ELSEVIER

Ecological Modelling 73 (1994) 215–268

ECOLOGICAL MODELLING

Emergy use, environmental loading and sustainability An emergy analysis of Italy

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(Received 9 December 1992; accepted 10 August 1993)

Abstract

Maximizing emergy flow is the new statement (Odum, 1988a, 1991) of Lotka's maximum power principle (1922a,b): self-organizing systems which maximize emergy flow and reinforce production are sustainable, the others are displaced by those with better reinforcement of their productive basis. An emergy analysis of the Italian system of economy and nature was performed in order to study its sustainability and emergy use. Indices of thermodynamic and economic vitality of Italy were evaluated and a comparison with indices of other developed and developing countries was performed.

Key words: Emergy; Sustainability

1. Introduction

The interface of environment and human society is often in the marketplace where resources are exploited and sold. In the process, the environment sustains some transformations that may or may not lead to long-term stability. As the population expands, it is increasingly important that humans consider the long-term environmental consequences of their economic decisions. A long-term perspective and macroscopic view are needed to adequately factor in questions of long-term sustainability in our public policy decision process.

Too often, economics, with its short time horizon and its small, closed value system, is the guiding rationale behind public policy decisions. Its value system is small by virtue of the fact that it considers utility as the means for determining value, and it is closed because it does not extend beyond the marketplace. Thus,

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SSDI 0304-3800(93)E0060-G

public policy decisions made under the assumption of maximizing some monetary value (increased sales, profits, marginal rate of return) are, in reality, basing the decision on individual human utility. Societal needs or environmental concerns are often not factored in because they are generally outside the realm of individual human preferences.

Public policy decisions need to be made on the basis of a value system consistent with Earth dynamics and equilibria. The new public policy value system used here (emergy analysis) recognizes the differences between short-term individual human preference and long-term macroscopic well-being and is capable of quantitatively determining value at the macroscopic scale of society and environment. It can equate the value of natural resources, wildlife, and industrial production as a means of determining relative importance and their contributions to overall well-being and long-term sustainability.

The emergy system of value is based on concepts of system organization and optimization that have their bases in the work of Lotka (1922a,b, 1945), von Bertalanffy (1968) and Odum (1983a). As a result of its foundations in ecology and general system theory, the conceptual framework for an Emergy Theory of value has longer time horizons and wider applicability than marketplace economics.

A main principle that offers some clear criteria for how systems are organized and why some prevail and others do not is the Maximum Emergy (or Empower) Principle. It suggests systems that develop and prevail are those that increase and take maximum advantage of the emergy that is available. Generally, this means that the system organization that can develop uses for the most emergy in the shortest time will displace other patterns that do not use resources as effectively. Social, economic, and political systems, as well as ecologic systems, prevail in a competitive environment only if they can develop more emergy inflows and use them more effectively than their competitors, in the same period of time. The pattern that prevails links all its parts in a symbiotic array using all by-products.

According to the above general issues, the Italian system of humanity and nature was analyzed, in the larger system of biosphere.

2. The Italian system

The development of Italian civilization since the foundation of Rome (753 B.C.) until the relatively recent national unity was supported by a notable input of mineral and energy resources, first from within the surrounding area and later from the conquered countries. Rome itself was founded in the natural converging point of marine and terrestrial resources, on both banks of the Tiber river. It was situated close to the river-mouth, surrounded by a fertile plain rich with water. After the decline of the Roman Empire, the successive and very fast growth of the powerful Sea Republics in the Middle Age (Genova, Pisa, Amalfi and Venice) was also supported by a very large input of marine resources.

This large flow of resources hierarchically converging toward few areas of storage and use stimulated the growth of an ancient civilization that extended to

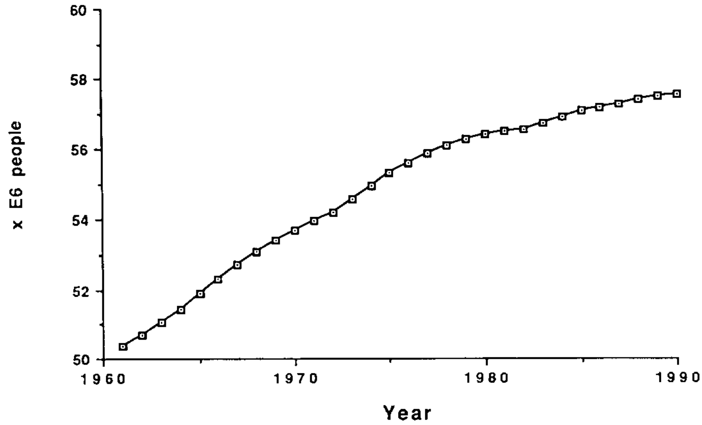

Fig. 1. Population of Italy over the last 30 years [1,2].

all of Europe and the Mediterranean countries, allowing the blooming of arts and architecture, science, and manufacturing technology. Still nowadays, even after a decrease in the political and economic importance of Italy, the country is at the point of convergence and use of a large flow of resources (for instance, today's large import of fossil fuels).

A macroscopic overview of Italy is given in Figs. 1 to 3. Fig. 1 shows the trend of population in the last 30 years; population is still growing, but the slope of the curve is decreasing and the zero-growth looks to be very close. Population density was 167 people/km^2 in 1961 and reached the level of 191 people/km^2 in the last three years (1988–90). Land use is shown in Fig. 2. Cultivated area accounts for around 56% of total surface of Italy, which is 30.1E + 6 ha. Forests cover less than

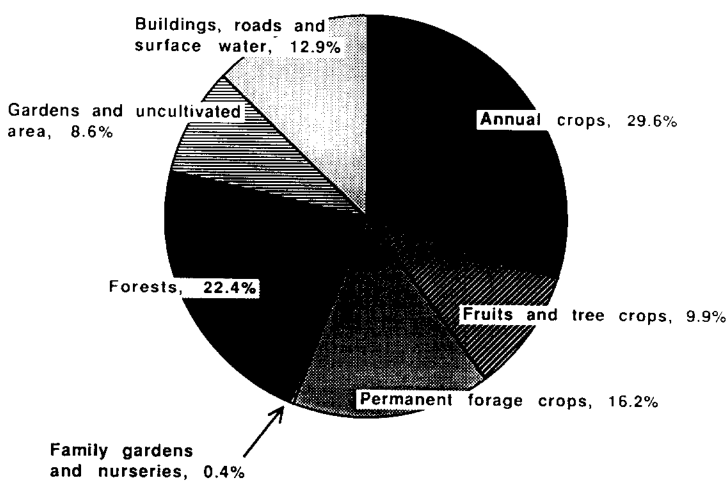

Fig. 2. Land use in Italy, 1989 (total surface of Italy is 30.1E + 6 ha) [1,2].

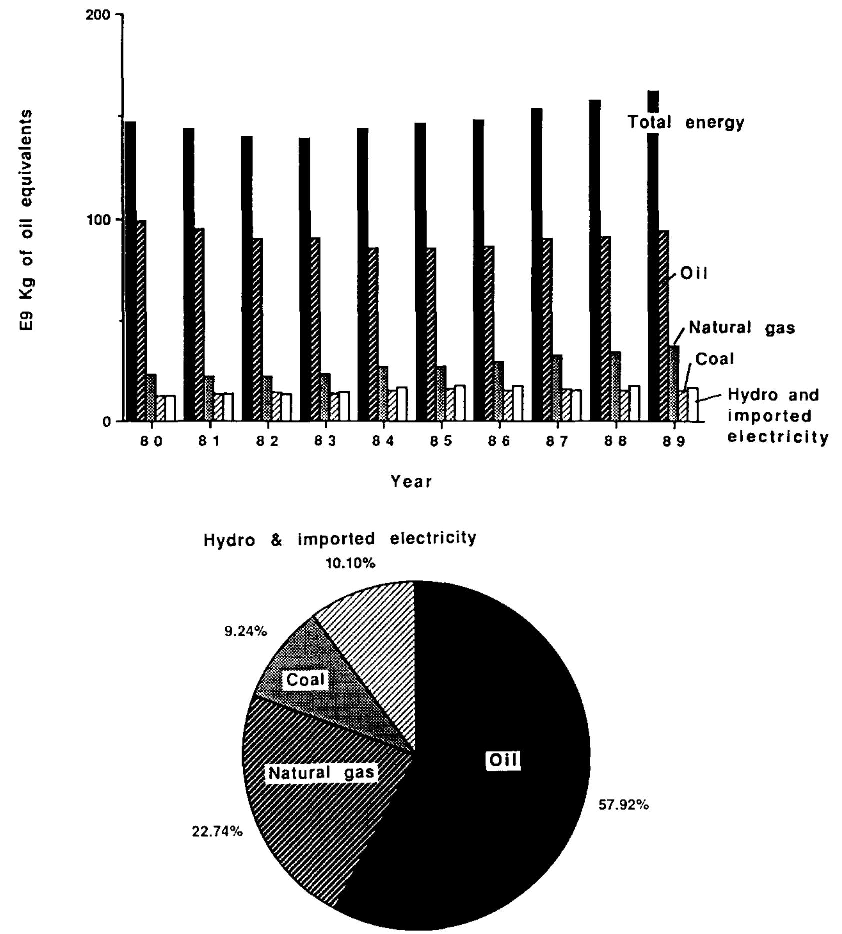

Fig. 3. (a) Conventional energy use in Italy over the last 10 years [1,3]. (b) Percentages of conventional energy use in Italy, 1989 [1,3].

one fourth of total surface. Annual crops accounted for 31.4% of total cultivated area in 1971 and 29.6% in 1989 (−1.8%); forests were 20.5% in 1971 and 22.4% in 1989 (+1.9%). The trend of slowly increasing forests can be explained by the attempt to stop the notable hydrogeologic disorder (increased runoff and erosion, modification of stream pathways, increased flooding) all around the country; in the last years, recent European Community policy suggested to decrease the exceeding production of grains and wine and to set-aside low-quality lands for reforesting. Finally, Fig. 3a shows the trend of conventional energy use in the last 10 years. The increase of total use is mostly due to increased imports of natural gas, a relatively high-quality and clean source of energy. Oil is still the main source of conventional energy (Fig. 3b). Italy has no more nuclear power plants. Conventional energy use was 2.82 tons of oil equivalent per person in 1989.

The industrial growth of the country and the industrialization of most agricultural practices have created notable environmental problems: one need only think of the contamination of the groundwater storages caused by chemicals used in agriculture, especially in the northern areas (Po river valley) (Donati et al., 1993).

Is the present state of industrial development, energy use and pollution level of Italy sustainable? Is Italian use of resources so effective that Italy can compete on foreign markets? What are the main resources that support the Italian standard of living? What is the importance of free environmental resources in the Italian system? What is the position of Italy in the general hierarchy of nations?

3. Concepts and definitions

Solar transformity and *solar emergy* (Odum, 1984, 1988a; Scienceman, 1987) are the basis of a methodology for systems analysis, being a measure for determining the best alternatives in resource use, environmental impact, national and international policies for a better equilibrium of human society and nature.

Emergy is defined as the total amount of energy of one kind directly or indirectly required to generate a product or a service. Transformity (previous name *transformation ratio*) is defined as the emergy required per unit product or service. When the total amount of energy used is in the form of coal (or coal equivalent, as usual in energy analyses) we can speak of *coal emergy* and *coal transformity*. When solar energy is considered, we can say *solar emergy* and *solar transformity*. When two primary natural processes have the same kind of product, they can be credited the same transformity. [1] By this analogy, it is possible to evaluate the relationship between primary flows having different origin, like solar energy, deep heat from earth processes or gravitational energy of tides (Odum, 1992).

Thus, we will speak of solar (equivalent) emergy and measure it in solar emergy joules (sej). We will also speak of solar (equivalent) transformity and measure it in solar emergy joules per joule or per gram of product (sej/J or sej/g). In the course of this paper we will say *emergy* and *transformity* to mean 'solar equivalent emergy' and 'solar equivalent transformity', for the sake of brevity. Transformities

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[1] The solar energy driving the ocean-winds-hydrologic cycle operates the terrestrial sedimentary cycle, which is coupled to the deep earth convection from deep heat. Rivers move sediments from the mountains to the sea, and isostatic readjustment raises the mountains to replace the matter eroded. Part of the heat that operates the convection of the sea-floor spreading cycle is from the independent heat sources deep in the earth: (a) radioactive disintegrations and (b) residual heat from earth formation (heat released when dispersed matter fell inward to the center of gravity). Heat energy is also added to the convection cycles from the surface processes that are solar driven: (c) the compression of sedimentary deposition under the river deltas; and (d) the chemical potential energy deposited in the sediments that move downward in the continental and oceanic cycles (oxidized and reduced compounds deposited together), which are later released at higher temperatures and pressures. Whereas the inflow solar energy per area of earth is dilute, a low-quality energy source, the high temperature concentrations deep in the crust are of higher quality. In overview the biogeological processes of the earth match the high-quality/low-quantity earth heat which is coamplified by the abundant flow of high-quantity/low-quality sunlight.

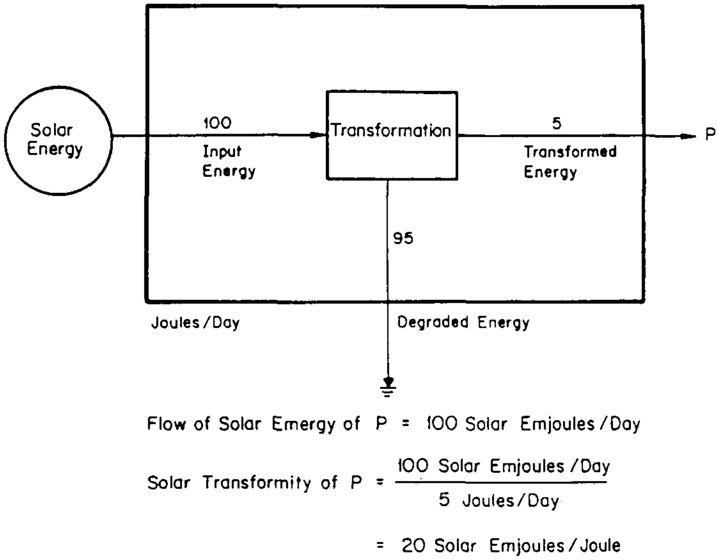


Fig. 4. Emergy, energy and transformity.

can be evaluated from input and output analyses of known natural and human processes in a steady state, i.e. in a state characterized by an optimum efficiency for maximum output, according to the maximum empower principle (Odum and Pinkerton, 1955; Odum, 1983b). Fig. 4 gives a simple scheme for evaluating emergy input and transformity in a process. Details can be found in the references cited in Appendix B.

Attempts to evaluate environmental and economic products or services in units of energy must recognize that all forms of energy do not accomplish equivalent amounts of work. To express the energy value of sunlight and fuel in joules of heat and then to suggest that each joule is equal in its ability to support work is not accurate. The "form" or "quality" of each type of energy is quite different and is capable of supporting very different types of work per unit of energy. Human labor, information, culture, complex life and expensive technological devices have relatively small energy flows, but very high solar emergy flows are required for their formation and maintenance. These are energy flows of higher quality because they have a greater ability to feed back and amplify other flows. Since more solar emergy was used to make them, their transformity is usually greater: the higher the transformity the higher the quality and the position in the hierarchy of a flow or storage.

Traditional energy or economic analyses usually do not take into account inputs they cannot evaluate on a monetary or energy basis. By doing so, different inputs have different units of measure (grams of mineral, joules of electricity, hours of labor, etc.) and a complete balance is not possible. When a transformity or an emergy content is given to a product, every input can be measured in emergy terms, i.e. on a common basis. Solar (equivalent) emergy drives the development of every system in the biosphere as well as the increase of complexity and biodiversity. The same holds for human economies, whose development is driven by unmonied inputs from nature and monied inputs from main economy. Only monetary values are recognized by the market, but economies rely upon very large inputs from environment: if these inputs are not considered and given a value, misuse of resources can follow and future prospects for the system cannot be inferred.

Solar emergy is used in this paper as a measure of work potential based on solar energy equivalence. If real surviving systems are organized to utilize emergy at optimum efficiency for maximum output, flows requiring more emergy to develop will be found only where the products of those flows have commensurate effect. Emergy is not only a measure of what went into a product, it is a measure of the useful contributions that can be expected from that product as a system self-organizes for maximum production.

Time is maybe required for self-organizing systems to develop strategies for effective use of available emergy. Studying the emergy flows and storages of a production system can help to make choices with less trial and error about what processes and designs are preferable for maximum sustainable wealth. Here we are using "wealth" to mean usable products and services however produced. Sometimes the emergy inflow to the system is not completely used by the system itself: a fraction of input emergy is exported without use, i.e. without contributing to system development. Thus hereafter we will speak both of *total emergy inflow* and *(actual) emergy use*.

4. Emergy analysis of Italy

An emergy system diagram of Italy is given in Fig. 5 for overview. Here environmental energies are diagrammed on the left-hand side of the diagram with higher-quality energy flows and storages diagrammed at the right, concluding with humans and cities as information processors whose actions affect lower level production processes.

Fig. 6 shows the national signature of emergy use for Italy. Emergy sources from within and outside the country are arranged in a column diagram from left to the right in order of their increasing transformity. Despite a common opinion that the economy of Italy mostly runs on fuels and electricity, there are very large contributions from renewable free emergy of marine resources and non-renewable emergy of minerals.

A detailed national analysis is given in Tables 1 to 3. A summary of the main emergy flows is given in Table 4 and diagrammed in Fig. 7. The emergy basis of the national economy is considered in perspective of economic and environmental emergy contributions, self-sufficiency and trade. Indices of fuel use, renewable and purchased emergy use, import–export ratios are also presented in Table 4, to lend insight to the country's emergy support basis. Their meaning is better discussed in Section 5.

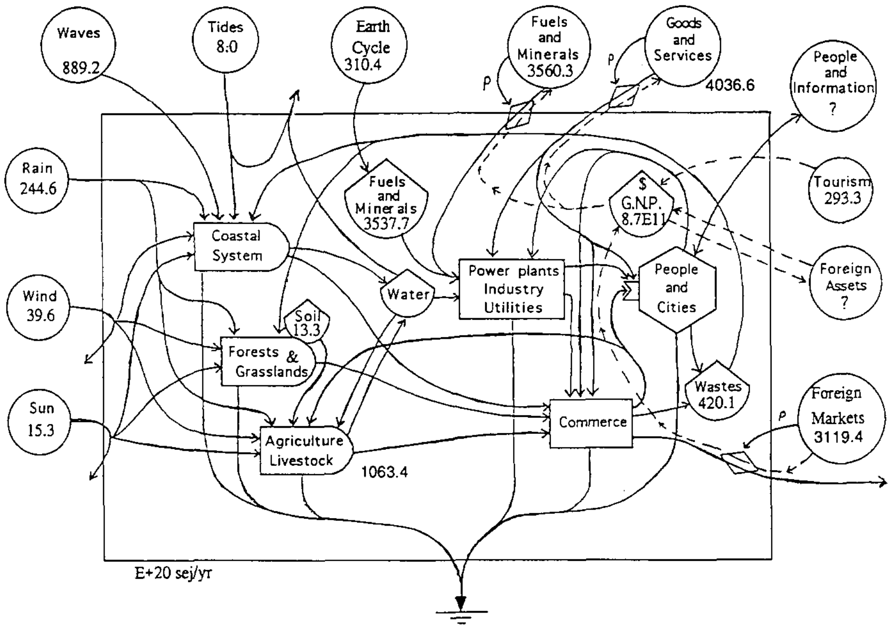


Fig. 5. Emergy diagram of Italy, 1989.

Total emergy use (U) for Italy in 1989 was estimated at 1.26E + 24 sej/yr. The total annual emergy use by a nation measures its annual wealth. By dividing the annual Italian emergy use by the GNP of Italy in 1989, the solar emergy supporting Italy's currency was calculated at 1.46E + 12 sej/$. This *emergy/money ratio*, a measure of emergy-buying power of Italian currency converted to international

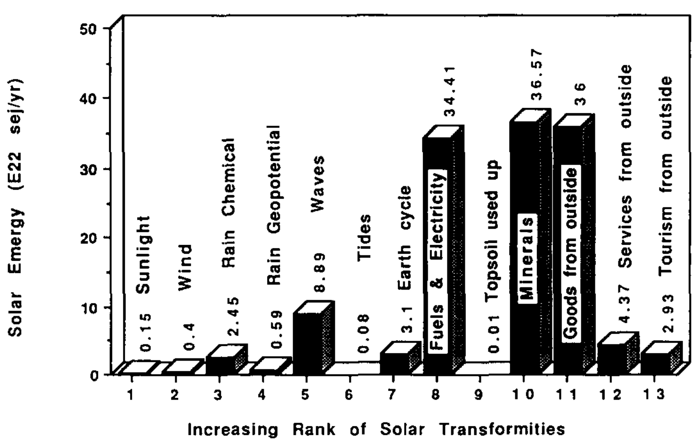


Fig. 6. National signature of emergy sources use for Italy, 1989.

Table 1
Emergy evaluation of indigenous resource basis for Italy, 1989 [a]

Note	Item	Raw units	Transform. (sej/unit)	Ref. transf. [b]	Emergy (E+20 sej/yr)	Macroecon. value [c] 1.00E+09 (1989 US $/yr)
Renewable energy sources						
1	Sunlight	1.53E+21 J	1	A	15.26	1.04
2	Rain chemical pot.	1.34E+18 J	18199	A	244.62	16.74
3	Rain geopotential	5.62E+17 J	10488	A	58.91	4.03
4	Wind kinetic	2.65E+18 J	1496	A	39.58	2.71
5	Waves	2.91E+18 J	30550	A	889.19	60.86
6	Tides	4.75E+16 J	16842	A	8.01	0.55
7	Earth cycle	9.03E+17 J	34377	A	310.42	21.25
Non-renewable sources from within the country						
8	Oil	1.93E+17 J	53000	A	102.05	6.99
9	Coal	5.61E+16 J	39800	A	22.32	1.53
10	Natural gas	5.73E+16 J	48000	A	27.53	1.88
11	Feldspar	1.34E+12 g	1.00E+09	A	13.36	0.91
12	Marl for cement	1.29E+13 g	1.00E+09	A	128.90	8.82
13	Salt rock	3.50E+12 g	1.00E+09	A	35.00	2.40
14	Potash salts	1.73E+12 g	1.00E+09	A	17.30	1.18
15	Pozzolan	5.00E+12 g	1.00E+09	A	50.00	3.42
16	Silica sand	4.30E+12 g	1.00E+09	A	43.00	2.94
17	Other sand and gravel	1.22E+14 g	1.00E+09	A	1220.00	83.50
18	Marble in blocks	3.40E+12 g	1.45E+09	A	49.30	3.37
19	Tufa	4.50E+12 g	1.00E+09	A	45.00	3.08
20	Granite	2.50E+12 g	5.00E+08	A	12.50	0.86
21	Lava, basalt, trachyte	8.00E+12 g	4.50E+09	A	360.00	24.64
22	Porphyry	1.20E+12 g	1.45E+09	A	17.40	1.19
23	Sandstone	1.80E+12 g	1.00E+09	A	18.00	1.23
24	Volcanic tuff	5.80E+12 g	4.50E+09	A	261.00	17.86
25	Limestone	1.10E+14 g	1.00E+09	A	1100.00	75.29
26	Serpentine	1.50E+12 g	1.00E+09	A	15.00	1.03
27	Net loss of topsoil	2.12E+16 J	62500	E	13.26	0.91

[a] All flows are evaluated on a yearly basis (see footnotes, Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.46E+12 sej/$ (emergy/$ ratio, Italy, 1989) [D].

dollars for 1989, is very close to the value of other industrially developed countries in the world.

The renewable environmental sources (R) are identified as waves, tides and earth cycle. They account for 9.5% of total emergy use. Rain, wind and sunlight were not added into the total of renewable flow of waves emergy since they are a part of the same coupled solar and earth-based flows: the independent emergy sources supporting each flow is the same and to add the emergy of each would be double counting. The total emergy from independent sources supporting nature and economy of Italy is calculated as the sum of free, renewable and mined,

Table 2
Emergy evaluation of commodities trade for Italy, 1989 [a]

Note	Item	Raw units	Transform. (sej/unit)	Ref. transf. [b]	Emergy (E+20 sej/yr)	Macroecon. value [c] 1.00E+09 (1989 US $/yr)
Import and outside sources						
1	Oil	4.41E+18 J	53000	A	2338.38	160.05
2	Coal	5.99E+17 J	39800	A	238.24	16.31
3	Natural gas	9.80E+17 J	48000	A	470.17	32.18
4	Electricity	1.21E+17 J	2.00E+05	A	242.64	16.61
5	Agric. & forest products	1.51E+17 J	1.04E+05	D	157.18	10.76
6	Livestock & livestock pr.	1.05E+16 J	3.17E+06	D	332.80	22.78
7	Food industry products	2.27E+17 g	2.00E+05	A	454.50	31.11
8	Fishery/hunting prod.	2.20E+15 J	2.00E+06	F	44.02	3.01
9	Metallic minerals	2.11E+13 g	1.00E+09	A	210.90	14.44
10	Metallic scraps	6.12E+12 g	2.64E+09	F	161.59	11.06
11	Non metallic minerals	6.00E+12 g	1.00E+09	A	60.00	4.11
12	Steel and pig-iron	1.37E+13 g	1.98E+09	D	271.26	18.57
13	Mech. & transp. equipm.	4.59E+12 g	6.70E+09	B	307.46	21.04
14	Non metal. miner. industry	3.88E+12 g	1.00E+09	A	38.80	2.66
15	Leather	3.91E+15 J	8.60E+06	G	336.15	23.01
16	Textiles	1.58E+16 J	3.80E+06	G	601.35	41.16
17	Rags	1.58E+16 J	3.80E+06	G	600.15	41.08
18	Wood	5.79E+16 J	34900	E	20.20	1.38
19	Wood industry products	7.44E+16 J	34900	E	25.98	1.78
20	Paper	4.67E+12 g	3.90E+09	F	182.13	12.47
21	Chemicals	1.39E+13 g	3.80E+08	B	52.82	3.62
22	Rubber	3.20E+11 g	4.30E+09	B	13.76	0.94
Exports						
23	Refined oil	6.28E+17 J	66000	A	414.41	28.37
24	Agricult. & forest prod.	2.72E+16 J	1.04E+05	D	28.25	1.93
25	Fishery/hunting prod.	2.10E+14 J	2.00E+06	F	4.21	0.29
26	Non metallic minerals	1.83E+12 g	1.00E+09	A	18.30	1.25
27	Steel and pig-iron	8.52E+12 g	1.98E+09	D	168.70	11.55
28	Mech. & transp. equipm.	9.85E+12 g	6.70E+09	B	659.95	45.17
29	Non metal. miner. industry	8.85E+12 g	1.00E+09	A	88.50	6.06
30	Leather	5.67E+15 J	8.60E+06	G	487.22	33.35
31	Textiles	1.72E+16 J	3.80E+06	G	655.47	44.86
32	Rags	6.14E+14 J	3.80E+06	G	23.33	1.60
33	Wood industry products	1.64E+16 J	34900	E	5.73	0.39
34	Paper	1.67E+12 g	3.90E+09	F	65.01	4.45
35	Chemicals	9.78E+12 g	3.80E+08	B	37.16	1.21
36	Rubber	4.11E+11 g	4.30E+09	B	17.67	1.21

[a] All flows are evaluated on a yearly basis (see footnotes, Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.46E+12 sej/$ (emergy/$ ratio, Italy, 1989) [D].

Table 3
Energy use, money flows and production for Italy, 1989 [a]

Note	Item	Raw units	Transform. (sej/unit)	Transf. ref. [b]	Emergy (E+20 sej/yr)	Macroecon. value [c] 1.00E+09 (1989 US $/yr)
Energy reserves use in the country						
1	Oil	4.60E+18 J	53000	A	2440.44	167.04
2	Coal	6.55E+17 J	39800	A	260.57	17.83
3	Natural gas	1.04E+18 J	48000	A	497.70	34.07
4	Electricity	8.80E+17 J	200000	A	1759.32	120.42
Money flows						
5	Gr. ntnl. product, 1989	8.66E+11 $	1.46E+12	D	12649.75	865.83
6	Goods imp., money basis	1.53E+11 $	2.50E+12	A	3824.46	261.77
7	Serv. imp., money basis	1.75E+10 $	2.50E+12	A	437.36	29.94
8	Tourism import	1.17E+10 $	2.50E+12	A	293.35	20.08
9	Goods exp., money basis	1.41E+11 $	1.46E+12	D	2057.88	140.86
10	Serv. exp., money basis	2.50E+10 $	1.46E+12	D	365.97	25.05
11	Tourism export	5.74E+09 $	1.46E+12	D	83.88	5.74
Production						
12	Hydroelectricity	1.35E+17 J	2.00E+05	A	270.00	18.48
13	Geoelectricity	1.13E+16 J	2.00E+05	A	22.68	1.55
14	Thermoelectricity	6.12E+17 J	2.00E+05	A	1224.00	83.78
15	Agricultural production	8.16E+17 J	1.04E+05	D	848.92	58.11
16	Livestock production	1.59E+16 J	3.17E+06	D	503.58	34.47
17	Fishery production	1.66E+15 J	2.00E+06	F	33.25	2.28
18	Industrial wastes	8.03E+13 g	3.80E+08	B	305.14	20.89
19	Urban wastes	1.10E+17 J	1.04E+05	D	113.89	7.80

[a] All flows are evaluated on a yearly basis (see footnotes, Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.46E+12 sej/$ (emergy/$ ratio, Italy, 1989) [D].

non-renewable environmental resources and the contribution of imported emergy that is used (usefully transformed) within Italy.

Internal use of stored minerals, unrefined metals and other geologic materials (N1) accounts for about 28% of Italy's annual emergy use. Almost all extracted minerals are at least partially processed within the country and their export is negligible.

Imports of goods (G1), fuels and electricity (F1), associated human services (P2I3) and tourism (T1) constituted the largest of the emergy inflows supporting Italian economy. The emergy in imported electricity and fuels (F1) and material goods (G1) represents about 54% of Italy's annual emergy use.

Italy exports 60% less emergy than it imports. Exported products and the direct and indirect emergy supporting the human labor expended in the production and transport of these products as well as in other services totals 3.12E + 23 sej/yr. Mechanical and transport equipments and textiles are the main exported products, accounting for about 57.8% of total exported emergy.

Including use of internal storages of minerals and free environmental contribu-

Table 4
Summary flows and overview indices for Italy, 1989

Item	Flow or index	Expression	Value	Unit
1	Renewable sources used (waves, tide, earth cycle)	R	1207.62	E+20 sej/yr
2	Nonrenewable sources from within Italy	N	3569.23	E+20 sej/yr
	Dispersed rural sources	No	13.26	E+20 sej/yr
	Concentrated use	N1	3537.67	E+20 sej/yr
	Exported without use	N2	18.30	E+20 sej/yr
3	Imported fuels & electricity	F1	3289.44	E+20 sej/yr
	Imported minerals	M1	270.90	E+20 sej/yr
	Imported goods (exc. fuels and minerals)	G1	3600.15	E+20 sej/yr
	Total imports (including tourism and services)	IMP	7891.20	E+20 sej/yr
4	Exported fuels	F2	414.41	E+20 sej/yr
	Exported minerals	M2	18.30	E+20 sej/yr
	Exported goods (exc. fuels and minerals	G2	2235.47	E+20 sej/yr
	Total exports (including tourism and services)	EXP	3118.04	E+20 sej/yr
5	Total emergy inflows	R+N+IMP	12668.05	E+20 sej/yr
	Total emergy used, U	R+N+IMP−N2	12649.75	E+20 sej/yr
6	Fraction of emergy used derived from home sources	(R+N)/U	0.38	
7	Ratio of exported to imported emergy	EXP/IMP	0.40	
8	Economic component of emergy used	U−R	11442.13	E+20 sej/yr
9	Environmental loading ratio	(U−R)/R	9.47	
10	Fraction of use that is free	(R+No)/U	0.10	
11	Empower density	U/area of country	42.03	E+11 sej/m^2/yr
12	Emergy use per person	U/population	22.00	E+15 sej/person/yr
13	Ratio of electricity to use	electr. emergy/U	0.14	
14	Emergy investment ratio	IMP/(R+N)	1.65	
15	Gross national product	GNP	865.83	E+9 US $
16	Emergy/$ ratio of Italy	P1 = U/GNP	1.46	E+12 sej/$
17	Europe emergy/$ ratio, used for imports from European countries	P2	2.50	E+12 sej/$

tions, 38% of the emergy utilized annually by Italy is derived from home sources, while 62% of the country's emergy use comes from purchased goods, fuels, services and tourism from outside. The ratio of import emergy to export emergy is 2.53, giving a measure of Italy's trade balance.

5. Indices based on emergy

Results from emergy analysis clearly display their potential if the country under study is compared with other different nations. In this way one can evaluate the

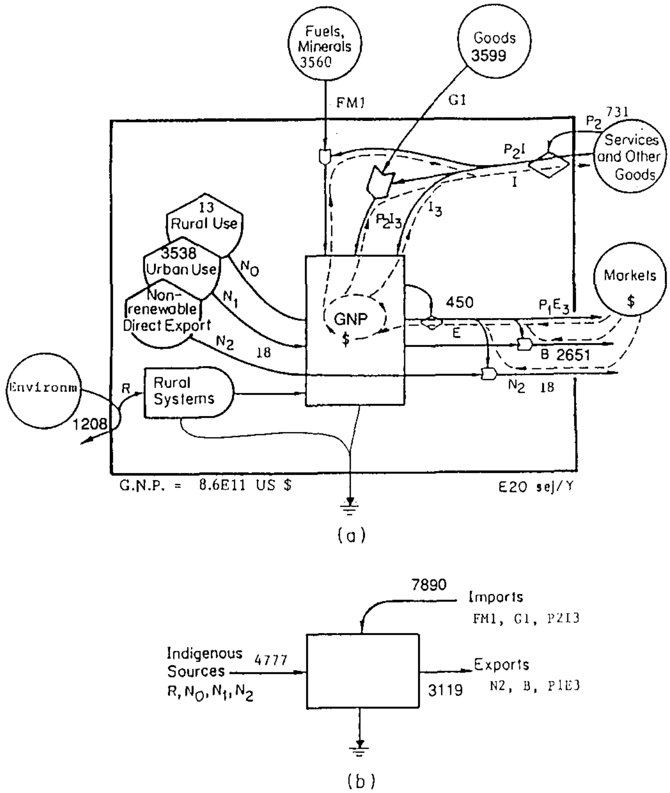


Fig. 7. Emergy analysis summary diagrams for Italy, 1989. (a) Flows evaluated in Tables 1 to 4; (b) Summary.

position of the country in the world's hierarchy of nations, examining the technological and financial development, resource use (environmental impact and conversion efficiency), long-term sustainability for the system as a whole, and equity in trade with other countries.

Emergy availability (or use) to a country and *emergy use per person* (average share of the annual emergy use of a nation) suggest a measure of standard of life in a country more effectively than just fuel use per person. Here standard of life should be intended as availability of resources and goods, availability of real stuff. It cannot be considered a measure of quality of life in the social sense (less crime, more happiness, higher level of culture and so on). Very often the two effects are linked and it is not easy to have the latter (quality of life) without the former (availability of goods). Emergy-use index takes into account the different quality of input joules and also includes renewable as well as non-renewable environmental resources, usually neglected in energy balances. These indices allow a more complete evaluation of the country's real standard of living and makes it easier to compare developed and developing countries; in fact, these latter are very often supported by large inputs of environmental emergy. Table 5 shows that Italy ranks

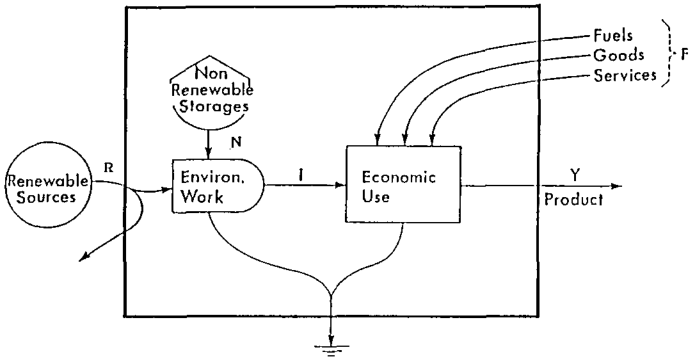
Table 5
Emergy use, population and per capita emergy use for Italy and other selected countries of the world [a]

Nation	Emergy used (E+20 sej/yr)	Population (E+6 people)	Emergy per person (E+15 sej/person/yr)
Australia	8850	15.00	59.00
Sweden	4110	8.50	48.00
Papua New Guinea	1216	3.50	35.00
USA	66400	227.00	29.00
Netherlands	3702	14.00	26.00
New Zealand	791	3.10	26.00
Liberia	465	1.30	26.00
Italy	**12650**	**57.51**	**22.00**
Soviet Union	43150	260.00	16.00
Brazil	17820	121.00	15.00
Dominica	7	0.08	13.00
West Germany	8027	62.00	12.90
Japan	15300	121.00	12.64
Switzerland	733	6.37	12.00
Ecuador	1029	9.60	10.72
Taiwan	2137	20.16	10.60
Poland	3305	34.50	9.58
China	71900	1100.00	6.54
Spain	2090	134.00	6.00
World	202400	5250.00	3.86
Thailand	1590	50.00	3.20
India	6750	630.00	1.00

[a] Data for countries are based on revised national analyses from Odum and Odum (1983), except Papua New Guinea (Doherty et al., 1992), Thailand (Brown and McClanahan, 1992), Sweden (Doherty et al., 1991), Taiwan (Huang and Odum, 1991; Huang and Shih, 1992) and Ecuador (Odum and Arding, 1991). Values for Italy are based on the analysis documented in this study.

between the nations with the highest emergy use per person. A high emergy use per person could suggest, but not necessarily, a very high level of technological and industrial development. Many indices (see the following definitions of empower density, emergy investment ratio, environmental loading ratio, percent of electricity to use) should be compared to evaluate technological development and efficient emergy use.

The *net emergy yield ratio* is the emergy of an output divided by the emergy of those inputs to the process that are fed back from the economy (Fig. 8). This ratio indicates whether the process can compete in supplying a primary energy source for an economy. Recently the ratio for typical competitive sources of fuels has been about 6 to 1 (Odum, 1988b). Processes yielding less than this cannot be considered primary emergy sources. If the ratio is lower than unity, the process is not a positive source of net emergy; if the ratio is lower than alternatives, less return will be obtained per unit of emergy invested in comparison with alternatives. Less competitive emergy sources (i.e. having a lower net emergy yield ratio) may have a lower cost, due to local conditions: costs are affected by international markets and value of currencies, which may not reflect the physical reality of a



I = N + R

Y = I + F

Net Emergy Yield Ratio = Y / F

Emergy Investment Ratio = F / I

Environmental Loading Ratio= (F + N) / R

Fig. 8. Emergy diagram illustrating computation of emergy yields and use ratios.

misuse of the emergy invested in comparison with actually available alternatives. Sources less competitive may become competitive when the others approach scarcity or are used up. Of course, this will affect the overall carrying capacity (see Sections 6.2 and 7.5).

The *emergy investment ratio* is the ratio of the emergy fed back from the economy to the indigenous emergy inputs (Fig. 8). This ratio indicates if the process is economical as utilizer of the economy's investments in comparison to alternatives. The physical meaning of this ratio is to evaluate the emergy input from the economy needed to exploit a unit of indigenous local resource. To be economical, the process should have a similar ratio to its competitors. If it receives less from the economy, the ratio is less and its prices are less, so that it will tend to compete in the market. Its prices are less when it is receiving a higher percentage of its useful work free from the environment than its competitors. However, operation at a low investment ratio uses less of the attracted investment than is possible, which will affect the amount of indigenous resource exploited. The tendency will be to increase the purchased inputs so as to process more output and more money. The tendency is towards optimum resource use. Thus, operations above or below the regional investment ratio will tend to change towards the investment ratio. Of course, this index is affected by the region boundaries. They can be determined by political reasons (boundaries of a nation) or socio-economical reasons (a special area within a nation, like the South of Italy) and usually show homogeneous conditions and trends of development over the whole area. This may

Table 6
Environmental and economic components of annual emergy use for Italy and other selected countries of the world [a]

Nation	Environmental component (E+20 sej/yr) (α)	Economic component (E+20 sej/yr) (β)	Environmental loading ratio (β)/(α)
West Germany	193.00	8027.00	41.59
Poland	159.00	3145.60	19.78
Netherlands	219.00	3483.00	15.90
Italy	**1207.62**	**11442.13**	**9.47**
Taiwan	213.00	1924.00	9.03
Switzerland	86.80	646.00	7.44
Spain	255.00	1835.00	7.20
USA	8240.00	58160.00	7.06
Sweden	511.00	3597.00	7.04
Dominica	1.80	4.80	2.67
World	94000.00	108000.00	1.15
Thailand	779.00	811.00	1.04
India	3340.00	3410.00	1.02
Soviet Union	9110.00	9110.00	1.00
Australia	4590.00	3960.00	0.86
New Zealand	438.00	353.00	0.81
Brazil	10100.00	7600.00	0.75
Ecuador	891.00	483.00	0.54
Papua New Guinea	1052.00	163.00	0.15
Liberia	427.00	38.00	0.09

[a] See footnote in Table 5.

require a special economic policy for investment and trade so that evaluation of indices on such a regional scale may be useful for comparison.

The *environmental loading ratio* (Fig. 8) is the ratio of purchased and non-renewable indigenous emergy to free environmental emergy. It is like the "load" on an electric circuit. A large ratio suggests a high technological level in emergy use as well as a high level of environmental stress. Even when the emergy investment ratio is low (the process runs upon indigenous minerals or fuels sources), the environmental loading ratio can be very high. The ratio of economic component (emergy use other than free renewable) to environmental component is almost 10 to 1 for Italy (Table 6). A very high value for this index could mean that the pressure of economic activities to local environmental resources is excessive and providing notable environmental stress. It is like an alarm-bell for a state of non-equilibrium which in the long run could become irreversible. The term 'stress' should be intended in the broad sense of total impact on environment. For example, environmental damage from agricultural practice may be considered as a weighted sum of specific damages due to combustion of fuels, soil erosion, chemical nature of pesticides, and so on, but all these sources of damage come from intensive management of agricultural production and, ultimately, from excessive emergy use other than locally renewable.

Table 7
Emergy use, Gross National Products and Emergy/GNP indices for Italy and other selected countries of the world [a]

Nation	Total emergy (E+20 sej/yr)	GNP (E+9 US $/yr)	Emergy use/GNP (E+12 sej/US $)
Papua New Guinea	1216	2.60	48.00
Liberia	465	1.34	34.50
Dominica	7	0.08	14.90
Ecuador	964	11.10	8.70
China	71900	376.00	8.70
Brazil	17820	214.00	8.40
India	6750	106.00	6.40
Australia	8850	139.00	6.40
World	202400	5000.00	4.05
Thailand	1509	43.10	3.70
Soviet Union	43150	1300.00	3.40
New Zealand	791	26.00	3.00
Sweden	4110	160.00	2.60
USA	66400	2600.00	2.50
Netherlands	3702	16.60	2.20
Japan	15300	715.00	2.14
Spain	2090	139.00	1.60
Italy	**12650**	**865.83**	**1.46**
Taiwan	2137	158.00	1.35
West Germany	8027	715.00	1.12
Switzerland	733	102.00	0.70

[a] See footnote in Table 5.

The above-cited *emergy / gross national product* or *emergy / dollar ratio* (sej/$) for a country and a particular year is the ratio of the total emergy used by the country from all sources divided by the gross national product (GNP) for that year. It includes emergy used in renewable environmental resources as well as non-renewable resources used up, such as fuel reserves and organic matter in soil; it also includes the emergy content of imported resources, goods and services. Rural countries have a higher emergy/dollar ratio because more of their economy involves direct environmental resources inputs not paid for. Developed countries, even when driven by large inputs of solar emergy, usually show a low emergy/dollar ratio (Table 7), signalling of a fast money circulation (large value of GNP). These countries are generally favored in buying resources from outside, because emergy embodied in money paid for is less than emergy purchased (Fig. 9). From this standpoint the purchase of primary resources from less financially developed countries is very advantageous for Italy, even if it could be considered a lack of self-sufficiency, as with the purchase of fossil fuels.

The term *macroeconomic value* (sometimes the term *emdollar* is used) in Tables 1 to 3 refers to the total amount of money flow generated in the entire economy by a given amount of emergy input. It is calculated by dividing the emergy input by the emergy/GNP ratio. A higher macroeconomic value means that a

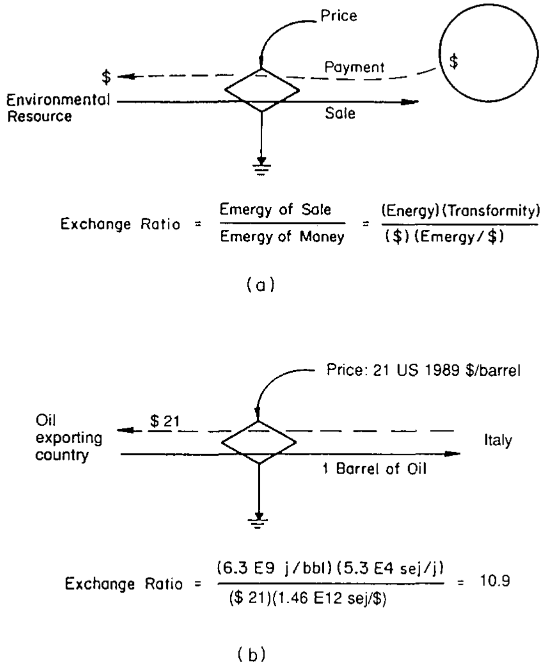


Fig. 9. Diagram illustrating the exchange ratio (ratio of emergy in a purchased product to emergy in the money paid for it). (a) Diagram and formulae used; (b) example of selling oil to Italy.

product or process contributes more to the economy. It has been proposed (Pillet, 1991) that the macroeconomic value of a resource could be considered as a shadow price of the resource itself: the examination of the role of indirect environmental services conjointly with the inputs of human labor and economic goods and services will help to avoid a misuse of these resources.

The *emergy exchange ratio* is the ratio of emergy received for emergy delivered in a trade or sales transaction (Fig. 9). For example, a trade of grain for oil can be expressed in emergy units. The area receiving the larger emergy receives the larger value and has its economy stimulated more. Raw products such as minerals, rural products from agriculture, fisheries and forestry, all tend to have high emergy exchange ratios when sold at market price. This is a result of money being paid for human services and not for the extensive work of nature that went into these products. The existence of emergy-attracting countries is underlined in Table 8. Many technologically and financially developed countries are not emergy self-sufficient (see Table 8, % of emergy from within) and show an emergy import much higher than the export. It contributes very much to the economy of the importing country, which will use more resources and will successfully compete with other countries. Italy shows a 38% self-sufficiency; it has an import/export ratio around 2.5, by importing mostly energy resources and exporting manufactured products. The consequence of these factors are increased gross national product and economic wealth.

Table 8
Emergy self-sufficiency and trade balance for Italy and other selected countries of the world [a]

Nation	% emergy from within	Emergy import/export
Netherlands	23	4.30
Japan	31	4.20
Switzerland	19	3.20
West Germany	23	2.60
Italy	**38**	**2.53**
Spain	24	2.30
USA	77	2.20
Taiwan	29	1.56
India	88	1.45
Sweden	46	1.30
Brazil	91	0.98
Dominica	69	0.84
New Zealand	60	0.76
Poland	66	0.65
Thailand	70	0.54
Australia	92	0.39
China	98	0.28
Soviet Union	97	0.23
Ecuador	94	0.20
Liberia	92	0.15
Papua New Guinea	96	0.09

[a] See footnote in Table 5.

The *empower density*, i.e. the emergy flow per unit time and unit area (with the units solar emjoules per m^2 per unit time), is a measure of spatial concentration of emergy flow within a process or system. A high empower density can be found in countries where emergy use is large if compared to available area (Table 9). It suggests a spatial hierarchy, where very industrialized countries or areas (cities, industrial regions in a nation) are in the top positions, followed by areas characterized by less concentrated or rural economies. According to emergy definition, we underline that "empower", the flow of *emergy* per unit time, is often a larger concept than "power", the flow of *energy* per unit time: this latter only refers to actual energy used, while the former includes all kinds of input flows contributing to the system.

This index does not look to be always directly proportional to population density. A high empower density eventually suggests land to be a limiting factor for the future economic growth (not for development, i.e. better use of available resources) of the country. Italy shows a high value for this index, due to a very intensive use of available land, for urban and production settlements.

Finally, Table 10 shows the percent of emergy that is electrical. Electricity is a very high-quality energy, that is usually used for interacting with low-quality inputs to feedback and stimulate the production process. Electricity can also support the manipulation and processing of information (computers, communications, automation, etc.), which characterizes the coming era. According to its high transformity,

Table 9
Population density and empower density for Italy and other selected countries of the world [a]

Nation	Area (E+10 m^2)	Population density (People/km^2)	Empower density (E+11 sej/m^2/yr)
Netherlands	3.70	378.00	100.00
Italy	**30.10**	**191.05**	**42.03**
Japan	37.20	325.00	41.09
Taiwan	3.60	560.00	37.24
West Germany	24.90	247.00	32.30
Switzerland	4.10	154.00	17.70
Poland	31.20	110.00	10.60
Sweden	41.10	20.70	10.00
Dominica	0.08	107.00	8.80
China	953.60	115.00	7.54
USA	940.00	24.20	7.00
Liberia	11.10	16.10	4.10
Ecuador	28.00	34.00	3.40
Spain	50.50	68.50	3.12
Papua New Guinea	46.20	7.60	2.63
Thailand	74.00	67.60	2.15
Brazil	918.00	13.20	2.08
India	329.00	192.00	2.05
New Zealand	26.90	11.50	1.94
Soviet Union	2240.00	11.60	1.71
Australia	768.00	1.90	1.42
World	14900.00	35.23	1.36

[a] See footnote in Table 5.

it should be used where it can have commensurate effects, allowing maximum and optimum use of large amounts of low-quality resources. Its use in Italy is around 14%: unfortunately, it is not always used to upgrade low-quality inputs but is very often degraded for low-quality purposes like home heating.

6. Analysis of selected subsystems

Some selected subsystems having a special role in Italian economy were analyzed.

6.1. Human service

Evaluation of human contribution has been one of the major differences among energy analysts. Some omit the category of labor, avoiding the question of evaluating service on the same basis as other inputs. Some (Pimentel and Pimentel, 1979; Pimentel, 1980; Triolo et al., 1984; Biondi et al., 1989) reported the hours of labor without assigning an energy or emergy value. Some assign the energy of a person's daily metabolism, a relatively small value. One may even reason that all a person's time is essential to the job including sleeping, eating, recreation, etc. However, others (Fluck and Baird, 1980) use just the hours spent directly in work.

Table 10
Percent of emergy that is electrical, for Italy and other selected countries in the world [a]

Nation	% Electrical
Switzerland	32
Japan	26.1
Sweden	23.5
West Germany	22.4
Spain	22
Taiwan	20
USA	20
Soviet Union	19
Poland	18
New Zealand	15
Italy	**14**
World	13.2
Thailand	10.8
India	10
Netherlands	10
Brazil	8
Australia	6.8
China	4.3
Ecuador	3.2
Liberia	1
Papua New Guinea	0.8
Dominica	< 0.01

[a] See footnote in Table 5.

We evaluated labor in agricultural and industrial production making two main assumptions: it is mostly untrained labor, and it should be evaluated taking into account all emergy sources supporting it, even when a worker is not just working, because all other activities (sleeping, free time, holidays, etc.) should be considered by-products of the same emergy flow.

Total solar emergy per person per year (365 days) was divided by total metabolic energy applied to work over 285 working days per year (not including Sundays and official holidays). The result, shown in Table 11, is the solar transformity of untrained labor in agricultural and manufacturing activities.

Table 11
Emergy evaluation of labor

Note	Item	Amount	Unit
1	Total solar emergy use in Italy, 1989	1.26E+24	sej/yr
2	Total population of Italy, 1989	5.75E+07	people
3	Solar emergy per person per year, 1989	2.20E+16	sej/yr/person
4	Daily metabolic energy	1.05E+07	J/day/person
5	Total energy applied in 285 working days (Sundays and holidays are not included)	2.98E+09	J/yr/person
6	Solar transformity of labor (item 3/item 5)	7.38E+06	sej/J

Table 12
Emergy analysis of resources basis for Italian agriculture, 1989 [a]

Note	Item	Raw units	Solar transform. (sej/unit)	Ref. transf. [b]	Solar emergy (E+20 sej/yr)	Macroeconom. value [c] (1989 US $/yr) 1.00E+09
Renewable resources						
1	Sunlight	6.17E+20 J	1	A	6.17	0.42
2	Rain chem. potential	3.59E+17 J	18199	A	65.33	4.47
3	Rain geopotential	3.15E+17 J	10488	A	33.07	2.27
4	Earth cycle	5.07E+17 J	34377	A	174.29	11.94
Non-renewable sources from within the system						
5	Net loss of topsoil	2.12E+16 J	62500	A	13.26	0.91
Applied energy and labor						
6	Electricity, crop prod.	1.05E+16 J	200000	A	21.02	1.44
7	Electricity, livestock	2.94E+15 J	200000	A	5.89	0.40
8	Lubricants	9.04E+14 J	66000	A	0.60	0.04
9	Diesel, crop prod.	9.53E+16 J	66000	A	62.88	4.31
10	Diesel, livestock	2.94E+15 J	66000	A	1.94	0.13
11	Gasoline	1.07E+16 J	66000	A	7.04	0.48
12	Labor, crop prod.	3.56E+15 J	7.38E+06	D	262.46	17.98
13	Labor, livestock	2.80E+15 J	7.38E+06	D	206.88	14.17
Goods and assets for crop production						
14	Potash fertilizers, K_2O	4.37E+11 g	2.96E+09	F	12.94	0.89
15	Nitrogen fertilizers, N	9.23E+11 g	4.62E+09	A	42.64	2.92
16	Phosphate fertil., P_2O_5	6.86E+11 g	1.78E+10	A	122.11	8.36
17	Pesticides	1.29E+16 J	6.60E+04	A	8.52	0.58
18	Mechanical equipment	6.42E+11 g	6.70E+09	F	43.01	2.95
19	Seeds	8.93E+15 J	66000	A	5.89	0.40
20	Assets, crop prod.	6.56E+15 J	66000	A	4.33	0.30
Goods and assets for livestock						
21	Assets, livestock	3.75E+15 J	66000	A	2.36	0.16
22	Industrial fodder	4.72E+16 J	66000	A	31.15	2.13
23	Forage	3.16E+17 J	79951	C	252.59	17.30
24	Self-produced fodder	3.00E+15 J	66000	A	1.98	0.14

[a] All flows are evaluated on a yearly basis (see footnotes in Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.46E+12 sej/$ (Emergy/dollar ratio of Italy, 1989) [D].

Because of their high transformity, human services have very high emergy values. Using emergy rather than energy in systems evaluations or completely omitting human services makes huge differences in the results.

6.2. Agriculture

Global data about Italian agriculture (crop and livestock production) are given in Tables 12 and 13, while Fig. 10 shows a summary diagram of emergy inputs driving the system (Ulgiati et al., 1993).

The crop production subsystem in Italian agriculture required 8.5E + 22 sej/yr, while the livestock subsystem was supported by 5.0E + 22 sej/yr. The sum of the

Table 13
Emergy analysis of selected crops and products in Italian agriculture, 1989 [a]

Note	Item	Raw units	Solar transform. (sej/unit)	Ref. Transf. [b]	Solar emergy (E20 sej/yr)	Macroeconom. value [c] (1989 US $/yr) 1.00E+09
Selected crops						
1	Rice	1.56E+16 J	77779	C	12.17	0.83
2	Forage	4.52E+17 J	79951	C	361.53	24.76
3	Sugar beet	4.74E+16 J	84901	C	40.25	2.76
4	Corn	9.44E+16 J	85178	C	80.37	5.50
5	Wheat	1.09E+17 J	1.59E+05	C	173.01	11.85
6	Fruits	9.99E+15 J	2.87E+05	C	28.72	1.97
7	Vineyard	2.74E+16 J	3.41E+05	C	93.57	6.41
8	Oranges & lemons	5.19E+15 J	3.82E+05	C	19.82	1.36
9	Olive	2.18E+16 J	5.30E+05	C	115.81	7.93
10	Sunflower	7.09E+15 J	7.91E+05	C	56.12	3.84
11	Almond	6.80E+14 J	8.43E+05	C	5.73	0.39
Total production						
12	Crop production	8.16E+17 J				
13	Livestock production	1.59E+16 J				
14	Crop residues	6.40E+17 J				
Transformities evaluation						
15	Solar emergy crop production				846.32 sej	
16	Solar emergy livestock production				502.78 sej	
17	Solar transformity crop production				1.04E+05 sej/J	
18	Solar transformity livestock production				3.17E+06 sej/J	

[a] All flows are evaluated on a yearly basis (see footnotes in Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.46E+12 sej/$ (Emergy/dollar ratio of Italy, 1989) [D].

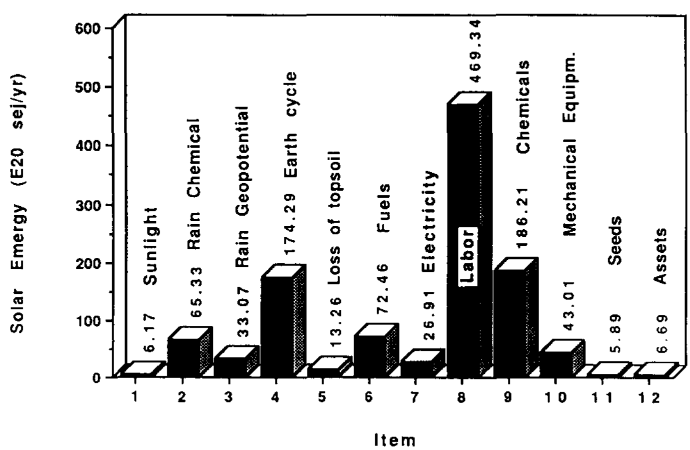


Fig. 10. Solar emergy inputs to Italian agricultural system, 1989.

Table 14
Emergy analysis of sugar beet production per hectare, Italy [a]

Note	Item	Raw units	Transform. (sej/unit)	Ref. transf. [b]	Emergy (E+14 sej/yr)	Macroecon. value [c] (1989 US $/yr)
Renewable resources						
1	Sunlight	3.65E+13 J	1	A	0.37	25.00
2	Rain Chemical Pot.	2.12E+10 J	18199	A	3.87	264.78
3	Earth cycle	3.00E+10 J	34377	A	10.31	706.38
Non-renewable sources from within the system						
4	Net loss of topsoil	1.26E+09 J	62500	A	0.78	53.76
Applied energy and labor						
5	Electricity	2.17E+08 J	200000	A	0.43	29.72
6	Lubricants	1.36E+08 J	66000	A	0.09	6.16
7	Diesel	1.53E+10 J	66000	A	10.13	693.61
8	Gasoline	4.60E+08 J	66000	A	0.30	20.79
9	Labor	2.87E+08 J	7.38E+06	D	21.20	1451.99
Goods and assets						
10	Potash fertilizers, K_2O	7.62E+04 g	2.96E+09	F	2.26	154.47
11	Nitrogen fertilizers, N	1.41E+05 g	4.62E+09	A	6.49	444.85
12	Phosphate fertil., P_2O_5	3.33E+05 g	1.78E+10	A	59.33	4063.89
13	Pesticides	3.61E+09 J	66000	A	2.38	163.06
14	Mechanical equipment	6.70E+08 J	66000	A	0.44	30.28
15	Seeds	4.19E+07 J	66000	A	0.03	1.89
Production						
16	Sugar beet harvested	1.39E+11 J				
17	Total emergy				118.05	
18	Solar transformity		8.49E+04 sej/J			
19	Total hectares	2.99E+05 ha				

[a] All flows are evaluated on a yearly basis (see footnotes in Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.46E+12 sej/$ (Emergy/dollar ratio of Italy in 1989) [D].

two items without double counting gives the total emergy driving Italian food production, estimated at 10.6E + 22 sej/yr. Table 14 shows the emergy analysis of sugar beet production. The same methodology was used to analyze the main crops produced in Italy: the results are shown in Table 13, where crops are listed in order of increasing transformity. Finally, the main indices for the emergy overview of Italian crop production are listed in Table 15.

A very large contribution to Italian food production comes from goods (mostly chemicals and machinery) and human labor. Goods are 24% of total emergy input. Labor accounts for 44% of total emergy: despite recent increase in mechanical equipment use, Italian agriculture is still based on a huge input of human service.

Free renewable sources to crop production were evaluated around 2.40E + 22 sej/yr. Human labor can be considered a product of the overall system of economy and nature of Italy, which runs on 9.5% renewable emergy and 90.5% non-renewable emergy, so it is possible to assign 9.5% of human labor emergy to renewable sources and the remaining part to non-renewable sources supporting agricultural

Table 15
Net emergy yield ratio and other indices for selected crops in Italian agriculture (Ulgiati et al., 1993)

Item	Crop	Solar transformity (E+4 sej/J)	Emergy invest. ratio	Environmental loading ratio	Net emergy yield ratio	Empower density (E+11 sej/m^2/yr)
1	Rice	7.78	2.66	2.86	1.38	5.47
2	Forage	8.00	1.32	1.45	1.76	3.47
3	Sugar beet	8.49	6.89	7.33	1.15	11.81
4	Corn	8.52	5.28	5.63	1.19	9.40
5	Wheat	15.90	3.15	3.38	1.32	6.21
6	Fruits	28.74	8.82	9.37	1.11	14.70
7	Vineyard	34.11	5.00	5.33	1.20	8.98
8	Oranges & lemons	38.17	11.15	11.82	1.09	18.18
9	Olive	53.03	4.12	4.40	1.24	7.66
10	Sunflower	79.12	26.27	27.78	1.04	40.81
11	Almonds	84.28	2.89	3.10	1.35	5.81
12	Tot. crop prod.	10.37	2.35	2.53	1.43	5.01
13	Italy		1.65	9.47		42.00

process in Italy. Thus renewable (environmental and 9.5% labor) emergy accounts for 31% of total emergy driving the process of crop production.

Crop production subsystem provides feed stuff to animal production, mostly in the form of forage (items 22 to 24, Table 12). The renewable environmental component in forage production was 46.9% of total emergy used, while non-renewable rural emergy accounted for 2.6% (Ulgiati et al., 1993). Therefore renewable and non-renewable environmental inputs were evaluated respectively as 46.9% and 2.6% of total feed stuff (mostly forage) provided to livestock. Grazing is a minor practice in Italy and it was included in forage production. It follows that the renewable emergy contribution to livestock subsystem accounts for 29% of total emergy flow. In this way it was not possible to evaluate the free emergy contributions to the livestock subsystem in the form of water storages use nor to evaluate other minor environmental inputs eventually occurring. Neither the total emergy flow to livestock nor livestock transformity should be much affected by neglecting these minor inputs.

Environmental loading ratio for Italy as a whole is 9.5 (Table 4), much higher than for crop production, which is 2.5 (Table 15), and for livestock subsystem, which is 3.3. Careful review of the production processes listed in Table 15 shows that some crops contribute more to environmental stress (the environmental loading ratio for sunflower is 27.8, for oranges 11.8, for fruits 8.8; see Section 5) while others are largely under the national average of Italy.

Empower density is very high for sunflower (40.8E + 11 sej/m^2/yr), close to the national average of emergy use in Italy (42.0E + 11 sej/m^2/yr). It is less for the other crops. The average for total crop production is 5.0E + 11 sej/m^2, while it is around 6.4E + 11 sej/m^2 for livestock.

The emergy investment ratio was evaluated for selected crops. Nation-wide averaging hides trends at a local level, yet it gives a general bench-mark to which

Table 16
Emergy evaluation of steel production in Italy, 1989 [a]

Note	Item	Raw units	Transform. (sej/unit)	Ref. transf. [b]	Emergy (E+20 sej/yr)	Macroeconomic 1.00E+09 (1989 US $/yr)
1	Oil	1.47E+15 J	53000	A	0.78	0.05
2	Coal	3.37E+15 J	39800	A	1.34	0.09
3	Methane	9.44E+15 J	48000	A	4.53	0.31
4	Electricity	3.04E+16 J	2.00E+05	A	60.77	4.16
5	Metallic minerals	2.04E+13 g	1.00E+09	A	204.00	13.96
6	Non-metallic minerals	1.76E+11 g	1.00E+09	A	1.76	0.12
7	Labor	1.78E+14 J	7.38E+06	D	13.12	0.90
8	Total product	2.28E+13 g				
9	Total emergy input				286.30	19.60
10	Transf. for steel		1.25E+09 sej/g			
11	Emergy/$, Italy, 1989		1.46E+12 sej/$			

[a] All flows are evaluated on a yearly basis (see footnotes, Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.461E+12 sej/$ (emergy/$ ratio for Italy in 1989) [D].

comparisons of economic advantage can be made for local crop production. For instance, if the investment ratio for one crop in region A is largely over the national average for that crop or the value for the same crop in region B, the production in region A may be not competitive, because it requires more purchased emergy to exploit the unit amount of local resource. Even if the total product is more, its emergy cost is high compared to alternatives. Otherwise, if a region has a low emergy investment ratio, it is probable that the local resources are not being exploited at optimum efficiency, as suggested by the maximum power principle.

Finally, the global net emergy yield ratio of Italian crop production was calculated as 1.43. This relatively low ratio indicates that Italian agriculture cannot be considered as a primary energy source: if agricultural products from the present Italian agricultural management practices were used as primary emergy sources, their emergy yield ratios are such that they would not be competitive with fossil fuels.

6.3. Steel and pig-iron production in Italian industry

Steel production (Table 16) required a total emergy input 2.9E + 22 sej, giving a total product 2.3E + 13 g of steel; solar transformity was evaluated around 1.25E + 9 sej/g. The main emergy contributions are metallic minerals (71% of total emergy input) and electricity (21% of total input).

Pig-iron production (Table 17) required a total emergy input 3.9E + 22 sej, giving a total product 1.1E + 13 g of pig-iron; solar transformity was evaluated around 3.5E + 9 sej/g. The main inputs are metallic minerals (67%) and coal (16%).

Table 17
Emergy evaluation of pig-iron production in Italy, 1989 [a]

Note	Item	Raw units	Transform (sej/unit)	Ref. transf. [b]	Emergy (E+20 sej/yr)	Macroeconomic value [c] 1.00E+09 (1989 US $/yr)
1	Oil	1.37E+16 J	53000	A	7.27	0.50
2	Coal	1.55E+17 J	39800	A	61.78	4.23
3	Methane	5.54E+16 J	48000	A	26.58	1.82
4	Electricity	8.17E+14 J	2.00E+05	A	1.63	0.11
5	Metallic minerals	2.62E+13 g	1.00E+09	A	262.00	17.93
6	Non-metallic minerals	1.93E+12 g	1.00E+09	A	19.29	1.32
7	Labor	1.76E+14 J	7.38E+06	D	12.97	0.89
8	Total product	1.13E+13 g				
9	Total emergy input				391.53	26.80
10	Transf. for pig-iron		3.46E+09 sej/g			
11	Emergy/$, Italy, 1989		1.46E+12 sej/$			

[a] All flows are evaluated on a yearly basis (see footnotes, Appendix A).
[b] References for transformities are given in Appendix B; footnotes in Appendix A.
[c] Emergy divided by 1.46E+12 sej/$ (emergy/$ ratio for Italy in 1989) [D].

Labor contributes 5% of total input to steel and 3% to pig-iron production: unlike agriculture, it is not a labor-intensive production. If agricultural and industrial activities are compared, the need of accounting for labor is evident.

Total input to steel and pig-iron production was 6.8E + 22 sej, around 5% of total emergy use in Italy.

7. Discussion

7.1. Boundaries and choice of inputs

The analytical surface boundary for a nation is its political boundary line with neighbouring countries. If a nation has a coastal line, the boundary is the end line of the shelf, because processes in shelf area (photosynthesis, fish life) or from shelf area (nutrients and salts from sea to land) largely affect the development of natural system on land as well as of human economy (fisheries, tourism, etc.). Inputs also come to the system as a whole from underground earth cycle, i.e. geothermal heat and land uplift coupled with atmospheric agents driving sedimentary cycles, etc. Finally, inputs from solar origin should be considered: one should only think to the importance of rain for the development of agriculture and life in the area under study (Odum, 1970). Wind, waves, rain and direct insolation are all by-products of the same solar energy flow, with different degree of concentration, i.e. different transformity. Only the largest one is added to total emergy flow to the nation, in order to avoid double counting. Each of these inputs contributes to system development, favoring minerals solution, nutrients cycling, and primary production; cleaning air and water; creating micro-conditions and micro- or macro-environments for life development. They all have to be considered as inputs across the boundary: we should be aware that without them no economy could exist.

7.2. Emergy and energy

When we compare different emergy inputs, we should never forget that emergy is not actual energy: emergy is a convergence of energy, time and space. For example, input from waves is higher quality than input from direct sunlight, being more concentrated. It requires a large convergence of solar energy, time and space to originate winds and waves. In the case of Italy, its very long coast line in comparison with its surface makes the importance of waves emergy even larger, as underlined by a history and an economy largely based on exploitation of sea resources. Relevance of inputs from minerals other than fossil fuels should be underlined: emergy from minerals is of the same order of magnitude as emergy from thermoelectricity or oil use. This is consistent with large contribution from these kind of inputs to past and present economy, life and arts in Italy (see the special development of Italian architecture largely using indigenous mineral resources). On our opinion, Italy presents a real peculiarity in comparison with most other countries (together with Sweden, having a 30% input from metallic minerals).

7.3. Problems of scales

Inputs to the system show very different temporal, spatial and technical scales. For example, input from waves is received at the shore, whose length is relevant for Italy; input from oil comes from a process developed over a very long time interval; input from minerals involves a formation process characterized by geological times. Uncertainties about primary processes or changes in technical efficiency not accounted for could largely affect the value of transformities and therefore the emergy value of inputs. Special care is thus required in evaluating raw inputs as well as transformities used in emergy calculations.

Moreover, the real word is observed to pulse and oscillate. There are oscillating steady states. In most systems, including those of which people are part, storages are observed to fill and discharge as part of oscillations. Some are chaotic. According to this pulsing paradigm, transformities and all other indices based on emergy also oscillate, with different values appropriate at different stages in the oscillatory cycle of the system. The human economic society may be constrained to track the thermodynamics that is appropriate for each stage of the global oscillation. In the longer run, the models of oscillating storage and indices give insights on when to use available resources and when to conserve.

7.4. Emergy and exergy

Exergy, i.e. the maximum amount of physical work that can be extracted from a given flow of energy, is sometimes suggested as a measure of energy quality, instead of emergy. Exergy cannot be a suitable measure of energy quality and work potential when environmental value is considered: for those energy types of quality lower than that of mechanical energy, exergy is a measure of theoretical efficiency, while energy flows of higher quality than mechanical work are not given greater value in exergy terms. Here quality means ability to contribute to the development of the system and different quality means different potential contribution.

7.5. *Carrying capacity*

The net emergy per unit time determines the carrying capacity. The global carrying capacity in developed countries is 10–25% on biomass. Energy from biomass is not enough to stimulate development in the way that coal and gasoline do (not enough net emergy to encourage the general economy).

Despite the present favorable cost of fossil fuels, there is no doubt that a gradual decline of availability of cheap fuel will occur the world over and the recent urban basis of the economy will have to decrease; agriculture will once again become more and more the mainstay of the economy. The overall economy will benefit from efficiencies in agriculture that replace high emergy purchased inputs with free environmental inputs. Agricultural policies need to recognize these inevitable trends and facilitate the adaptation to more, but low-intensity, agriculture. Fuels, chemical fertilizers and pesticides will have to be replaced by the optimum use of land and labor. Land and labor will have to be utilized in a fashion that will increase the efficiency of using environmental inputs so that agriculture will become once again the main source of net emergy. Optimum rather than maximum production will be the goal.

7.6. *Sustainability and emergy use*

To be sustainable a system should be able to:

- find and receive emergy input flows. If they come from a process characterized by large time or space scales, this only means that the system is driven by the convergence of large primary processes pushing it to higher levels of the natural hierarchy. This is what we mean when we underline the unpaid contribution of the environment. Here sustainability means: you can't live if you don't eat.
- maximize the total inflow of available emergy by adequate feedbacks from higher levels (higher transformities) components and use inflows more effectively than competitors; misuse leads to displacement of that system. Here sustainability means: you can't grow nor even survive if you are not able to compete.
- discharge final wastes (and high entropy heat) into a suitable sink. If the system is not able to do this, it will be flooded by wastes: this is pollution. If wastes have still an emergy content, they should be recycled or transferred to another system able to do this and to reinforce the whole. Here sustainability means: living systems cannot survive if they are isolated or even closed thermodynamic systems.
- finally, processes occurring in the system should not modify the constraints within which the system developed until its present state. For example, even if there is still uncertainty about the real meaning and consequences of increasing CO_2 content in the atmosphere, it should be avoided. A negative feedback might follow, decreasing instead of increasing the emergy flow through the system. Here sustainability means: do not forget that every system is a sub-system of

biosphere, which self-organized its equilibria over million years of "trial and error" evolution for maximum power output.

8. Conclusion

The Italian position between nations still looks to be favorable. By efficiently attracting foreign emergy, Italy has been able to settle itself between the nations with the higher levels of industrial development and standards of living.

8.1. Balance of trade

As we have already underlined, trade (i.e. emergy exchange among Italy and less developed nations) is not balanced, for two main reasons:

a. Italy imports much more emergy than it exports, thereby avoiding the integral exploitation of indigenous resources, which are however used mostly at home; what is good for Italian economy could not be the same for world stability, because less availability for other countries is the obvious consequence of a practically unidirectional flow of resources.
b. Every import is made with an exchange coefficient quite unfavorable to exporting countries, due to the low value of Italy's emergy/dollar ratio.

8.2. Efficient use of available emergy

Very often by-products, residues and wastes are not fully utilized in order to feedback Italian economy. This is true for agricultural residues as well as for livestock, industry and urban wastes. Even efficiency in resources use is not yet the optimum, so that more non-renewable resources are needed to exploit an equal amount of free environmental resource in comparison with other countries, as suggested by Italy's very high value of environmental loading ratio.

What follows is a notable negative impact to the environment; in the long run something could jeopardize the very environmental basis which allowed the development of the country. Eutrophication of the Adriatic Sea due to organic inputs carried by Po river is a clear example. Organic and industrial residues are originated by the very large emergy use in northern Italy (due to high industrial development and population density): eutrophication and intoxication of the sea are damaging fisheries and tourism all along the east coast of Italy, which is so deprived of two very large traditional inputs of wealth.

8.3. Suggestions for public policy in Italy

The long run perspectives of emergy analysis hardly can be of some interest for individuals, whose short time perspectives may seem more consistent with maximization of monetary values and fast exploitation of natural resources irrespective of their environmental quality. Emergy analysis results should be taken into account by public policy makers in programming sustainable pathways for their country as well as in careful managing with natural resources. Favorable emergy balance of trade and agro-industrial production, sustainable exploitation of indigenous storages of resources, foreign resources import, competitive resources investments on a local scale, efficiency in non-renewable emergy use when environmental resources are exploited, attraction of foreign emergy (tourism, information, trained immigrants, etc.) are all long-term purposes which are the basis of any sustainable development and increase in wealth.

In the course of this paper we met indices clearly showing suggestions for a good public policy: processing at home indigenous resources, importing goods and fuels from countries with higher emergy/dollar ratio, comparing the emergy investment ratios before undertaking a project, displacing productions with higher environmental loading ratios or higher emergy investment ratio than competitors, saving storages of indigenous non-renewable resources, using resources where expected results are commensurate to their quality.

Since care in the best use of environmental resources maximizes the total resource available from resident and attracted inputs, good use of environment may increase economic vitality.

Acknowledgments

Part of this work was made possible by funds from European Economic Community R&D Programme in the Field of Environment, Contract No. EV5V-CT92-0152 (SUS.T.E.E. project).

Appendix A

Footnotes to Table 1; references for data are given in Appendix C

Renewable resources

1. SOLAR ENERGY

Cont. shelf area	$= 1.44E + 11\ m^2$ at 200 m depth	[8]
Land area	$= 3.01E + 11\ m^2$	[1]
Insolation	$= 1.09E + 02$ kcal/cm^2/yr	[3]
Albedo land	= 0.20 (% given as decimal)	[6]
Albedo shelf	= 0.35 (% given as decimal)	[6]
Land energy	= (land area)(avg. insolation)(1-albedo)	
	= (3.01E + 11 m^2)(109 kcal/cm^2/yr)(E + 04 cm^2/m^2)(1 − 0.20)(4186 J/kcal) =	
	= 1.10E + 21 J/yr	
Shelf energy	= (Shelf area)(avg. insolation)(1-albedo)	
	= (1.44E + 11 m^2)(109 kcal/cm^2/yr)(E + 04 cm^2/m^2)(1 − 0.35)(4186 J/kcal) =	
	= 4.27E + 20 J/yr	
Tot. solar energy	= 1.53E + 21 J/yr	

2. RAIN CHEMICAL POTENTIAL

Cont. shelf area	= 1.44E + 11 m^2 at 200 m depth	[8]
Land area	= 3.01E + 11 m^2	[1]
Rain (average)	= 0.99 m/yr	[3]
Evapotransp. rate	= 0.43 m/yr (43.6% of total rainfall)	[3,6]
Energy (land)	= (area)(Evapotranspired rainfall)(water dens.)(Gibbs no.)	
	= (3.01E + 11 m^2)(0.43 m/yr)(1000 kg/m^3)(4.94E + 03 J/kg)	
	= 6.39E + 17 J/yr	
Energy (shelf)	= (area of shelf)(rainfall)(water density)(Gibbs no.)	
	= (1.44E + 11 m^2)(0.99 m/yr)(1000 kg/m^3)(4.94E + 03 J/kg)	
	= 7.05E + 17 J/yr	
Total energy	= 1.34E + 18 J/yr	

3. RAIN GEOPOTENTIAL ENERGY

Area	= 3.01E + 11 m^2	[1]
Rainfall	= 0.99 m/yr	[3]
Average elevation	= 340.00 m	[10]
Runoff rate	= 0.56 m/yr (56.4% of total rainfall)	[3]
Energy	= (area)(runoff rate)(water density)(avg. elevation)(gravity)	
	= (3.01E + 11 m^2)(0.56 m/yr)(1000 kg/m^3)(340 m)(9.8 m/s^2)	
	= 5.62E + 17 J/yr	

4. WIND KINETIC ENERGY

Wind energy on land	= 7.35E + 11 kWh/yr	[11]
	= (wind energy on land)(3.6E6 J/kWh)	
	= 2.65E + 18 J/yr	

5. WAVE ENERGY

Coast length (incl. isl.)	= 7.46E + 06 m	[8]
Component of length parallel to front wave:		
	= 4.20E + 06 m	
Front wave energy	= 2.20E + 04 W/m	[9]
Time	= 3.15E + 07 s/yr	
Energy	= (Parallel component of length)(front wave energy)(time in s/yr) =	
	= 2.19E + 18 J/yr	

6. TIDAL ENERGY (half of tidal energy is supposed to be absorbed at the shelf)

Continental shelf area	= 1.44E + 11 m^2	[8]
Avg. tide range	= 0.30 m	

Density	= 1.03E + 03 kg/m^3	[9]
Tides/year	= 7.30E + 02 (2 tides/day in 365 days)	
Energy	= (shelf)(0.5)(tides/yr)(mean tidal range)^2 (density of seawater)(gravity)	
	= (1.44E + 11 m^2)(0.5)(730 tides/yr)(0.5 m)^2(1030 kg/m^3)(9.8 m/s^2) =	
	= 4.75E + 16 J/yr	

7. EARTH CYCLE (steady state uplift balanced by erosion)

Heat flow per area	= 3.00E + 06 J/m^2/yr	[12]
Land area	= 3.01E + 11 m^2	[1]
Energy	= (land area)(heat flow per area)	
	= (3.01E + 11 m^2)(3.00E + 6 J/m^2/yr)	
	= 9.03E + 17 J/yr	

Non-renewable sources from within the country

8. OIL

Total production	= 4.60E + 06 tons of oil equivalent/yr	[1,3]
Energy	= (total production)(1E + 7 kcal/t)(4186 J/kcal)	
	= (4.60E + 6t/yr)(1E + 7 kcal/t)(4186 J/kcal)	
	= 1.93 + 17 J/yr	

9. COAL

Total production	= 1.34E + 06 tons of oil equivalent/yr	[1,3]
Energy	= (total production)(1E + 7 kcal/t)(4186 J/kcal)	
	= (1.34E + 6 t/yr)(1E + 7 kcal/t)(4186 J/kcal)	
	= 5.61E + 16 J/yr	

10. NATURAL GAS

Total production	= 1.37E + 06 tons of oil equivalent/yr	[1,3]
Energy	= (total production)(1E + 7 kcal/t)(4186 J/kcal)	
	= (1.37E + 6 t/yr)(1E + 7 kcal/t)(4186 J/kcal)	
	= 5.73E + 16 J/yr	

11. FELDSPAR [1,3,7]

Mine output = 1.34E + 12 g/yr

12. MARL FOR CEMENT [1,3,7]

Mine output = 1.29E + 13 g/yr

13. ROCK SALT [1,3,7]

Mine output = 3.50E + 12 g/yr

14. POTASH SALT		[1,3,7]
Mine output	= 1.73E + 12 g/yr	
15. POZZOLAN		[1,3,7]
Mine output	= 5.00E + 12 g/yr	
16. SILICA SAND		[1,3,7]
Mine output	= 4.30E + 12 g/yr	
17. OTHER SAND AND GRAVEL		[1,3,7]
Mine output	= 1.22E + 14 g/yr	
18. MARBLE IN BLOCKS		[1,3,7]
Mine output	= 3.40E + 12 g/yr	
19. TUFA		[1,3,7]
Mine output	= 4.50E + 12 g/yr	
20. GRANITE		[1,3,7]
Mine output	= 2.50E + 12 g/yr	
21. LAVA, BASALT, TRACHYTE		[1,3,7]
Mine output	= 8.00E + 12 g/yr	
22. PORPHYRY		[1,3,7]
Mine output	= 1.20E + 12 g/yr	
23. SANDSTONE		[1,3,7]
Mine output	= 1.80E + 12 g/yr	
24. VOLCANIC TUFF		[1,3,7]
Mine output	= 5.80E + 12 g/yr	
25. LIMESTONE		[1,3,7]
Mine output	= 1.10E + 14 g/yr	
26. SERPENTINE		[1,3,7]
Mine output	= 1.50E + 12 g/yr	

27. LOSS OF TOPSOIL

(areas with mature vegetation are assumed to have little net gain or loss of topsoil)

Farmed area	= 1.69E + 11 m^2	[2]
Erosion rate	= 2.00E + 02 $g/m^2/yr$	[4]
% organic in soil	= 3.00E-02	[12]

Ener. cont. per g organic	= 5.00E + 00 kcal/g	[12]
Net loss	= (farmed area)(erosion rate)	
	= (1.69E + 11 m^2)(200 g/m^2/yr) =	
	= 3.38E + 13 g/yr	
Energy of net loss	= (net loss)(% org. in soil)(5.4 kcal/g)(4186 J/kcal)	
	= (3.38E + 13 g/yr)(0.03)(5.0 kcal/g)(4186 J/kcal)	
	= 2.12E + 16 J/yr	

Footnotes to Table 2; references for data are given in Appendix C

Imports and outside sources

1. OIL

Total import	= 1.05E + 08 tons of oil equivalent/yr	[1,3]
Energy	= (total imports)(1E + 7 kcal/t)(4186 J/kcal)	
	= (1.05E + 8 t/yr)(1E + 7 kcal/t)(4186 J/kcal)	
	= 4.41E + 18 J/yr	

2. COAL

Total import	= 1.43E + 07 tons of oil equivalent/yr	[1,3]
Energy	= (total imports)(1E + 7 kcal/t)(4186 J/kcal)	
	= (1.43E + 8 t/yr)(1E + 7 kcal/t)(4186 J/kcal)	
	= 5.99E + 17 J/yr	

3. NATURAL GAS

Total import	= 2.34E + 07 tons of oil equivalent/yr	[1,3]
Energy	= (total imports)(1E + 7 kcal/t)(4186 J/kcal)	
	= (2.34E + 7 t/yr)(1E + 7 kcal/t)(4186 J/kcal)	
	= 9.80E + 17 J/yr	

4. ELECTRICITY

Total import	= 3.37E + 10 kWh/yr	[1,3]
Energy	= (yearly imports)(3.6E + 6 J/kWh/yr)	
	= (3.37E + 10 kWh/yr)(3.6E + 6 J/kWh)	
	= 1.21E + 17 J/yr	

5. AGRICULTURAL AND FOREST PRODUCTS

(evaluated from [1] with energy equivalents from [5])

Agricultural import	= 3.61E + 13 kcal/yr
Forests import	= 4.33E + 09 kcal/yr
Total products	= 3.61E + 13 kcal/yr
Energy	= (total products)(4186 J/kcal)
	= 1.51E + 17 J/yr

6. LIVESTOCK AND LIVESTOCK PRODUCTS

Total import	= 2.28E + 09 kg/yr (dead weight)	[1]
Total protein content	= (total imp.)(0.22 organic)	
Energy	= (total imports)(0.22)(1000 g/kg)(5.0 kcal/g) (4186 J/kcal)	
	= (2.28E + 9 kg/yr)(1E + 03 g/kg)(5.0 kcal/g) (4186 J/kcal)(0.22)	
	= 1.05E + 16 J/yr	

7. FOOD INDUSTRY PRODUCTS [1]

Human food	= 3.75E + 12 g/yr
Not human food	= 3.79E + 12 g/yr
Alcohol/wine/beer	= 2.99E + 14 l/yr
	= 2.27E + 17 g/yr
Min. water & soft drinks	= 1.78E + 12 g/yr
Total import	= 2.27E + 17 g/yr

8. FISHERY AND HUNTING IMPORTS

Total imports	= 4.78E + 08 kg/yr (dead weight)	[1]
Total protein content	= (total imp.)(0.22 organic)	
Energy	= (total imports)(0.22)(1000 g/kg)(5.0 kcal/g) (4186 J/kcal)	
	= (4.78E + 8 kg/yr)(1E + 03 g/kg)(5.0 kcal/g) (4186 J/kcal)(0.22)	
	= 2.20E + 15 J/yr	

9. METALLIC MINERALS [1,7]

Iron ore	= 1.82E + 13 g/yr
Others	= 2.89E + 12 g/yr
Total import	= 2.11E + 13 g/yr

10. METALLIC SCRAPS [1,7]

Iron & steel	= 5.73E + 12 g/yr
Others	= 3.91E + 11 g/yr
Total import	= 6.12E + 12 g/yr

11. NON METALLIC MINERALS (EXCEPT FUELS) [1,7]

Total import	= 6.00E + 12 g/yr

12. STEEL AND PIG-IRON

Total import	= 1.37E + 13 g/yr	[1]

13. MECH. & TRANSP. EQUIPMENT [1]

Mechanical equip.	= 2.41E + 12 g/yr
Vehicles	= 2.18E + 12 g/yr
Total import	= 4.59E + 12 g/yr

14. NON METALLIC MINERALS INDUSTRY (EXC. FUELS)		
Total import	= 3.88E + 12 g/yr	[1]
15. LEATHER		
Total import	= 2.47E + 05 t/yr	[1]
Energy content	= 1.50E + 07 BTU/t	[13]
	= (1.5E + 7 BTU/t)(1055 J/BTU)	
	= 1.58E + 10 J/t	
Total energy	= 3.91E + 15 J/yr	
16. TEXTILES		[1]
Raw materials	= 8.67E + 11 g/yr	
Processed materials	= 1.36E + 11 g/yr	
Total import	= 1.00E + 12 g/yr	
	= 1.00E + 06 t/yr	
Energy content	= 1.50E + 07 BTU/t	[13]
	= (1.5E + 7 BTU/t)(1055 J/BTU) =	
	= 1.58E + 10 J/t	
Total energy	= 1.58E + 16 J/yr	
17. RAGS		
Total import	= 9.98E + 11 g/yr	[1]
	= 9.98E + 05 t/yr	
Energy content	= 1.50E + 07 BTU/t	[13]
	= (1.50E + 7 BTU/t)(1055 J/BTU)	
	= 1.58E + 10 J/t	
Total energy	= 1.58E + 16 J/yr	
18. WOOD		
Total import	= 3.84E + 12 g/yr	[1]
Ener. cont. per g	= 3.60E + 00 kcal/g	
Energy	= (total imports)(energy cont. per g)(4186 J/kcal)	
	= (3.84E + 12 g/yr)(3.6 kcal/g)(4186 J/kcal)	
	= 5.79E + 16 J/yr	
19. WOOD INDUSTRY PRODUCTS		
Total import	= 4.94E + 12 g/yr	[1]
Energy content	= 3.60E + 00 kcal/g	
Total energy content	= (imports of wood)(energy content per g)(4186 J/kcal)	
	= 7.44E + 16 J/yr	
20. PAPER		
Total import	= 4.67E + 12 g/yr	[1]

21. CHEMICALS
Total import = 1.39E + 13 g/yr [1]

22. RUBBER
Total import = 3.20E + 11 g/yr [1]

Exports
23. REFINED OIL
Total export = 1.50E + 07 tons of oil equivalent/yr [1,3]
Energy = (total exports)(1E + 7 kcal/t)(4186 J/kcal)
= (1.50E + 7 t/yr)(1E + 7 kcal/t)(4186 J/kcal)
= 6.28E + 17 J/yr

24. AGRICULTURAL AND FOREST PRODUCTS
(evaluated from [1] with energy equivalents from [5])
Agricultural export = 6.48E + 12 kcal/yr
Forests export = 8.78E + 09 kcal/yr
Total products = 6.49E + 12 kcal/yr
Energy = (Total products)(4186 J/kcal)
= 2.72E + 16 J/yr

25. FISHERY AND HUNTING EXPORTS
Total export = 4.57 + 07 kg/yr (dead weight) [1]
Total protein content = (total exp.)(0.22 organic)
Energy = (total exports)(0.22)(1000 g/kg)(5.0 kcal/g)(4186 J/kcal)
= (4.57E + 7 kg/yr)(1E + 03 g/kg)(5.0 kcal/g)(4186 J/kcal)(0.22)
= 2.10E + 14 J/yr

26. NON METALLIC MINERALS (EXCEPT FUELS)
Total export = 1.83E + 12 g/yr [1,7]

27. STEEL AND PIG-IRON
Total export = 8.52E + 12 g/yr [1]

28. MECH. & TRANSP. EQUIPMENT [1]
Mechanical equip. = 6.39E + 12 g/yr
Vehicles = 3.46E + 12 g/yr
Total export = 9.85E + 12 g/yr

29. NON METALLIC MINERALS INDUSTRY (EXC. FUELS)
Total export = 8.85E + 12 g/yr [1]

30. LEATHER

Total export	= 3.58E + 11 g/yr	[1]
	= 3.58E + 05 t/yr	
Energy content	= 1.50E + 07 BTU/t	[13]
	= (1.50E + 7 BTU/t)(1055 J/BTU)	
	= 1.58E + 10 J/t	
Total energy	= 5.67E + 15 J/yr	

31. TEXTILES

Raw material	= 8.63E + 11 g/yr	[1]
Processed material	= 2.31E + 11 g/yr	
Total export	= 1.09E + 12 g/yr	
	= 1.09E + 06 t/yr	
Energy content	= 1.50E + 07 BTU/t	[13]
	= (1.50E + 7 BTU/t)(1055 J/BTU)	
	= 1.58E + 10 J/t	
Total energy	= 1.72E + 16 J/yr	

32. RAGS

Total export	= 3.88E + 10 g/yr	[1]
	= 3.88E + 04 t/yr	
Energy content	= 1.50E + 07 BTU/t	[13]
	= (1.50E + 7 BTU/t)(1055 J/BTU)	
	= 1.58E + 10 J/t	
Total energy	= 6.14E + 14 J/yr	

33. WOOD INDUSTRY PRODUCTS

Total export	= 1.09E + 12 g/yr	[1]
Energy content	= 3.60E + 00 kcal/g	
Total energy content	= (exports of wood)(energy content per g)(4186 J/kcal)	
	= 1.64E + 16 J/yr	

34. PAPER

Total export	= 1.44E + 12 g/yr	[1]
PRINTED PAPER		
Total exports	= 2.27E + 11 g/yr	[1]
TOTAL PAPER	= (Paper + printed paper) =	
	= 1.67E + 12 g/yr	

35. CHEMICALS

Total export	= 9.78E + 12 g/yr	[1]

36. RUBBER

Total export	= 4.11E + 11 g/yr	[1]

Footnotes to Table 3; references for data are given in Appendix C

Energy use in the country

1. OIL

Used	= imported + produced	
	= 4.60E + 18 J/yr	

2. COAL

Used	= imported + produced	
	= 6.55E + 17 J/yr	

3. NATURAL GAS

Used	= imported + produced	
	= 1.04E + 18 J/yr	

4. ELECTRICITY

Used	= imported + produced	
	= 8.80E + 17 J/yr	

Money flows

5. GROSS NATIONAL PRODUCT

GNP at market prices	= 1.19E + 15 It.Lit.	[1]
Aver. Lit/$ 1989 ratio	= 1.37E + 03 It.Lit/$	
Total international $	= 8.66E + 11 $	
Emergy/$ ratio	= 1.46E + 12 sej/$	[14]

6. GOODS IMPORT (MONEY BASIS)

Total import	= 2.10E + 14 It.Lit	[1]
Aver. Lit/$ 1989 ratio	= 1.37E + 03 It.Lit/$	
Total international $	= 1.53E + 11 $	
Emergy/$ of the country from which goods come:		
	= 2.50E + 12 sej/$	[12]

7. SERVICES IMPORT

Total import	= 2.40E + 13 It.Lit	[1]
Aver. Lit/$ 1989 ratio	= 1.37E + 03 It.Lit/$	
Total international $	= 1.75E + 10 $	
Emergy/$ of the country from which services come:		
	= 2.50E + 12 sej/$	[12]

8. TOURISM IMPORT

Total import	= 1.61E + 13 It.Lit	[1]
Aver. Lit/$ 1989 ratio	= 1.37E + 03 It.Lit/$	
Total international $	= 1.17E + 10 $	
Emergy/$ of the country from which tourists come:		
	= 2.50E + 12 sej/$	[12]

9. GOODS EXPORT (MONEY BASIS)

Total export	= 1.93E + 14 It.Lit	[1]
Aver. Lit/$ 1989 ratio	= 1.37E + 03 It.Lit/$	
Total international $	= 1.41E + 11 $	
Emergy/$ of the country under study:		
	= 1.46E + 12 sej/$	[14]

10. SERVICES EXPORT

Total export	= 3.44E + 13 It.Lit	[1]
Aver. Lit/$ 1989 ratio	= 1.37E + 03 It.Lit/$	
Total international $	= 2.50E + 10 $	
Emergy/$ of the country under study:		
	= 1.46E + 12 sej/$	[14]

11. TOURISM EXPORT

Total export	= 7.88E + 12 It.Lit	[1]
Aver. Lit/$ 1989 ratio	= 1.37E + 03 It.Lit/$	
Total international $	= 5.74E + 09 $	
Emergy/$ of the country under study:		
	= 1.46E + 12 sej/$	[14]

Indigenous production

12. HYDROELECTRICITY:

Yearly production	= 3.75E + 10 kWh/yr	[1,3]
Energy	= (yearly production)(3.6E + 6 J/kWh)	
	= (3.75E + 10 kWh/yr)(3.6E + 6 J/kWh)	
	= 1.35E + 17 J/yr	

13. GEOELECTRICITY

Yearly production	= 3.15E + 09 kWh/yr	[1,3]
Energy	= (yearly production)(3.6E + 6 J/kWh)	
	= (3.15E + 9 kWh/yr)(3.6E + 6 J/kWh)	
	= 1.13E + 16 J/yr	

14. THERMOELECTRICITY

Yearly production	= 1.70E + 11 kWh/yr	[1,3]
Energy	= (yearly production)(3.6E + 6 J/kWh)	
	= (1.70E + 11 kWh/yr)(3.6E + 6 J/kWh)	
	= 6.12E + 17 J/yr	

15. AGRICULTURAL PRODUCTION

(Evaluated from [1,2] with energy equivalents from [5])

Energy	= 1.95E + 14 kcal/yr * (4186 J/kcal)
	= 8.16E + 17 J/yr

16. LIVESTOCK PRODUCTION (meat only)

Total production	= 3.45E + 09 kg/yr (dead weight)	[1,2]
Total protein content	= (total prod.)(0.22 organic)	
Energy	= (total production)(0.22)(1000 g/kg)(5.0 kcal/g)(4186 J/kcal)	
	= (3.45E + 9 kg/yr)(1E + 03 g/kg)(5.0 kcal/g)(4186 J/kcal)(0.22)	
	= 1.59E + 16 J/yr	

17. FISHERIES PRODUCTION:

Total production	= 3.61E + 08 kg/yr (dead weight)	[1,3]
Total protein content	= (total prod.)(0.22 organic)	
Energy	= (3.61E + 8 kg/yr)(0.22)(1000 g/kg)(5.0 kcal/g)(4186 J/kcal)	
	= 1.66E + 15 J/yr	

18. INDUSTRIAL WASTES

Total production	= 8.03E + 13 g/yr	[2]

19. URBAN WASTES (Miscellaneous)

Total production	= 1.73E + 07 t/yr	[2]
Energy content	= 6.00E + 06 BTU/t	[13]
	= (6.00E + 6 BTU/t)(1055 J/BTU)	
	= 6.33E + 09 J/t	
Energy	= (production)(energy content)	
	= (1.73E + 7 t/yr)(6.33E + 9 J/t)	
	= 1.10E + 17 J/yr	

Footnotes to Table 12; references for data are given in Appendix C

Renewable resources

1. SOLAR ENERGY:

Land area	= 1.69E + 11 m^2	[1]
Insolation	= 1.09E + 02 kcal/cm^2/yr	[3]
Albedo land	= 0.20 (% given as decimal)	[6]
Energy	= (land area)(avg. insolation)(1-albedo) =	
	= (1.69E + 11 m^2)(1.09E + 2 kcal/cm^2/yr)(E + 04 cm^2/m^2)(1 − 0.20)(4186 J/kcal) =	
	= 6.17E + 20 J/yr	

2. RAIN CHEMICAL POTENTIAL:

Land area	= 1.69E + 11 m^2	[1]
Rain (average)	= 0.99 m/yr	[3]
Evapotransp. rate	= 0.43 m/yr (43.6% of total rainfall)	[3,6]

Energy on land	= (area)(evapotranspired rainfall)(water density)(Gibbs no.)	
	= (1.69E + 11 m^2)(0.43 m)(1000 kg/m^3)(4.94E + 03 J/kg)	
	= 3.59E + 17 J/yr	

3. RAIN GEOPOTENTIAL ENERGY:

Area	= 1.69E + 11 m^2	[1]
Rainfall	= 0.99 m/yr	[3]
Average elevation	= 340.00 m	[10]
Runoff rate	= 0.56 m/yr (56.4% of total rainfall)	[3]
Energy	= (area)(runoff rate)(water density)(avg. elevation)(gravity)	
	= (1.69E + 11 m^2)(0.56 m/yr)(1000 kg/m^3)(340 m)(9.8 m/s^2)	
	= 3.15E + 17 J/yr	

4. EARTH CYCLE (steady state uplift balanced by erosion)

Heat flow per area	= 3.00E + 06 J/m^2/yr	[12]
Land area	= 1.69E + 11 m^2	[1]
Energy	= (land area)(heat flow per area)	
	= (1.69E + 11 m^2)(3.00E + 6 J/m^2/yr)	
	= 5.07E + 17 J/yr	

Non-renewable sources from within the system

5. NET LOSS OF TOPSOIL

Farmed area	1.69E + 11 m^2	[1]
Erosion rate	= 2.00E + 02 g/m^2/yr	[4]
% organic in soil	= 3.00E-02	[12]
Energy cont./g organic	= 5.00E + 00 kcal/g	[12]
Net loss	= (farmed area)(erosion rate)	
	= (1.69E + 11 m^2)(200 g/m^2/yr) =	
	= 3.38E + 13 g/yr	
Energy of net loss	= (net loss)(% org.in soil)(5.4 kcal/g)(4186 J/kcal)	
	= (3.38E + 13 g/yr)(0.03)(5.0 kcal/g)(4186 J/kcal)	
	= 2.12E + 16 J/yr	

Applied energy and labor

6. ELECTRICITY USED FOR CROP PRODUCTION

Total use	= 2.92E + 09 kWh/yr	[1,3]
Energy	= (2.92E + 9 kWh/yr)(3.6E + 6 J/kWh)	
	= 1.05E + 16 J/yr	

7. ELECTRICITY USED FOR LIVESTOCK

Total use	= 8.18E + 08 kWh/yr	[1,3]
Energy	= (8.18E + 8 kWh/yr)(3.6E + 6 J/kWh)	
	= 2.94E + 15 J/yr	

7. ELECTRICITY USED FOR LIVESTOCK

Total use	= 8.18E + 08 kWh/yr	[1,3]
Energy	= (8.18E + 8 kWh/yr)(3.6E + 6 J/kWh)	
	= 2.94E + 15 J/yr	

8. LUBRICANTS, CROP PRODUCTION

Total use	= 1.20E + 07 kg/yr	[1]
Energy content per kg	= 7.53 + 07 J/kg	[5]
Energy	= (total use)(energy content per kg)	
	= (1.20E + 7 kg/y)(5.00E + 7 J/kg)	
	= 9.04E + 14 J/yr	

9. DIESEL FOR CROP PRODUCTION (included fodder production for livestock)

Total use	= 1.85E + 09 kg/yr	[1]
Energy content per kg	= 5.15E + 07 J/kg	[15]
Energy	= (total use)(energy content per kg)	
	= (1.85E + 9 kg/yr)(5.15E + 7 J/kg)	
	= 9.53E + 16 J/yr	

10. DIESEL FOR LIVESTOCK (fodder production is not included)

Total use	= 5.71E + 07 kg/yr	[1,5]
Energy content per kg	= 5.15E + 07 J/kg	[15]
Energy	= (total use)(energy content per kg)	
	= (5.71E + 7 kg/yr)(5.15E + 7 J/kg)	
	= 2.94E + 15 J/yr	

11. GASOLINE

Total use	= 1.93E + 08 kg/yr	[1]
Energy content per kg	= 5.53E + 07 J/kg	[15]
Energy	= (total use)(energy content per kg)	
	= (1.93E + 8 kg/yr)(5.53E + 7 J/kg)	
	= 1.07E + 16 J/yr	

12. LABOR FOR CROP PRODUCTION

Energy input:		[1,5,15]
Total man-days applied	= 3.40E + 08 working days (mostly not trained labor)	
Daily metabol. energy	= 2.50E + 03 kcal/day per person	[12]
Total energy applied per person per year	= 7.13E + 05 kcal/person/yr (285 working days/year)	
	= 2.98E + 9 J/yr/person	
Total energy input	= (total metabolic energy/person/day)(total man-days applied)(4186 J/kcal)	
	= 3.56E + 15 J/yr	

Emergy per person	= 2.20E + 16 sej/yr (Italy, 1989)	[14]
Solar transformity of labor	= (total emergy/yr/person)/(total applied energy/yr/person) =	
	= 7.38E + 06 sej/J	

13. LABOR FOR LIVESTOCK

Energy input:		[1,5,15]
Total man-days applied	= 2.68E + 08 working days (mostly not trained labor)	
Daily metabol. energy	= 2.50E + 03 kcal/day per person	[12]
Total energy input		
	= (total metabolic energy/person/day)(total man-days applied)(4186 J/kcal)	
	= 2.80E + 15 J/yr	

Goods and assets for crop production

14. POTASH FERTILIZER

K_2O content	= 4.37E + 11 g/yr	[3]

15. NITROGEN FERTILIZER

N content	= 9.23E + 11 g/yr	[3]

16. PHOSPHATE FERTILIZER

P_2O_5 content	= 6.86E + 11 g/yr	[3]

17. PESTICIDES/Commercial products

Total use	= 1.95E + 08 kg/yr	[3]
Pesticides used and energy for their production:		
Anticryptogamics	= 1.06E + 08 kg/yr [3]; 5.60E = 07 J/kg	[15]
Herbicides	= 2.88E + 07 kg/yr [3]; 9.10E + 07 J/kg	[15]
Insecticides	= 3.59E + 07 kg/yr [3]; 5.30E + 07 J/kg	[15]
Fytohormones	= 2.47E + 07 kg/yr [3]; 1.00E + 08 J/kg	[15]
Total energy	= 1.29E + 16 J/yr (oil equivalents)	

18. MECHANICAL EQUIPMENT

Total equipment used	= 6.42E + 11 g/yr	[15]
Energy for production of machinery	= 9.20E + 07 J/kg	[15]
Total energy for machinery	= 5.91E + 19 J/yr (oil equivalents)	

19. SEEDS [2]

Cereal seeds	= 3.25E + 08 kg/yr	
Potato	= 7.65E + 07 kg/yr	

Vegetables	= 1.11E + 07 kg/yr	
Oilseeds	1.52E + 06 kg/yr	
Sugar beet	= 1.15E + 06 kg/yr	
Tobacco	= 7.70E + 03 kg/yr	
Forage	= 3.11E + 07 kg/yr	
Total use of seeds	= 4.46E + 08 kg/yr	
Average energy for production of seeds		
	= 2.00E + 07 J/kg	[15]
Total energy for seeds	= (total use)(energy for production)	
	8.93E + 15 J/yr (oil equivalents)	

20. ASSETS FOR CROP PRODUCTION [15]

(Total assets and energy embodied for production and maintenance)

Greenhouses	= 2.00E + 04 ha;	2.50E + 11 J/ha/yr
Plastic mulch	= 2.00E + 04 ha;	7.80E + 10 J/ha/yr
Total energy in assets	= 6.56E + 15 J/yr (oil equivalents)	

Goods and assets for livestock

21. ASSETS FOR LIVESTOCK [15]

(Total assets and energy embodied for production and maintenance)

Stables	= 8.50E + 03 ha;	4.20E + 11 J/ha/yr
Total energy in assets	= 3.57E + 15 J/yr (oil equivalents)	

22. FORAGE

Forage crops	= 1.04E + 11 kg/yr	[1]
Pasture	= 8.68E + 09 kg/yr	
Total forage	= 1.13E + 11 kg/yr	
Energy content/unit	= 7.25E + 02 kcal/kg	[5]
Total energy content	= (total fodder)(energy content per unit)	
	= (1.13E + 11 kg/yr)(725 kcal/kg)(4186 J/kcal)	
	= 3.16E + 17 J/yr	

23. INDUSTRIAL FODDER

Total used	= 1.18E + 13 g/yr	[1]
Energy for production	= 4.00E + 03 J/g	[15]
Total energy required	= (total used)(energy requirement)	
	= 4.72E + 16 J/yr (oil equivalents)	

24. SELF-PRODUCED FODDER (production on the farm)

Total used	= 7.49E + 11 g/yr	[1]
Energy for production	= 4.00E + 03 J/g	[15]
Total energy required	= (total used)(energy requirement)	
	= 3.00E + 15 J/yr (oil equivalents)	

Footnotes to Table 13; references for data are given in Appendix C

Selected crops

1. RICE

Total production	= 1.25E + 09 kg/yr	[1]
Energy content per kg	= 3.00E + 03 kcal/kg	[5]
Total energy content	= 3.74E + 12 kcal/yr	
	= 1.56E + 16 J/yr	

2. FORAGE

Total production	= 1.49E + 11 kg/yr	[1]
Energy content per kg	= 7.25E + 02 kcal/kg	[5]
Total energy content	= 1.08E + 14 kcal/yr	
	= 4.52E + 17 J/yr	

3. SUGAR BEET

Total production	= 1.70E + 10 kg/yr	[1]
Energy content per kg	= 6.67E + 02 kcal/kg	[5]
Total energy content	= 1.13E + 13 kcal/yr	
	= 4.74E + 16 J/yr	

4. CORN

Total production	= 6.44E + 09 kg/yr	[1]
Energy content per kg	= 3.50E + 03 kcal/kg	[5]
Total energy content	= 2.25E + 13 kcal/yr	
	= 9.44E + 16 J/yr	

5. WHEAT

Total production	= 7.88E + 09 kg/yr	[1]
Energy content per kg	= 3.30E + 03 kcal/kg	[5]
Total energy content	= 2.60E + 13 kcal/yr	
	= 1.09E + 17 J/yr	

6. FRUITS (apples, pears, peaches, plums and apricots)

Total production	= 4.34E + 09 kg/yr	[1]
Energy content per kg	= 5.50E + 02 kcal/kg	[5]
Total energy content	= 2.39E + 12 kcal/yr	
	= 9.99E + 15 J/yr	

7. VINEYARD

Total production	= 9.64E + 09 kg/yr	[1]
Energy content per kg	= 6.80E + 02 kcal/kg	[5]
Total energy content	= 6.55E + 12 kcal/yr	
	= 2.74E + 16 J/yr	

8. ORANGES AND LEMONS

Total production	= 2.82E + 09 kg/yr	[1]
Energy content per kg	= 4.40E + 02 kcal/kg	[5]
Total energy content	= 1.24E + 12 kcal/yr	
	= 5.19E + 15 J/yr	

9. OLIVE

Total production	= 3.07E + 09 kg/yr	[1]
Energy content per kg	= 1.70E + 03 kcal/kg	[5]
Total energy content	= 5.22E + 12 kcal/yr	
	= 2.18E + 16 J/yr	

10. SUNFLOWER

Total production	= 2.78E + 08 kg/yr	[1]
Energy content per kg	= 6.10E + 03 kcal/kg	[5]
Total energy content	= 1.69E + 12 kcal/yr	
	= 7.09E + 15 J/yr	

11. ALMOND

Total production	= 1.02E + 08 kg/yr	[1]
Energy content per kg	= 1.60E + 03 kcal/kg	[5]
Total energy content	= 1.63E + 11 kcal/yr	
	= 6.80E + 14 J/yr	

Total production

12. AGRICULTURAL PRODUCTION (see also items 1 to 11) [1,5]

Energy	= 1.95E + 14 kcal/yr * (4186 J/kcal)	
	= 8.16E + 17 J/yr	

13. LIVESTOCK PRODUCTION (meat, eggs, milk)

Total meat	= 3.45E + 09 kg/yr	[1]
Total milk and cheese	= 1.05E + 10 kg/yr	[1]
Total eggs	= 6.52E + 09 kg/yr	[1]

a) Meat:

Total protein content	= (total prod.)(0.22 organic)	[12]
Energy	= (total production)(0.22)(1000 g/kg)(5.0 kcal/g)(4186 J/kcal)	
	= (3.45E + 9 kg/yr)(1E + 03 g/kg)(5.0 kcal/g)(4186 J/kcal)(0.22) =	
	= 1.59E + 16 J/yr	

b) Milk & cheese (cheese produced in the farm):

Total protein content	= (total prod.)(0.22 organic)	[12]
Energy	= (total production)(0.22)(1000 g/kg)(5.0 kcal/g)(4186 J/kcal)	
	= (1.05E + 10 kg/yr)(1E + 03 g/kg)(5.0 kcal/g)(4186 J/kcal)(0.22) =	
	= 4.83E + 16 J/yr	

c) Eggs:

Total protein content	= (Total prod.)(0.22 organic)	[12]
Energy	= (total production)(0.22)(1000 g/kg)(5.0 kcal/g)(4186 J/kcal)	
	= (6.52E + 9 kg/yr)(1E + 03 g/kg)(5.0 kcal/g)(4186 J/kcal)(0.22) =	
	= 3.00E + 16 J/yr	

d) Total production	= 2.05E + 10 kg/yr	[1]
Total protein content	= (total prod.)(0.22 organic)	[12]
Energy	= (total production)(0.22)(1000 g/kg)(5.0 kcal/g)(4186 J/kcal)	
	= (1.54E + 10 kg/yr)(1E + 03 g/kg)(5.0 kcal/g)(4186 J/kcal)(0.22) =	
	= 9.42E + 16 J/yr	

14. AGRICULTURAL RESIDUES

(Estimated an average 1:1 main product/residue weight ratio)

Total weight	= 7.65E + 10 kg/yr	[1]
Average energy content	= 2.00E + 03 kcal/kg of residue	
Energy	= (total weight)(average energy content)(4186 J/kcal)	
	= 6.40E + 17 J/yr	

Footnotes to Table 16. References for data are given in Appendix C

1. OIL

Total use	= 3.52E + 07 kg/yr	[1,3]
Energy content per unit	= 1.00E + 04 kcal/kg	
Energy	= (total use)(energy content per unit)(4186 J/kcal)	
	= 1.47E + 15 J/yr	

2. COAL

Total use	= 1.15E + 08 kg/yr	[1,3]
Energy content per unit	= 2.93E + 07 J/kg	
Energy	= (total use)(energy content per unit)	
	= 3.37E + 15 J/yr	

3. METHANE and other gases from coal
   - Total use = 2.42E + 8 m^3/yr [1,3]
   - Energy content per unit = 3.90E + 07 J/m^3
   - Total energy content = (total use)(energy content per unit) = 9.44E + 15 J/yr

4. ELECTRICITY
   - Total use = 8.44E + 09 kWh/yr [1,3]
   - Energy = (total use)(3.6E + 6 J/kWh) = 3.04E + 16 J/yr

5. IRON AND OTHER METALLIC MINERALS [1,3]
   - Total use = 2.04E + 13 g/yr

6. NON-METALLIC MINERALS (limestone, etc.)
   - Total use = 1.76E + 11 g/yr [1,3]

7. LABOR
   - Energy input:
   - Total man-days = 1.70E + 07 working days [1,3]
   - Daily metabolic energy = 2.50E + 03 kcal/day per person [12]
   - Total energy input = (tot. metab. energy/person/day)(working days)(4186 J/kcal) = 1.78E + 14 J/yr

8. TOTAL STEEL PRODUCTION
   - Yearly production = 2.28E + 13 g/yr [1,3]

9. TOTAL EMERGY INPUT
   - Sum of items 1 to 7 2.86E + 22 sej/yr

10. TRANSFORMITY FOR STEEL
    - Solar transformity = total emergy input/total product = 1.25E + 09 sej/g

Footnotes to Table 17. References for data are given in Appendix C

1. OIL
   - Total use = 3.28E + 08 kg/yr [1,3]
   - Energy content per unit = 1.00E + 04 kcal/kg
   - Energy = (total use)(energy content per unit)(4186 J/kcal) = 1.37E + 16 J/yr

2. COAL

Total use	= 5.30E + 09 kg/yr	[1,3]
Energy content per unit	= 2.93E + 07 J/kg	
Energy	= (total use)(energy content per unit)	
	= 1.55E + 17 J/yr	

3. METHANE and other gases from coal

Total use	= 1.42E + 9 m^3/yr	[1,3]
Energy content per unit	= 3.90E + 07 J/m^3	
Total energy content	= (total use)(energy content per unit)	
	= 5.54E + 16 J/yr	

4. ELECTRICITY

Total use	= 2.27E + 08 kWh/yr	[1,3]
Energy	= (total use)(3.6E + 6 J/kWh)	
	= 8.17E + 14 J/yr	

5. IRON AND OTHER METALLIC MINERALS

Total use	= 2.62E + 13 g/yr	

6. NON-METALLIC MINERALS (limestone, etc.)

Total use	= 1.93E + 12 g/yr	[1,3]

7. LABOR

Energy input:		
Total man-days	= 1.68E + 07 working days	[1,3]
Daily metabolic energy	= 2.50E + 03 kcal/day per person	[12]
Total energy input	= (tot. metab. energy/person/day)(working days)(4186 J/kcal)	
	= 1.76E + 14 J/yr	

8. TOTAL PIG-IRON PRODUCTION

Yearly production	= 1.13E + 13 g/yr	[1,3]

9. TOTAL EMERGY INPUT

Sum of items 1 to 7	3.92E + 22 sej/yr	

10. TRANSFORMITY FOR PIG-IRON

Solar transformity	= total emergy input/total product	
	= 3.46E + 09 sej/g	

Evaluation of global steel + pig-iron transformity, for use in Table 2, items 12 and 27

Transformity of steel + pig-iron =
= (emergy input of steel + emergy input of pig-iron)/total grams of both
= 1.98E + 09 sej/g

Appendix B: References for Transformities

A Odum, H.T., 1992. Emergy and Public Policy. Part I–II, Environmental Engineering Sciences, University of Florida, Gainesville, FL.
B Odum, H.T. and Odum, E.C., 1983. Energy Analysis Overview of Nations. WP-83-82, International Institute for Applied Systems Analysis, Laxenburg, Austria.
C Ulgiati, S., Odum, H.T. and Bastianoni, S., 1993. Emergy analysis of Italian agricultural system. The role of energy quality and environmental inputs. In: L. Bonati, U. Cosentino, M. Lasagni, G. Moro, D. Pitea and A. Schiraldi (Editors), Trends in Ecological Physical Chemistry. Elsevier, Amsterdam, pp. 187–215.
D This study.
E Odum, H.T. and Arding, J.E., 1991. Emergy analysis of shrimp mariculture in Ecuador. Department of Environmental Engineering Sciences, University of Florida, Working Paper prepared for Coastal Resources Center, University of Rhode Island, Narragansett, RI.
F Brown, M.T. and Arding, J., 1991. Transformities Working Paper. Center for Wetlands, University of Florida, Gainesville, FL.
G Odum, H.T. and Odum, E.C., 1987. Ecology and economy. Emergy analysis and public policy in Texas. Lyndon B. Johnson School of Public Affairs, Policy Research Project Report No. 78.

Appendix C: References for data

1 ISTAT (Istituto Nazionale di Statistica), 1990. Annuario Statistico Italiano. Rome, Italy.
2 ISTAT (Istituto Nazionale di Statistica), 1990. Statistiche dell'Agricoltura, Zootecnia e mezzi di Produzione. Rome, Italy.
3 ISTAT (Istituto Nazionale di Statistica), 1991. Statistiche Ambientali. Rome, Italy.
4 Triolo, L., 1989. Energia Agricoltura Ambiente. Libri di base, Editori Riuniti, Rome, Italy.
5 Triolo, L., Mariani, A. and Tomarchio, L., 1984. L'uso dell'energia nella produzione agricola e vegetale in Italia. Bilanci energetici e considerazioni medodologiche. Working Paper RT/ FARE/ 84/ 12, ENEA (Comitato Nazionale per la Ricerca e lo Sviluppo dell'Energia Nucleare e delle Energie Alternative), Rome, Italy, 115 pp.
6 Henning, D., 1989. Atlas of the Surface Heat Balance of the Continents. Gebruder Borntraeger, Berlin, Germany, 402 pp.
7 Panulas, J.G., 1989. The Mineral Industry of Italy. Bureau of Mines Mineral Yearbook 1987, United States Department of the Interior, U.S. Government Printing Office, Vol. III.

8 World Resources, 1990–91, Report by the World Resources Institute, Oxford University Press, New York, 1990.
9 Couper, A. (Editor), 1990. The Times Atlas of the Oceans. Van Nostrand Reinhold Co., New York, NY.
10 Istituto Geografico De Agostini, 1975. Calendario Atlante. Novara, Italy.
11 Himschoot, A.R., 1988. Emergy analysis of Italy, a preliminary study. A final Report to EES 5306 Course, Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL.
12 Odum, H.T., 1992. Emergy and Public Policy. Part I–II, Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL.
13 Odum, H.T. and Odum, E.C., 1987. Ecology and economy. Emergy analysis and public policy in Texas. Lyndon B. Johnson School of Public Affairs, Policy Research Project Report No. 78.
14 This study.
15 Biondi, P., Panaro, V. and Pellizzi, G. (Editors), 1989. Le richieste di energia del sistema agricolo italiano. CNR, Consiglio Nazionale delle Ricerche, Progetto Finalizzato Energetica, Sottoprogetto Biomasse ed Agricoltura, Report LB-20, Rome, Italy, 389 pp.

References

Biondi, P., Panaro, V. and Pellizzi, G. (Editors), 1989. Le richieste di energia del sistema agricolo italiano. CNR, Consiglio Nazionale delle Ricerche, Progetto Finalizzato Energetica, Sottoprogetto Biomasse ed Agricoltura, Report LB-20, Rome, Italy, 389 pp.

Brown, M.T. and McClanahan, T., 1992. Emergy analysis perspectives of Thailand and Mekong River dam proposals. A Research Report to the Cousteau Society. Center for Wetlands, University of Florida, Gainesville, FL, 63 pp.

Doherty, S.J., Odum, H.T. and Nilsson, P.O., 1991. Emergy analysis overview of Sweden. In: P.O. Nilsson and U. Sundberg (Editors), Emergy Analysis: a Biophysical Bridging between the Economies of Humanity and Nature. A Report of initial studies to Vattenfall and the Royal Academy of Agricultural Sciences. Working Paper of the Royal Swedish Academy of Agricultural Sciences.

Doherty, S.J., Brown, M.T. and Murphy, R.C., 1992. Emergy analysis and public policy perspectives for Papua New Guinea. A Research Report to the Cousteau Society. Center for Wetlands, University of Florida, Gainesville, FL.

Donati, A., Giolitti, A., Marchettini, N., Rossi, C., Tiezzi, E. and Ulgiati, S., 1993. Environmental aspects of pesticide use in the Italian agriculture. Sci. Total Environ., 129: 125–135.

Fluck, R.C. and Baird, D.C., 1980. Agricultural Energetics. AVI Publishing, Westport, CT.

Huang, S. and Odum, H.T., 1991. Ecology and economy: emergy synthesis and public policy in Taiwan. J. Environ. Manage., 32: 313–333.

Huang, S. and Shih, T., 1992. The evolution and prospects of Taiwan's ecological economic system. Paper presented at the Second Summer Institute of the Pacific Regional Science Conference Organization, Taipei, Taiwan, 20–23 July 1992, Chinese Regional Science Association, Taipei, Taiwan.

Lotka, A.J., 1922a. Contribution to the energetics of evolution. Proc. Natl. Acad. Sci. USA, 8: 147–150.

Lotka, A.J., 1922b. Natural selection as a physical principle. Proc. Natl. Acad. Sci. USA, 8: 151–155.

Lotka, A.J., 1945. The law of evolution as a maximal principle. Hum. Biol., 17: 167–194.

Odum, H.T., 1970. Energy values of water resources. Proceedings of the Nineteenth Southern Water Resources and Pollution Control Conference, April 1970.

Odum, H.T., 1983a. Systems Ecology. An Introduction. John Wiley & Sons, New York, NY, 644 pp.
Odum, H.T., 1983b. Maximum power and efficiency: a rebuttal. Ecol. Modelling, 20: 71–82.
Odum, H.T., 1984. Energy analysis of the environmental role in agriculture. In: G. Stanhill (Editor), Energy and Agriculture. Advanced Series in Agricultural Sciences 14. Springer, Berlin, pp. 24–51.
Odum, H.T., 1988a. Self organization, transformity and information. Science, 242: 1132–1139.
Odum, H.T., 1988b. Energy, environment and public policy. A guide to the analysis of systems. UNEP, United Nations Environmental Programme, Regional Seas Reports and Studies No. 95, 109 pp.
Odum, H.T., 1991. Emergy and biogeochemical cycles. In: C. Rossi and E. Tiezzi (Editors), Ecological Physical Chemistry. Elsevier, Amsterdam, pp. 25–56.
Odum, H.T., 1992. Emergy and Public Policy. Part I–II, Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL.
Odum, H.T. and Arding, J.E., 1991. Emergy analysis of shrimp mariculture in Ecuador. Department of Environmental Engineering Sciences, University of Florida, Working Paper prepared for Coastal Resources Center, University of Rhode Island, Narragansett, RI.
Odum, H.T. and Odum, E.C., 1983. Energy Analysis Overview of Nations. WP-83-82, International Institute for Applied Systems Analysis, Laxenburg, Austria.
Odum, H.T. and Pinkerton, R.C., 1955. Time's speed regulator: the optimum efficiency for maximum power output in physical and biological systems. Am. Sci., 43: 331–343.
Pillet, G., 1991. Shadow pricing for natural resource good and services, using the emergy method. In: O. Guvenen, W. Labys and J.B. Lesourd (Editors), International Commodity Market Models-Advances in Methodology and Applications. Chapman and Hall, London, pp. 91–100.
Pimentel, D., 1980. Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, FL, 475 pp.
Pimentel, D. and Pimentel, M., 1979. Food, Energy and Society. John Wiley & Sons, New York, NY.
Scienceman, D., 1987. Energy and emergy. In: G. Pillet and T. Murota (Editors), Environmental Economics. Roland Leimgruber, Geneva, Switzerland, pp. 257–276.
Triolo, L., Mariani, A. and Tomarchio, L., 1984. L'uso dell'energia nella produzione agricola e vegetale in Italia. Bilanci energetici e considerazioni medodologiche. Working Paper RT/FARE/84/12, ENEA (Comitato Nazionale per la Ricerca e lo Sviluppo dell'Energia Nucleare e delle Energie Alternative), Rome, Italy, 115 pp.
Ulgiati, S., Odum, H.T. and Bastianoni, S., 1993. Emergy analysis of Italian agricultural system. The role of energy quality and environmental inputs. In: L. Bonati, U. Cosentino, M. Lasagni, G. Moro, D. Pitea and A. Schiraldi (Editors), Trends in Ecological Physical Chemistry. Elsevier, Amsterdam, pp. 187–215.
von Bertalanffy, L., 1968. General System Theory. George Braziller, New York, NY, 295 pp.