EMERGY ANALYSIS OVERVIEW OF THIRTEEN NATIONS*

Howard T. Odum
Elisabeth C. Odum

with contributions by

Gisela Bosch
Leon C. Braat
William Dunn
Gordon de R. Innes
Gonzague Pillet
John R. Richardson
David M. Scienceman
Jan P. Sendzimir
David J. Smith
Michael V. Thomas

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International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

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1. INTRODUCTION AND CONCEPTS

Overview perspectives on whole nations and their public policies have often come from broad education, history, experience, interpretation of economic indices, and common-sense wisdom, all difficult to learn. As the world moves into uncharted patterns of culture, technology and environmental relationships, better ways are needed for gaining overviews of national systems and their international exchanges.

In this study an energy systems procedure is applied to nations, evaluating their energetics and basis for economic vitality. New perspectives result on growth, foreign trade, defense, environmental management, standard of living, carrying capacity and future trends.

The various economic measures that are usually used for comparing nations come from human willingness to pay in markets. However, here a different approach uses concepts of energy from science and engineering to evaluate national characteristics. It differs from earlier efforts to do this by recognizing and evaluating the different qualities of energy and resources. See brief review of earlier efforts (Odum, 1983).

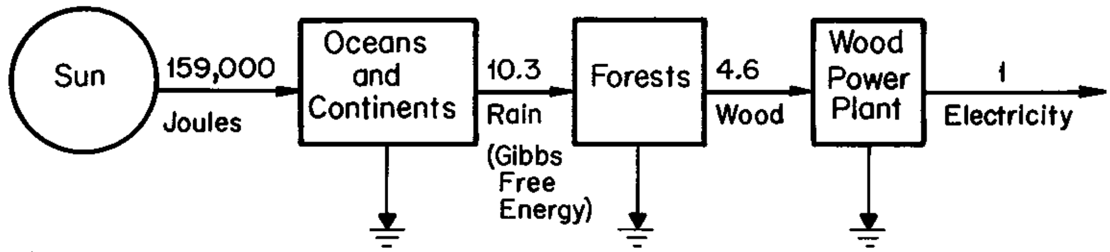
In order to measure the contribution that a resource makes to an economy a common demonimator was needed that puts resources and inputs of different kinds on a common basis of their substitutability. In this paper a new measure EMERGY, spelled with an M, was used as a common denominator to evaluate the environmental and resource basis of nations. Then indices were calculated for comparing nations and their exchanges.

1.1 EMERGY

EMERGY, spelled with an M, is defined as the energy of one type required to generate a flow or storage of another kind. In this paper solar EMERGY is used. Its unit of measure is the solar emjoule, abbreviated sej. The concept has been in use for a decade (Odum, 1976) under the name "embodied energy." However, that name is ambiguous, since there are several different concepts of embodied energy in the literature, which should not be confused. The new name EMERGY was suggested by David Scienceman of the University and Schools Club, Sydney, Australia, as appropriate for a new concept of "energy memory."

For example, in Figure 1 the solar EMERGY of rain falling on Jari has 159,000 solar emjoules per year (Odum et al., 1985).

EMERGY is a measure of input contribution to vitality of the combined economy of humans and nature. By expressing resources, fuels, environmental



Solar EMERGY of these flows is 159,000 solar emjoules/unit time.

Solar Transformities in solar emjoules per joule (sej/j):

$$\text{Rain} = \frac{159{,}000 \text{ solar joules}}{10.3 \text{ rain joules}} = 1.54 \text{ E4 sej/j}$$

$$\text{Wood} = \frac{159{,}000 \text{ solar joules}}{4.6 \text{ wood joules}} = 3.46 \text{ E4 sej/j}$$

$$\text{Electricity} = \frac{159{,}000 \text{ solar joules}}{1 \text{ electricity joule}} = 15.9 \text{ E4 sej/j}$$

Figure 1. Example of chain of energy transformations in a wood power plant at Jari, Brazil, showing calculation of solar transformities (Odum et al., 1986).

work, and human work on a common basis in EMERGY units, they are all expressed in units that measure resource substitutability.

Because of the way EMERGY is defined, maximizing EMERGY inputs and use maximizes vitality of the combined and coupled system of the economy and nature.

In this paper EMERGY is capitalized so as to clearly distinguish it from energy, which has similar spelling.

1.2 Transformity

Transformity is defined as the EMERGY of one type required to generate energy of another kind. In this paper solar transformities are used which are the joules of solar energy required to generate a joule of another kind of energy. The units are solar emjoules per joule which is abbreviated sej/J.

The concept was defined earlier (Odum, 1976) as "energy transformation ratio" but was later named transformity (Odum, 1986). Since it measures the convergence of energy of one scale in generating items of larger scale in natural hierarchies, it is an energy scale factor of nature.

An estimate of transformity of a commodity was obtained by an EMERGY analysis of the system producing that commodity. For example, solar transformities for agricultural inputs and products were obtained by systems evaluations for fertilizers, corn, honey, wool, etc. (Odum, 1984b).

Estimates of transformities of environmental inputs such as direct sunlight, rain, rock uplift, tides, waves, etc., were obtained from the global web of energy flow (Odum, 1978; Odum et al., 1983).

Starting in 1983, our calculations of the solar EMERGY generating the atmospheric, oceanic, gelological, and biological processes included the total solar insolation of the earth plus the solar EMERGY of the earth heat flow causing geologic convection cycles. Data on the heat budget of the earth from Sclater et al. (1980) were used to identify the heat from the earth, which was equilvaent to solar insolation. The result suggests that the annual solar EMERGY use from the earth heat (from radioactivity and residual heat (3.93 E24 sej/yr) is about equal to that from the direct sunlight (4.07 E24 sej/yr). Adding this earth heat source of EMERGY increased the transformities used prior to 1983.

The transformities used in this bulletin are given in Table 1, which indicates the source of each.

For example, the solar transformity of electricity was estimated from the solar EMERGY used by a wood power plant in generating electricity at Jari, Brazil. See Figure 1 (Odum et al., 1986).

1.3 Macroeconomic Value

Macroeconomic value is defined as the dollars of gross economic product of a nation which could be assigned to an input in proportion to the EMERGY

Table 1. Solar transformities used in this study.

Footnote*	Item	Transformity sej/J	Transformity sej/g
1	Solar energy	1	
2	Vapor gradient in surface winds	62	
3	Kinetic energy in surface winds	623	
4	Uranium-generated heat	1,800	
5	Geothermal heat	6,100	
6	Plantation pine wood	6,700	
7	Physical potential energy in rain over land	8,888	
8	Chemical energy in rain dispersed over land	15,423	
9	Tides absorbed on shores and shelves	23,564	
10	Physical potential energy in rivers	23,564	
11	Waves absorbed at shore	25,889	
12	Earth cycle without net uplift	29,000	
13	Harvested rainforest wood	34,900	
14	Coal	40,000	
15	Chemical energy in rivers	41,068	
16	Natural gas	48,000	
17	Oil	53,000	
18	Topsoil profile	63,000	
19	Corn from intensive agriculture	68,000	
20	Electricity	159,000	
21	Bananas	530,000	
22	Butter	1,300,000	
23	Mutton	1,710,000	
24	Wool	3,800,000	
25	Veal	4,000,000	
26	Nitrogen fertilizer		1.69 E6
27	Potassium fertilizer		2.62 E6
28	Bauxite		8.5 E8
29	Iron ore		8.6 E8
30	Iron		1.28 E9
31	Machinery		6.7 E9
32	Soil clay		1.71 E9
33	Phosphate rock		1.41 E10
34	Aluminum ingots		1.63 E10

sej/J = solar emjoules per joule
sej/g = solar emjoules per gram
* Calculations are given in the Appendix: Footnotes for Table 1.

contribution of that input. For example, if the annual solar EMERGY of beach waves is 7% of the total solar EMERGY budget of Dominica, then waves are assigned 7% of the gross economic product.

Figure 2 shows main inputs to a natural economy from local environment. Sources on the left are from resource reserves within the boundary and imports from the right. The sum of these divided by gross national product is the EMERGY/$ ratio (Figure 2b). More detail is given in Figure 3.

If the EMERGY/$ ratio of a nation has been calculated for a given year, then an EMERGY contribution may be divided by the EMERGY/$ ratio to obtain the macroeconomic value. For example, the waves received on the shores of Dominica have a macroeconomic value of 5.3 million 1980 dollars (47 E18 sej/yr divided by 8.7 E12 sej/$).

This concept should not be confused with regular economic value, which is derived from the willingness of humans to pay, as in a market. Macroeconomic value is what the public policy should consider when planning to maximize economic vitality.

1.4 EMERGY in Webs and Double Counting

EMERGY is defined as a sum of entirely separate pathway inputs not counting closed loop feedbacks. An input that is a by-product of inputs already counted should not be recounted. To do so is called double counting. Diagramming a larger system than the one analyzed is necessary to determine which are separate independent inputs and which are by-products. For example, direct sunlgiht is already included in the transformity for rain and should not be counted again.

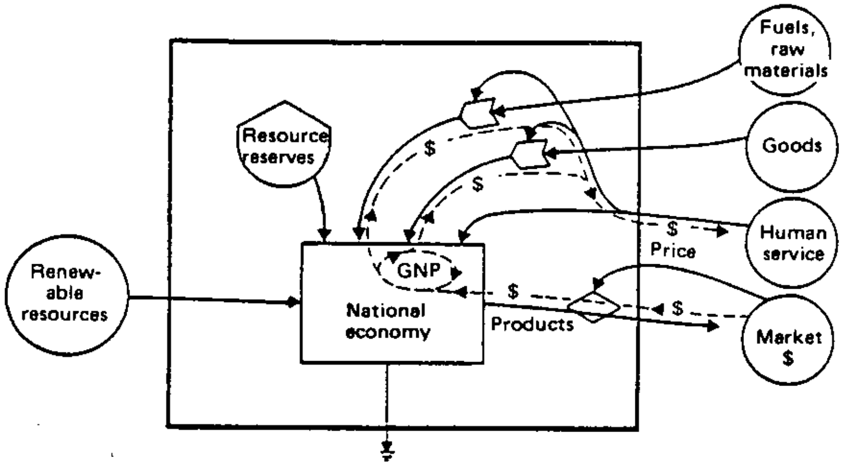
EMERGY in human service inputs was often evaluated from economic data using the appropriate EMERGY/$ ratio. In the same evaluation the EMERGY evaluation of commodities was often made with transformities that included human service. Thus, some human services could be counted twice. Figure 3 shows the way services became part of the EMERGY of inputs F and G. Usually the correction was 1% or less and ignored. Corrections were applied where double counting was larger.

2. METHODS

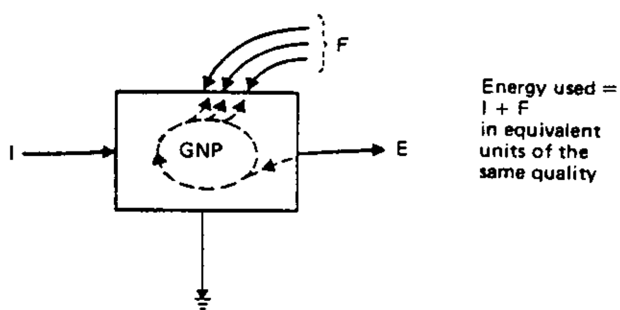
In this study EMERGY and macroeconomic values of inputs to countries and resource reserves were evaluated and used to calculate indices for comparing countries. Raw data were assembled into an EMERGY Analysis Table in which calculations were made. By summing some of the items from this table, aggregate flows were calculated and used to calculate EMERGY Indices for comparing nations.

2.1 Raw Data

Evaluation of an input began with raw data from various sources of geographical or economic data and statistics. Data on energy inputs were usually expressed in energy units (joules), minerals in mass units (grams), and



(a)



(b)

Figure 2. Overview diagrams of a national economy. (a) Main flows of dollars and EMERGY; (b) summary of procedure for summing EMERGY inflows. Exports are subtracted only if they are raw products exported without transformation, such as minerals.

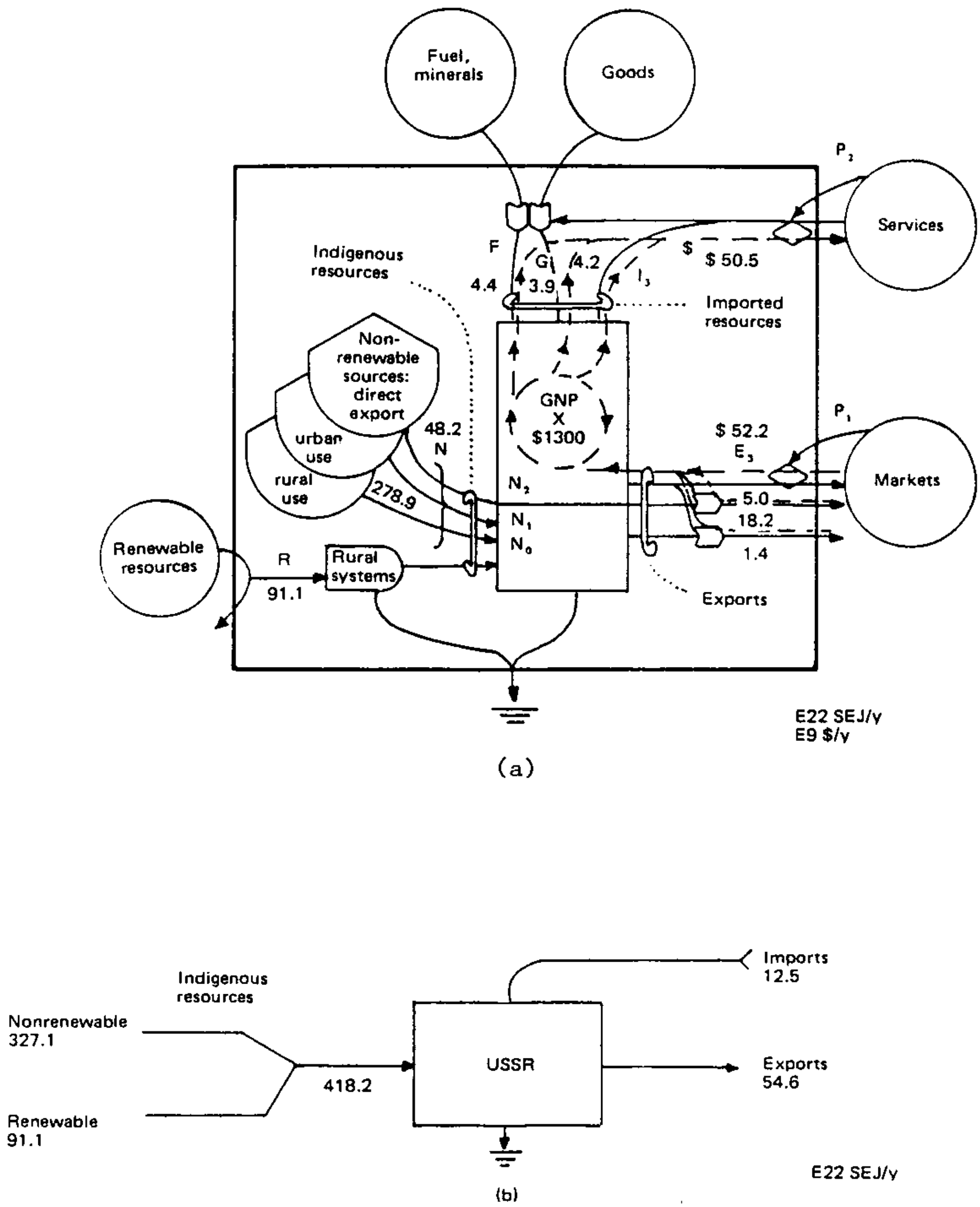


Figure 3. Summary diagrams of the EMERGY flows of the U.S.S.R. (a) Main flows; (b) three-arm diagram.

human labor and services in currency units (i.e., $). The various formulae used for evaluating environmental inputs in energy units are given in Table 2.

2.2 EMERGY Analysis Table

Overview EMERGY Analysis of a nation was done by evaluating an EMERGY Analysis Table like that in Tables 3 and 4 for the Soviet Union. One table is for annual use; the other is for storage reserves.

An overview energy systems diagram was prepared with the help of people knowledgeable of that nation. See, for example, Figure 5 for the Soviet Union. Symbols used are identified in Figure 4. Then the main inputs to that nation from outside were identified and main resource uses from storage reserves. These became line items in the EMERGY table. Each was evaluated separately even if it overlapped and inlcuded other items in the table.

As shown in Tables 3 and 4, each item was evaluated in raw units that are typical for that class of input (energy, mass or $). Then in the next column the transformity was written. The next column has the EMERGY obtained from the product of raw data and the transformity (from the previous columns). Finally in the last column the macroeconomic value was calculated in units of a particular currency and year.

Comparison of EMERGY or macroeconomic values shows which inputs or storages were important to that economy.

As shown in Figure 5, the EMERGY flows may be written on the input pathways of the national energy diagram, making it quantitative and helping a reader overview what is important to that economy. For example, in the diagram of the Soviet Union the preponderance of the resource base was from indigenous non-renewable sources.

2.3 Aggregate EMERGY Flows of a Nation

With the help of the national EMERGY components diagram (Figure 5), main categories of a nation's EMERGY are aggregated, containing separate line items from the EMERGY Analysis Table. See Table 5. As given in Figure 3, these were further aggregated into the following EMERGY flows:

R, rural indigenous renewable such as rain;

N_o, rural indigenous non-renewable uses such as consumptive use of soil;

N, urban use of indigenous reserves such as minerals and fuels;

F, imported use of fuels and minerals;

G, imported use of goods;

P_2I_3, imported services, where P2 is EMERGY/$ ratio of imports expressed in dollars;

Table 2. Descriptions of energy formulae; details in Appendix Tables A and B.

Direct sunlight	Insolation data times area of the nation.
Wind energy used	Eddy transfer of kinetic energy of wind into ground system estimated from wind velocity at 1000 m and the eddy diffusion coefficient which is a function of stability.
Chemical energy, rain	Gibbs free energy of a gram of rain water relative to sea water (or to chemical potential of transpiring vegetation at that salinity) multiplied by quantity of rain.
Chemical energy, rivers	Calculation similar to that for rain.
Earth cycle heat	Heat outflow from the ground of an area estimated from the type of geology (or from heat flow data if available).
Geopotential, net uplift	Increase in potential energy estimated from distance the center of gravity is raised times mass and gravity. (Not used in this study.)
Net loss of earth	Loss or gain of mass of clay materials estimated from difference between the estimated rate of clay formation from weathering and estimated erosion rate.
Net loss of topsoil	Net gain or loss of topsoil was evaluated using joule content of organic matter as an energy index.
Geopotential, rain	Geopotential energy of a gram of rain was calculated for the height of the land relative to the lowest elevation in the country and multiplied by the quantity of rain. Where this input is minor, mean heights and mean volumes were used.
Geopotential, rivers	Similar to geopotential for rain.
Ocean waves at shore	Physical energy of ocean waves absorbed by shores was estimated by multiplying the energy per mean wave by the length of facing shore and wave velocity. Velocity was estimated using shallow water formula and the depth of the wave gauge.
Tide absorbed, estuaries	Volume of water between tides in the estuary was multiplied by work done in raising the center of gravity assuming these energies are retained within the estuary.
Tide absorbed, shelves	Calculation similar to that for estuaries assuming half of energy absorbed in shelf system.
Fuels	Weight of fuel multiplied by its unit heat content.

Table 2 continued.

Electric power	Kilowatt-hours multiplied by energy content per kilowatt-hour.
Heat, nuclear fission	Weight of uranium multiplied by fraction that is fissionable and the energy per unit.
Services	Human services evaluated in some cases by multiplying dollars paid by EMERGY/$ ratio. In other cases hours of service (including necessary off duty hours) were multiplied by metabolic energy per hour and then by transformity of the level of service.
Geothermal heat	Flow or storage of heat was multiplied by half the theoretical Carnot Efficiency of heat conversion to mechanical energy.

Table 3. EMERGY flows for the Soviet Union in 1980.

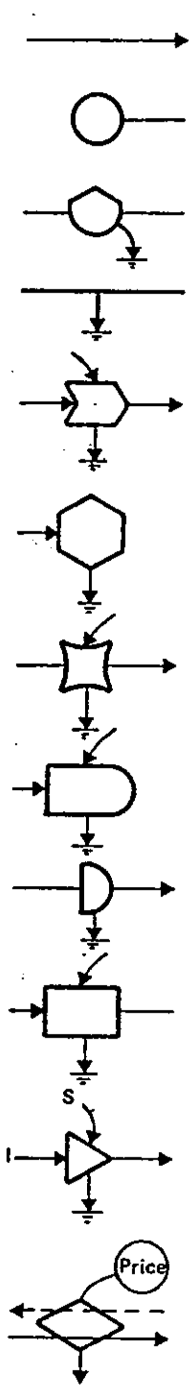
Foot-note	Type of Energy	Actual Energy J/yr	Transformity sej/j or sej/T	EMERGY sej/yr
1.	Direct sunlight	9.98 E22	1	9.98
2.	Wind, kinetic	2.48 E20	663	16.4
3.	Rain, chemical potential	5.9 E19	15,444	91.1
4.	Rain, geopotential	1.93 E19	8,888	16.9
5.	Tide	1.27 E18	23,564	29.7
6.	Waves	2.22 E15	25,889	0.57
7.	Earth cycle	3.68 E19	2.9 E4	77.7
8.	Earth deposition, 2.72 E8 T	-	1.7 E15/T	46.5
9a.	Iron production	1.89 E15	6.02 E7	11.4
9b.	Iron export	-	-	1.9
10a.	Coal production	2.30 E19	3.98 E4	91.5
10b.	Coal export	7.96 E17	3.98 E4	3.2
11a.	Oil production	2.74 E19	5.3 E4	148.4
11b.	Oil export	7.27 E18	5.3 E4	38.5
11c.	Oil import	4.24 E17	5.3 E4	2.2
12a.	Natural gas production	1.58 E19	4.8 E4	75.8
12b.	Natural gas export	-	-	4.6
12c.	Natural gas import	0.46 E18	4.8 E4	2.2
13.	Hardwood timber harvest	0.54 E18	5.7 E4	3.07
14a.	Softwood timber harvest	3.7 E18	1.9 E4	7.0
14b.	Softwood timber export	-	-	0.35
15a.	Machinery & equipment imports - 3.3 E6 T	-	5.9 E15/T	1.95
15b.	Machinery & equipment exports, 1.8 E6 T	-	5.9 E15/T	1.06
16.	Food imports	1.64 E17	2.67 E4	0.44
17a.	Electricity production	4.66 E18	15.9 E4	74.1
17b.	Hydroelectricity	6.08 E17	15.9 E4	9.6
17c.	Nuclear electricity	1.4 E17	15.9 E4	2.2
18.	Minerals, metals import	8.82 E14	1.69 E7	1.5
19.	Phosphate import, 8.2 E3 T	-	1.41 E16/T	0.0093
20.	Services in imports	-	-	31.4
21.	Services in exports	-	-	16.2

For details of calculations see Footnotes for Table 3 in the Appendix.

Table 4. EMERGY storages in the Soviet Union in 1980.

Foot-note	Type of Energy	Actual Energy J	Transformity sej/J	EMERGY E24 sej
1	Soil, chemical potential	4.69 E18	6.25 E4	0.293
2	Forest wood, conifers	2.22 E21	1.9 E4	42.1
3	Forest wood, deciduous	3.52 E20	5.7 E4	20.1
4	Water storage, chemical	2.22 E20	15,444	3.4
5	Iron, chemical potential	1.57 E18	6.02 E7	94.5
6	Coal	8.8 E21	3.98 E4	350.2
7	Natural gas	3.8 E20	4.8 E4	41.8
8	Oil	3.8 E20	5.3 E4	20.1

Footnotes with calculation details are given in the Appendix.



Energy circuit. A pathway whose flow is proportional to the quantity in the storage or source upstream.

Source. Outside source of energy delivering forces according to a program controlled from outside; a forcing function.

Tank. A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.

Heat sink. Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.

Interaction. Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.

Consumer. Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.

Switching action. A symbol that indicates one or more switching actions.

Producer. Unit that collects and transforms low-quality energy under control interactions of high-quality flows.

Self-limiting energy receiver. A unit that has a self-limiting output when input drives are high because there is a limiting constant quantity of material reacting on a circular pathway within.

Box. Miscellaneous symbol to use for whatever unit or function is labeled.

Constant-gain amplifier. A unit that delivers an output in proportion to the input *I* but changed by a constant factor as long as the energy source *S* is sufficient.

Transaction. A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed). Price is shown as an external source.

Figure 4. Symbols of the energy language used to represent national systems in overview (Odum 1983).

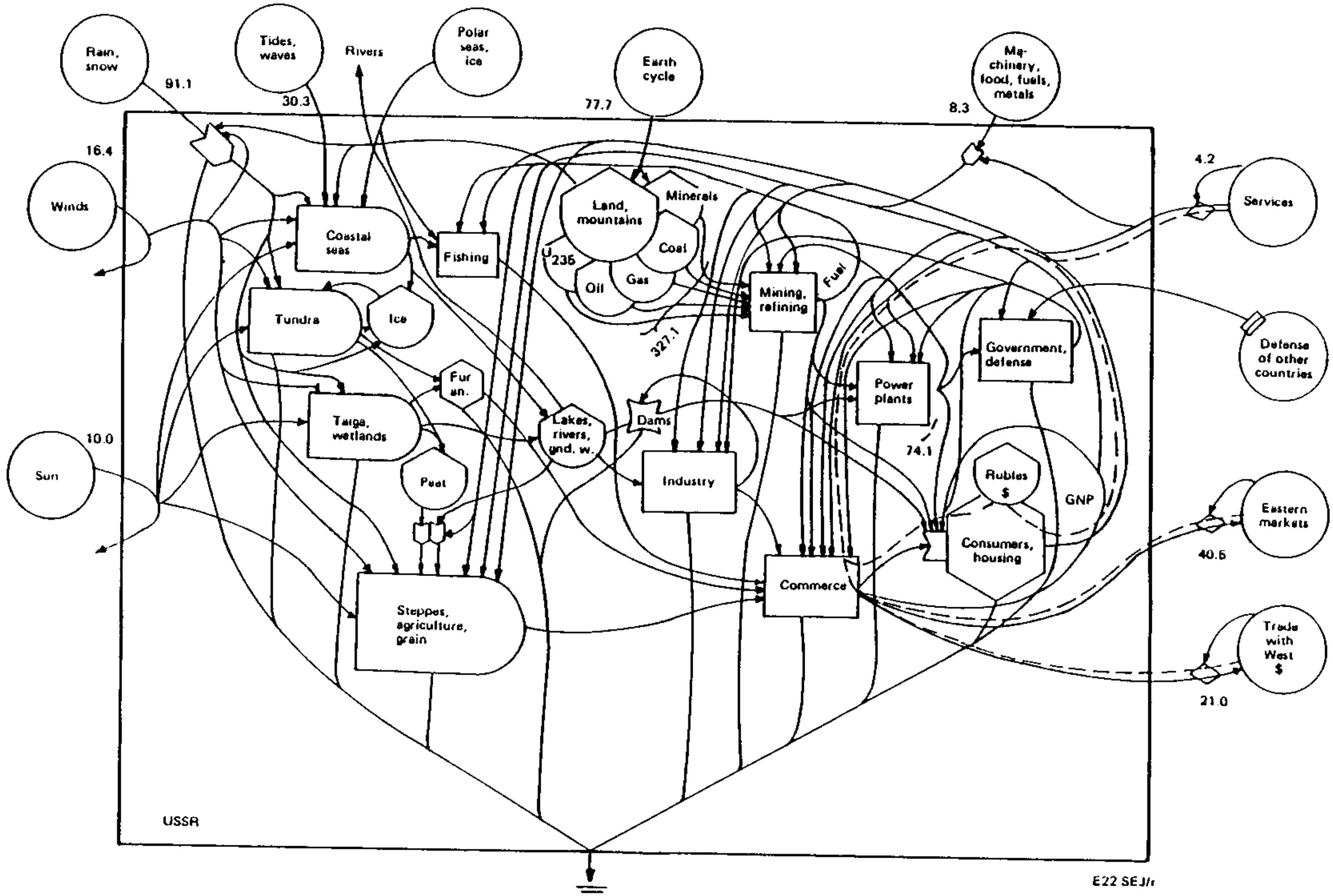


Figure 5. EMERGY diagram of the U.S.S.R.

Table 5. Aggregated EMERGY flows for the Soviet Union in 1980.

Letter in Figure 3	Item	EMERGY E22 sej/yr	Dollars E9 $ /yr
R	Renewable sources used (rain,chem.)	91.1	-
N	Nonrenewable indigenous sources		-
	N_o dispersed rural sources	-	-
	N_1 Concentrated urban use (iron, coal, oil, gas)	278.9	-
	N_2 Exported without use (iron, coal, oil, gas)	48.2	-
F	Imported minerals and fuels	4.4	-
G	Imported goods	3.9	-
P_2I_3	Imported service	4.2	-
I	Dollars paid for imports,1978	-	50.5
E	Dollars paid for exports,1978	-	52.2
P_1E_3	Exported service	5.0	-
B	Exported products transformed in the country (wood, machinery)	1.4	-
X	Gross national product	-	1300.
P_2	Embodied energy/dollar ratio of US	2.37 E12 SEJ/$	
P_1	Embodied energy/dollar ratio of USSR	3.37 E12 SEJ/$US	

N2, indigenous minerals and fuels exported without use and is omitted from the total EMERGY use (U).

2.4 EMERGY/Money Ratio

The characteristic EMERGY/$ ratio of imports was calculated by dividing the sum of annual EMERGY use (U) by the gross economic product after correcting for double counting where necessary. The EMERGY/money ratio may either be in local currency units or converted to an international currency such as US $ using market conversions at that time.

2.5 EMERGY Indices for Comparing Nations

For comparing nations, various indices may be calculated from the EMERGY flows and storages. Examples are given in Table 6 for the Soviet Union using the aggregated flows in Table 5.

EMERGY Use per area is a measure of the density of activity of the economy of humanity and nature.

EMERGY Use per person is a measure of standard of living that is better than income because it includes all the direct inputs to humans from the environment which are very large in rural, undeveloped areas.

EMERGY in Electricity per person is a measure of the high quality energy use in peoples' lives. It is high in developed countries.

Fraction of EMERGY Use which is indigenous is a measure of self-sufficiency and conversely of vulnerability in times of war.

EMERGY per $ is a measure of the real buying power of currency. It is an independently determined price index. High values mean that more of human service is supported by environmental inputs without payment. It is a measure of the ability of labor to compete in attracting labor-intensive economic activity.

2.6 Economic - Environment Ratio

Illustrated in Figure 6 is the coupling of environmental inputs to economic uses. As shown, money goes to pay for human service, which brings in resources such as fuels from outside the local area. For this index the economic feedback (F) includes resources from within and from outside the country in relation to local renewables (R). The inflows that are paid for are economic, but can be expressed in units of solar EMERGY flow. The free, renewable and local flows from nature within the country (R) are inputs such as sun, wind, and rainfall. The economic inputs were evaluated as the total (U) minus renewables (R). In highly developed countries the ratio of economic to environment inputs (F/R) is 7 or more. In the world as a whole the ratio is about 1.3 (ratio of fuel use, 10.8 E24 sej/yr to 8.0 E24 sej/yr renewable EMERGY). In undeveloped areas it is much less than one.

Table 6. Indices using EMERGY for overview of the Soviet Union.

Item	Name of Index	Expression See Figure 3	Value
1.	Renewable EMERGY flow	R	91.1 E22 sej/yr
2.	Flow from indigenous nonrenewable reserves	N	327.1 E22 sej/yr
3.	Flow of imported EMERGY	$F + G + P_2I_3$	12.5 E12 sej/yr
4.	Total EMERGY inflows	$R + N + (F + G + P_2I_3)$	431.5 E22 sej/yr
5.	Total EMERGY used, U	$U = N_o + N_1 + R + (F + G + P_2I_3)$	382.5 E22 sej/yr
6.	Total exported EMERGY	$B + P_1E$	6.4 E22 sej/yr
7.	Fraction of EMERGY used derived from home sources	$(N_o + N_1 + R) / O$	.97
8.	Exports minus imports	$(N_2 + B + P_1E) - (F + G + P_2I_3)$	42.1 E22 sej/yr
9.	Ratio of exports to imports	$(N_2 + B + P_1E)/(F + G + P_2I_3)$	4.4 /1
10a.	Fraction used of locally renewable	R/U	.24
10b.	Fraction used of nonrenewable local	$(N_o + N_1) / U$	.73
11.	Fraction of use purchased abroad	$(F + G + P_2I_3) / U$	.03
12.	Fraction used that is imported service	P_2I_3 / U	.07
13.	Fraction of use that is free	$(R + N_o) / U$	.24
14.	Ratio of concentrated to rural	$(F + G + P_2I_3 + N_1) / (R + N_o)$	3.2 /1
15.	Use per unit area (22.4 E12 m^2)	U/(area)	1.71 E11 sej/m^2/yr
16.	Use per capita (2.6 E8 population)	U/(population)	1.47 E16 sej/cap/yr
17.	Fuel per capita	373.8 E22 sej/yr/(population)	1.46 E16 sej/cap/yr
18.	Renewable carrying capacity at present standard of living	(R/&)(population)	.62 E8 people
19.	Developed carrying capacity at the same standard of living	8 (R/U)(population)	5.0 E8 people
20.	Ratio of use to Gross National Product (energy-dollar ratio)	$P_1 = U/GNP$	2.94 E12 sej/$US

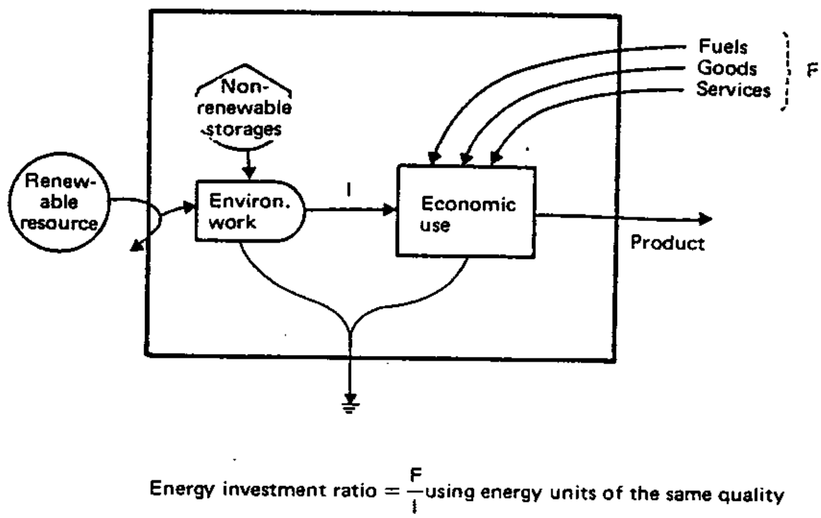


Figure 6. Diagram defining the energy investment ratio (transformity) for evaluating whether matching of investments with environmental contributions is competitive and its loading of environmental systems.

In economic competition areas with lower ratios tend to grow and develop further because there is more free resource to attract further economic investment. To economic users such an area is cheaper and gives the economic user a competitive edge. The less developed areas can take business from the areas with high ratios because their prices can be less.

This measure is also a measure of environmental loading and impact.

2.7 EMERGY Exchange Ratios

Illustrated in Figure 7 is an exchange between two countries in which there is more EMERGY transferred from one country (on the left) than is received from the other in exchange. This is the usual situation when raw commodities such as fuels, water, minerals, forest and agicultural products are sold on international markets to developed countries. If the suppliers receive only market $ value, they receive only payment for human services, whereas the buyer receives also the results of nature's service. For example, EMERGY ratio of a number of agricultural commodities yield 2.5-126 times more EMERGY to buyer than seller.

In unequal EMERGY trade situations the developed country can use the extra EMERGY received for other purposes such as luxury consumption, research, art, war, etc.

The ratio of EMERGY of imports to exports shows the status of a country in trade exchange. The ratio can be used to show how much other kinds of foreign aids, military protection, etc., the developed country could feed back in order to develop an exchange equity.

3. COMPARISONS AMONG NATIONS

In Tables 7-14 the EMERGY indices evaluated for each nation were compared. In each table nations are arranged in a different order according to the index given in that table.

3.1 EMERGY Use and Gross Economic Product

In Table 7 are given annual EMERGY uses for each country in column 1 and in column 2 the gross economic product, the latter expressed as international U.S. $ for 1980. Larger and more developed nations had larger values.

3.2 EMERGY/$ Ratio

In the third column of Table 7 is the ratio of annual EMERGY use to gross national product. The nations are arranged in declining order of the EMERGY/$ ratio. Countries with less developed and more environmental contributions have much higher values. In other words, money buys more human service in these countries. This is because more human support comes direct from the environment without payment.

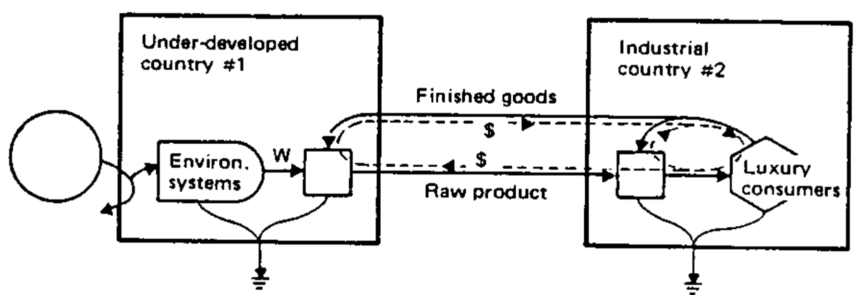


Figure 7. EMERGY and money relations in foreign trade. Although a balance of payments may exist in dollars, more work-stimulating real buying power goes from left to right than is returned from right to left. Work of nature, W, is not recognized in the payments made for the raw products.

Table 7. National activity and EMERGY/$.

Nation	U, EMERGY used/yr* E20 sej/yr	GNP E9 $/yr	EMERGY/$ E12
Liberia	465.	1.34	34.5
Dominica	7.	.075	14.9
Brazil	17820.	214.	8.4
India	6750.	106.	6.4
Australia	8850.	139.	6.4
Poland	3305.	54.9	6.0
World	188000.	5000.	3.8
Soviet Union	43150.	1300.	3.4
New Zealand	791.	26.	3.0
USA	66400.	2600.	2.6
West Germany	17500.	715.	2.5
Netherlands	3702.	16.6	2.2
Spain	2090.	139.	1.6
Switzerland	733.	102.	0.7

* Calculated as in Table 6 line 5.

3.3 Loans and EMERGY/$ Ratio

When a country with a high EMERGY/$ ratio borrows from one with a low EMERGY/$ ratio it pays back much more EMERGY than it received initially. For example, if Brazil borrows from sources in the USA when Brazil's EMERGY/$ ratio is twice that of the USA, it pays back twice as much real buying power as it received. If its interest rate for the loan is stated as 10%, it really pays back 20% in buying power. The economic depressing effects of development loans in South America is thus explained. The solution is to recompute loans and payments on an EMERGY basis rather than a currency basis.

3.4 EMERGY per Person

In Table 8 national EMERGY use (first column) is related to population given in the second column. The quotient in the the last column is the EMERGY use per person per year. High values were found in highly developed countries or sparsely settled countries. In 1980 highest values were in the US and western Europe. The lowest among countries examined was India. Because this measure includes the substantial life support of rural areas, it is a better general index of stanrdard of living than income.

3.5 Environment and Economic Components

In Table 9 components of EMERGY use are compared with renewable, free environmental inputs in the first column. The economic input in the second column is the purchased EMERGY. Its ratio to environmental input is given in the third column. Highly developed countries have more of their inputs purchased. They are vulnerable to competition from the less developed areas that have lower economic-environment ratios.

Within such a country the average ratio (column 3) provides a reference value for determining if a proposed economic activity will be economically competitive. A proposed activity is predicted by the theory to compete well if its economic-environment ratio is lower than the norm for that country. A lower ratio means it is getting more help from the environmental resource than the average economic activity in that area.

3.6 Concentration of EMERGY Use

The concentration of resource use is compared in Table 10. First a familiar measure of activity concentration is given, population density. In the next column is the concentration of EMERGY use (empower per unit area). In poor countries such as India, high densities of people were found with a lower empower density. Urbanized, developed areas with a high concentration of EMERGY, like Holland, are centers of world economic hierarchy. Developed countries with large areas of low population have a lower empower average, although their cities, if analyzed separately, might have a higher empower density.

Table 8. EMERGY use and population.

Nation	EMERGY used E20 sej/yr U*	Population E6	EMERGY use per person E15 sej/person/yr
Australia	8850	15	59
USA	66400	227	29
West Germany	17500	62	28
Netherlands	3702	14	26
New Zealand	791	3.1	26
Liberia	465	1.3	26
Soviet Union	43150	260	16
Brazil	17820	121.	15
Dominica	7	0.08	13
Switzerland	733	6.37	12
Poland	3305	34.5	10
Spain	2090	134.	6
India	6750	630.	1

* U, see example in Table 6, Line 5.

Table 9. Environment and economic components of EMERGY use.

Nation	R Environmental* component, renewable EMERGY E20 sej/yr	Economic# component of EMERGY E20 sej/yr	Economic/ environment ratio
West Germany	193	17300	90
Poland	159	2946	18.5
Holland	219	3483	15.9
Switzerland	86.8	646	7.4
USA	8240.	58160	7.1
Spain	255	1835	7.2
Dominica	1.75	4.8	2.7
World	8000	18800	2.35
Australia	4590	3960	1.1
India	3340	3410	1.0
USSR	9110	9110	1.0
New Zealand	438	353	0.8
Brazil	10200	7600	0.74
Liberia	427	38	0.09

* As calculated for Tables 5 and 6.

Total EMERGY (U in Table 7) minus renewable component = U-R.

Table 10. Concentration of EMERGY use.

Nation	Area E10 m2	Population* density people/km2	Empower density# E11 sej/m2/yr
Netherlands	3.7	378.	100.0
West Germany	24.9	247.	70.4
Switzerland	4.1	154.	17.7
Poland	31.2	111.	10.6
Dominica	0.075	107.	8.8
USA	940.	24.2	7.0
Liberia	11.1	16.1	4.18
Spain	50.5	68.5	3.12
New Zealand	26.9	11.5	2.94
Brazil	918.	13.2	2.08
India	329.	192.	2.05
Soviet Union	2240.	11.6	1.71
Australia	768.	1.9	1.42

* Population from Table 8 divided by national area where 1 $km^2 = 10^6 m^2$.

Rate of EMERGY use (Table 8) divided by national area.

3.7 Self Sufficiency and Exchange

Status of nations in international exchange is given in Table 11. In the first column of numbers are given the percent of the annual EMERGY use that is derived from within each nation's boundaries including renewable inflow and reserves. In general, the larger the country the more self sufficient.

In the last column the EMERGY exchange ratio is given relating EMERGY received from all sources to all the EMERGY exported. Concentrated developed countries that import many of their resources have high ratios, receiving more than four times more EMERGY than they give in exchange.

The EMERGY exchange of the Soviet Union with western countries and with Comecon countries in 1980 is shown in Figure 8. Whereas the balance of trade expressed in dollars shows only slight imbalance, when expressed in EMERGY units there is a large imbalance. Because of its export of fossil fuels, the Soviet Union's trade apparently helped its neighbor's economies more than its own economy. For develping equity in foreign trade, EMERGY is a better unit of measure than money.

3.8 Quality of Development

Electric power is higher quality than fuels, as shown by its solar transformity (1.6 E5 sej/J), four times that of coal (4.0 E4 sej/J). Electrical energy is a principal step in developing information and higher quality flows. The percent of a nation's EMERGY that culminates in electrical energy may be a measure of its industrial development. See Table 12. To some extent electrical use goes with availability of hydroelectric power. The nations low on the scale of electrical use have less means for processing information.

3.9 Fossil Fuels and Future Support

Because fossil fuels are the principle source of EMERGY for developed countries and also the resource being depleted world wide, the fraction of a nation's EMERGY budget from fuels is a measure of the impact declining fuels may have. In Table 13 the EMERGY use fraction due to fossil fuels is given. Clearly, most of the present developed nations with high EMERGY use are those with the largest percent of the economy to be affected.

3.10 Indigenous Renewable EMERGY

Also given in Table 13 is the percent of the current annual EMERGY budget which is renewable and indigenous (within national boundaries). This is a nation's base-level support without imports. Given in percent of present EMERGY, this indicates how much of the present activitiy could be supported if the nation became isolated from world resources outside their boundaries.

3.11 Longevity of Fuel Reserves

Different nations have different storages of fuel resources (reserves) such as coal, oil, natural gas, lignite, peat, and wood. These can be

Table 11. EMERGY self sufficiency and exchange.

Nation	EMERGY from within %	EMERGY received / EMERGY exported
Netherlands	23	4.3
West Germany	10	4.2
Switzerland	19	3.2
Spain	24	2.3
USA	77	2.2
India	88	1.45
Brazil	91	0.98
Dominica	69	0.84
New Zealand	60	0.76
Poland	66	0.65
Australia	92	0.39
Soviet Union	97	0.23
Liberia	92	0.151

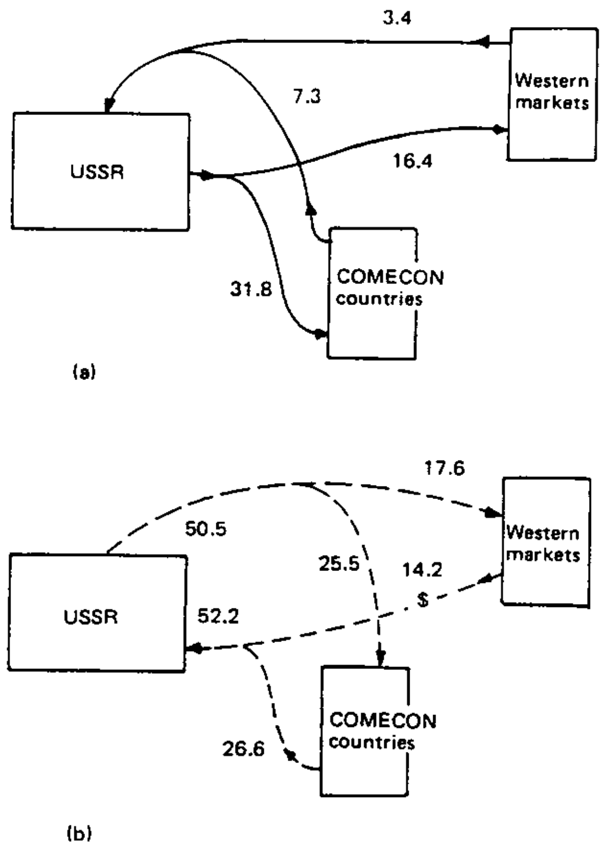


Figure 8. Import-export relations between the Soviet Union, Comecon , and Western markets. (a) EMERGY; (b) dollars.

Table 12. Percent of EMERGY that is electrical.

Nation	% Electrical
Switzerland	32
Spain	22
USA	20
Soviet Union	19
Poland	18
New Zealand	15
India	10
West Germany	10
Netherlands	10
Brazil	8
Australia	6.8
Liberia	1
Dominica	<.01

Table 13. EMERGY components in percent.

Nation	Indigenous renewable*	Fossil fuel#
Soviet Union	21	73
Poland	5	69
Australia	53	15
Spain	12	66
USA	12	59
Switzerland	12	38
Netherlands	6	32
India	50	30
West Germany	1.1	29
New Zealand	55	18
Brazil	57	16
Dominica	27	2
Liberia	92	2

* Indigenous renewable EMERGY use (R from Table 9) divided by total EMERGY use (U from Table 7) times 100.

EMERGY of annual fossil fuel use divided by total EMERGY use (U, from Table 7) times 100.

expressed as year's of duration by dividing the quantity by the rates of use per year.

To gain an aggregated perspective the total EMERGY of all the reserves of each nation were added together, regardless of type, and divided by the current annual EMERGY use budget of that country. The results in Table 14 are the numbers of years reserves might sustain the country if foreign sources were unavailable.

Thus, Tables 13 and 14 indicate nations with more indigenous resource security. Nations with more indigenous resources in the long run have a high carrying capacity in a low energy era.

3.12 EMERGY Carrying Capacity

The carrying capacity of a nation may be defined as its indigenous EMERGY use plus that which can be attracted, invested, or purchased from outside. In the previous discussions of Table 9, developed countries were observed with EMERGY of purchased economic inputs 7 to 90 times the indigenous environmental component. (See the economic/environment ratio in Table 9). By multiplying the indigenous resource flows by 7 (the ratio for U.S.A., Holland, Switzerland, Spain), the outside EMERGY that can be attracted to match indigenous resources may be calculated. This is an estimate of carrying capacity whether given in EMERGY units or macroeconomic equivalents. Defined in this way, the carrying capacity of a country is the EMERGY it would use if it had equivalent economic development to some of the most developed nations.

For a given EMERGY per person (Table 8) the population carrying capacity may be calculated by dividing the EMERGY carrying capacity by the EMERGY per person.

4. DISCUSSION

These evaluations and comparisons among nations with new EMERGY measures are an application of theory and their use may help test the utility of these measures.

With experience to date, one must regard the EMERGY evaluations as incomplete. Not only are there lesser flows that need to be evaluated, but some categories such as international immigration and information transfer are not adequately evaluated yet and will need to be added in the future. No doubt the process of getting more accurate transformities will continue.

Perhaps the next step is extending these evaluations to 146 nations of the world so that generalizations suggested here can be tested against more examples.

This paper defines new parameters for resource economics. Perhaps EMERGY analysis can become a better system for determining international values and equity.

Table 14. Longevity of fuel reserves.

Nation	EMERGY of Reserves* E22 sej	Years of support#
USA	49090	74
USSR	47400	260
West Germany	29000	166
Australia	15860	146
Brazil	7910	44
Poland	5610	170
India	1980	29
New Zealand	510	64
Liberia	509	109
Holland	383	10
Spain	256	12
Dominica	35	533
Switzerland	--	--

* Fuel reserves including wood storages.

Years if total economy were using fuels only;
EMERGY of fuel reserves divided by total EMERGY use per year (U in Table 7).

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Liberia	E.C. Odum
Soviet Union	E.C. Odum
India	E.C. Odum
USA	H.T. Odum and E.C. Odum
Holland	L. Braat
* Australia	D. Scienceman, B. El Youssef, and H.T. Odum (1986)
Poland	J. Sendzimir, H.T. Odum
Dominica	J. Sendzimir
* Switzerland	G. Pillet and H.T. Odum (1984)
* Spain	H.T. Odum (1986)
New Zealand	H.T. Odum, E.C. Odum and D.J. Smith
* Brazil	H.T. Odum (Odum et al., 1986)
Federal Republic of Germany	G. Bosch

The Australian analysis in the working paper was made by H.T. Odum, G. Innes, D. Scienceman, B. El Youssef, and M.V. Thomas. Data used here are from a later revision.

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