year (Energy content, 0.58E+06g/m^3 of Rueda and Williamson, 1992); Transformity=2.21E+04sej/J (Romitelli 2000).

13. FOREST EXTRACTION: Harvest = 1.13E+07 m^3 (Faostat 2004); Energy (J) = (total production in m^3) x (Energy content, 0.58E+06 g/m^3) x (80%) x (3.6 kcal/g) x (4186 J/kcal)=6.78E+16J/year; Transformity=2.21E+04sej/J (Romitelli 2000).

14. NATURAL GAS: Consumption=1.14E+09m^3/year (Minem 2005); Energy(J)= (cons. in m^3/year)x(Energy content, 8966kcal/m^3)x(4186J/kcal)=4.28E+16J/year; Transformity=5.88E+04sej/J (Romitelli 2000).

15. OIL: Consumption = 2.96E+17 J/year (Minem 2005); Transformity = 8.90E+04 sej/J (Odum 1996).

16. COAL: Consumption=2.23E+16J/year (Minem 2005); Transformity= 6.69E+04 sej/J (Odum 1996).

17. MINERALS (including limestone and fertilizers): Consumption=2.74E+05 t/year; (Mef 2005); Mass (g) = (cons. in t/year) x (1E+06 g/t) = 2.74E+11 g/year; Transformity = 1.35E+10 sej/g (weighed 2.99E+10 sej/g P; 2.92E+09 sej/g K; 7.73E+09 sej/g N, Odum 1996).

18. METALS: Zinc=1.74E+05t/year (Mef 2005); Transformity=1.43E+09sej/g (Odum 1996); Iron=4.38E+05t/year (Mef 2005); Transformity= 1.44E+09sej/g (Odum 1996); Copper=9.55E+04t/year (Mef 2005); Transformity=1.61E+08 sej/g (Odum and Arding 1991); Gold = 2.14 t/year (Mef 2005); Transformity = 4.22E+08 sej/g (Odum and Arding 1991); Others = 2.84E+04 t/year (Mef 2005); Transformity=1.68E+09sej/g (Odum 1996); Total consumption=7.35E+05t/year; Mass(g)=(cons. in t/year)x(1E+06g/t)= 7.35E+11g/year; Transformity (weighed) = 1.28E+09sej/g.

19. SOIL, MINERAL FRACTION: Harvested cropland=3.75E+08m^2; Soil loss= 4.00E+05 g/m^2/year (Valdivia 2002); Mass (g) = (soil loss in g/m^2/year) x (harvested cropland in m^2)=1.46E+14 g/year; Transformity (world sedimentary cycle) = 1.68E+09 sej/g (Odum 1996).

20. SOIL, ORGANIC FRACTION: Average organic content (%) = 3% (Scott 1999); Energy (J) = (soil loss in g/m^2/year) x (harvested cropland in m^2) x (% organic) x (5.4kcal/g) x (4186 J/kcal) = 1.02E+17 J/year; Transformity = 7.40E+04 sej/J (Brown and Bardi 2001).

21. FUELS: Oil derived fuels = 1.76E+17 J/year (Minem, 2005); Transformity = 1.11E+05 sej/J (Odum 1996); Coal = 2.67E+16 J/year (Minem 2005); Transformity = 6.69E+04 sej/J (Odum 1996); Transformity (weighed)= 1.05E+05 sej/J.

22. METALS: Aluminum=7.63E+03t/year (Mef 2005); Transformity=1.25E+10 sej/g (Brown and Buranakan 2000); Iron and steel=6.37E+05t/year (Mef 2005); Transformity = 2.78E+09 sej/g (Brown and Buranakan 2000); Copper wire = 3.12E+03 t/year (Mef 2005); Transformity=1.66E+11sej/g (Odum 1996); Others = 4.78E+03 t/year (Mef 2005); Transformity = 1.68E+09 sej/g (Odum 1996); Mass (g) = (total imported in t/year)x(1E+06g/t)=6.53E+11g/year; Transformity (weighed) = 3.67E+09 sej/g.

23. MINERALS: Cement=5.80E+03t/year (Mef 2005); Transformity=1.97E+09sej/g (Brown and Buranakan 2000); Phosphorus=1.65E+05t/year (Mef 2005); Transformity=2.99E+10sej/g (Odum 1996); Potash=8.43E+04t/year (Mef 2005); Transformity=2.92E+09sej/g (Odum 1996); Nitrogen=4.47E+05 t/year (Mef 2005); Transformity=7.73E+09sej/g (Odum 1996); Others= 9.70E+04t/year (Mef 2005); Transformity=1.68E+09sej/g (Odum 1996); Mass(g)=(total import. in t/year)x(1E+06g/t)=7.99E+11g/year; Transformity(weighed)=1.10E+10 sej/g.

24. FOOD AND AGRICULTURAL PRODUCTS: Imports=4.20E+06t/year (Mef 2005); Energy(J)=(import. in t/year)x(1E+06g/t)x(3.5kcal/g)x(4186 J/kcal)x(80%) =4.92E+16J/year; Transformity=3.36E+05sej/J (Brown and MacClanaham 1996).

25. LIVESTOCK, MEAT, FISH: Imports=9.02E+04 t/year (Mef 2005); Energy (J) = (import. in t/year)x(1E+06 g/t)x(5 kcal/g)x(4186 J/kcal)x(0.22 protein)=4.15E+14 J/year; Transformity=3.36E+06 sej/J (Brown and MacClanaham 1996).

26. PLASTICS & RUBBER: Imports = 5.68E+05 t/year (Mef 2005); Energy (J) = (import. in t/year)x(1000kg/t)x(30.0E+06J/kg)=1.70E+16J/year; Transformity= 1.11E+05sej/J (Odum 1996).

27. CHEMICALS: Imports=5.30E+05t/year (Mef 2005); Mass(g)=(import. in t/year) x (1E+06 g/t)= 5.30E+11 g/year; Transformity = 1.48E+10 sej/g (Brown and Arding 1991).

28. FINISHED MATERIALS: Lumber=8.82E+04t/year (Mef 2005); Transformity= 8.80E+08sej/g (Brown and Buranakan 2000); Paper=2.92E+05t/year (Mef 2005); Transformity=3.69E+09sej/g (Luchi and Ulgiati 2000); Others=1.71E+05t/year (Mef 2005); Transformity=5.85E+09sej/g (as pvc) (Brown and Buranakan 2000); Mass (g) = (import. in t/year) x (1 E+06 g/t) = 5.52E+11 g/year; Transformity (weighed) = 3.91E+09 sej/g.

29. MACHINERY, TRANSPORTATION, EQUIPMENT: Imports = 2.86E+05t/year (Mef 2005); Mass (g) = (import in t/year) x (1 E+06 g/t) = 2.86E+11 g/year; Transformity=6.70E+09sej/g (Brown and Bardi 2001).

30. IMPORTED SERVICES: Dollar value=2.61E+09$US (FAO 2003); World emergy/$ ratio=1.85E+12sej/USD (Brown 2003).

31. TOURISM: Dollar value=1.08E+09 USD (Mincetur 2005).

32. FOOD AND AGRICULTURAL PRODUCTS: Exports=1.03E+06t/year (Mef 2005); Energy(J) = (export in t) x (1E+06 g/t) x (80%) x (3.5cal/g) x (4186 J/cal)= 1.21E+16J/year; Transformity=3.36E+05sej/J (Brown and MacClanaham 1996).

33. LIVESTOCK, MEAT, FISH: Exports=3.00E+06 t/year (Mef 2005); Energy (J)= (export in t) x (1E+06 g/t) x (5 cal/g) x (4187 J/cal) x (0.22 prot)=1.38E+16J/year; Transformity=3.36E+06sej/J (Brown and MacClanaham 1996).

34. FINISHED MATERIALS: Exported lumber =1.18E+05t/year (Mef 2005); Transformity=8.80E+08 sej/g (Brown and Buranakan 2000); Exported paper= 1.85E+04t/year (Mef 2005); Transfomity=3.69E+09sej/g (Luchi and Ulgiati 2000); Others=9.75E+04t/year (Mef 2005); Transformity=5.85E+09sej/g (as pvc) (Brown and Buranakan 2000); Mass (g) = (export in t) x (1 E+06 g/t) = 2.34E+11g/year; Transformity(weighed)=3.17E+09sej/g.

35. FUELS: Oil derived fuels=3.52E+16J/year (Minem 2005); Transfomity= 1.11E+05sej/J (Odum 1996).

36. METALS: Iron ore=8.88E+04t/year (Mef 2005); Transformity=1.44E+09sej/g (Odum 1996); Cinc=2.08E+06t/year (Mef 2005); Transformity=1.68E+09sej/g (Odum 1996); Copper wire=2.24E+06t/year(Mef 2005); Transformity= 1.66E+11sej/g (Odum 1996); Gold=4.35E+02t/year (Mef 2005); Transformity= 4.22E+08sej/g (Odum and Arding 1991); Others=6.81E+06t/year (Mef 2005); Transformity=1.68E+09sej/g (Odum 1996); Mass(g)=(export in t)x(1E+06g/t)= 1.12E+13g/year; Transformity (weighed)=3.46E+10sej/g.

37. MINERALS: Cement=6.98E+05t/year (Mef 2005); Transformity=1.97E+09sej/g (Brown and Buranakan 2000); Phosphorus=6.75E+04t/year (Mef 2005); Transformity = 2.99E+10 sej/g (Odum 1996); Nitrogen = 1.03E+04 t/year (Mef 2005); Transformity= 7.73E+09sej/g (Odum 1996); Others=6.51E+05t/year (Mef 2005); Transformity=1.68E+09sej/g (Odum 1996); Mass(g)=(export in t)x (1E+06g/t)=1.43E+12g/year; Transformity (weighed)=3.20E+09sej/g.

38. CHEMICALS: Exports=6.15E+05t/year (Mef 2005); Mass(g)=(export in t)x (1E+06g/t)=6.15E+11g/year; Transformity=1.48E+10sej/g (as pesticides) (Brown and Arding 1991).

39. MACHINERY, TRANSPORTATION, EQUIPMENT: Exports = 3.80E+04 t/year (Mef 2005); Mass (g) = (export in t/year) x (1 E+06 g/t) = 3.80E+10 g/year; Transformity=6.70E+09sej/g (Brown and Bardi 2001).

40. PLASTICS & RUBBER: Exports = 1.83 E+04 t/year (Mef 2005); Energy (J)= (export in t/year)x(1000 kg/t)x(30E+06 J/kg)=5.50E+14; Transformity=1.11E+05 sej/J (Odum 1996).

41. SERVICES IN EXPORTS: Dollar value = 1.68 E+09 USD (Faostat 2004).