TRENDS IN ECOLOGICAL PHYSICAL CHEMISTRY

Proceedings of the Second International Workshop on Ecological Physical Chemistry, Milan, Italy, 25–29 May 1992

Edited by

L. BONATI
U. COSENTINO
M. LASAGNI
G. MORO
D. PITEA
A. SCHIRALDI

Dipartimento di Chimica Fisica e Elettrochimica
Università degli Studi di Milano
Milan, Italy

ELSEVIER
AMSTERDAM – LONDON – NEW YORK – TOKYO 1993

EMergy Analysis of Italian Agricultural System. The role of Energy Quality and Environmental Inputs

S.Ulgiati[a], H.T.Odum[b] and S.Bastianoni[c]

[a] Department of Chemistry, University of Sassari, via Vienna 2, 07100 Sassari, Italy

[b] Department of Environmental Engineering Science, University of Florida, A.P.Black Hall, Gainesville, USA

[c] Department of Chemistry, University of Siena, Pian dei Mantellini 44, 5300 Siena, Italy

Abstract

In these times of changing availability of energy, designs of agroecosystems which are economically successful are changing and with them the role of agriculture in national economies and foreign trade: understanding the structure and process of agroecosystems and their role in the economies of humanity and nature has become an important way of studying alternatives.

An *emergy* analysis of Italian agroecosystem is presented, showing its sustainability and net emergy yield, giving the total amount of emergy used, some new transformities and indices to evaluate the quality of products and processes. A comparison with previous energy analyses of Italian agriculture is performed, in order to evaluate the effect of including transformities.

1. INTRODUCTION

As a nation becomes highly developed with urban civilization, what kinds of agriculture are compatible? A spatial hierarchy develops with cities as the centers. Lands near cities are either removed from agricultural production or require intensive, high value crops to compete with alternative economic uses, pay the high taxes and continue as part of the high density urban economy. In this study main kinds of agriculture in contemporary Italy were evaluated using emergy indices to evaluate contributions and concentration.

Maximum power theory (Lotka 1922, Odum 1988) suggests that system designs which maximize emergy production and use will prevail over less optimal system configurations. Systems which maximize emergy and reinforce production are sustainable, the others are displaced by those with better reinforcement of their productive basis. Consumption which does not reinforce production does not compete.

Despite the present favourable 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.

2. PREVIOUS ENERGY EVALUATIONS

A number of papers have evaluated the main inputs to current agriculture in Italy (Triolo *et al,* 1984; Samperi *et al.* 1989; Biondi *et al,* 1989).

All these studies only take into account the direct and indirect use of fossil energy in Italian agriculture. Material goods used in agricultural production are evaluated using only the energy required in their production from raw material and delivery (mining, processing and transporting); fuels are also evaluated for their energy content per unit quantity.

Samperi also estimates the energy value of human service as the caloric equivalent of daily diet of the worker, while Triolo and Biondi report the total working hours, without including them into the total input: in their opinion, labor can be considered negligible and of minor importance in comparison with fossil energy inputs. There is also considerable controversy regarding appropriate evaluation of labor inputs.

Biondi and Samperi do not evaluate the energy content of products, while Triolo evaluates the output/input ratio of Italian agriculture, using the enthalpy of combustion of products. All these authors underline that combustion enthalpy doesn't account for the nutritional value of agricultural products, due to complexity of their chemical composition and function. Triolo also underlines the quality difference between energy inputs from different sources, but no methodology is suggested to perform a better evaluation. Output/input ratio of Italian agriculture is evaluated as 1.86 in Triolo's analysis; it is 1.9 for wheat, 2.9 for rice and corn, 3.1 for sugar beet, 1,3 for sunflower, 3.3 for forage, 0.92 for vineyard, 0.77 for olive, 0.71 for fruits, 0.52 for oranges, 0.22 for almonds. Output/input ratio is considered like a measure of the process efficiency in using energy inputs: ratios less than 1 do not provide net energy, since these crops require more energy than they provide.

Finally, the energy inputs from free environmental sources (sunlight, rain, earth cycle, topsoil used up) are not taken into account, even if they are sometimes scarce (water) or slowly renewable (topsoil) and their misuse should be carefully avoided.

Despite their accuracy, the previous analyses cannot provide an overall view of Italian agriculture. For this purpose, a complete analysis of all energy sources is needed, comparing them on a common equivalent basis. Calculation of more comprehensive indices than the usual output/input ratio is required to lend insight into energy hierarchy of crops, environmental loading, net energy yield, energy investment and effective contribution of a product to the self-organizing system of economy and nature.

3. CONCEPTS AND DEFINITIONS

In this paper, the inputs of solar energy, fuels, electricity, fertilizer materials, human services, capital assets and information required for agriculture have been put on a common basis by evaluating the solar emergy as done in some previous papers on agriculture (Odum 1984; Odum and Odum 1985, 1987). The following are definitions and concepts used in the evaluation of Italian agriculture.

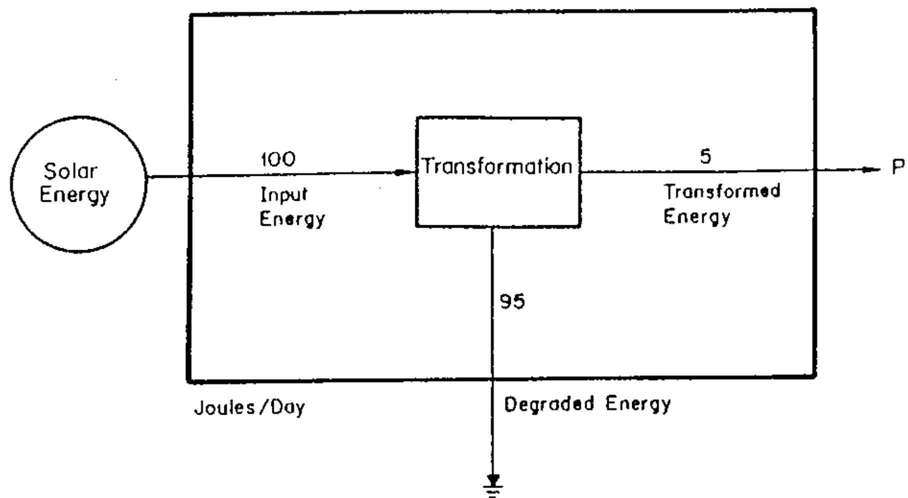
Solar transformity, the solar equivalent energy directly and indirectly required for a joule of product (Figure 1), and *solar emergy*, the total solar energy required to generate a product, are the basis of a methodology for systems analysis, being a measure for determining the best alternatives in resource use, environmental impact, national and international policies for a better equilibrium of human society and nature. Solar emergy expressed in solar emjoules (Odum, 1984, 1991; Scienceman, 1987) is the energy of one kind (solar insolation) required directly and indirectly to generate a product or service. Figure 2 shows the energy language diagramming symbols and definitions used in this study.

Emergy is not only a measure of what went into a product, it is a measure of the useful contributions which 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.

Solar transformity defined as the solar emergy per unit energy measures position of an item in the energy hierarchy of the universe. It is a quality index for every input or product and it accounts for the total solar or solar equivalent energy involved in the unit process. The larger it is the larger is the prior use of solar energy in generating that flow. If real surviving systems are organized to utilize emergy at optimum efficiency for maximum power, flows requiring more emergy to develop will be found only where the products of those flows have commensurate effect. Thus the transformity is a measure of the quality of the process or product both in the sense of what is invested in it and in the effect it has in real systems.

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 (Figure 3). 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. Processes yielding less than this cannot be considered primary emergy sources.

The *emergy investment ratio* is the ratio of the emergy fed back from the economy to the indigenous emergy inputs (Figure 3). This ratio indicates if the



Flow of Solar Emergy of P = 100 Solar Emjoules/Day

$$\text{Solar Transformity of } P = \frac{100 \text{ Solar Emjoules/Day}}{5 \text{ Joules/Day}}$$

$$= 20 \text{ Solar Emjoules/Joule}$$

Figure 1. Diagram of a one source energy transformation illustrating the concepts of energy conservation, solar emergy and solar transformity.

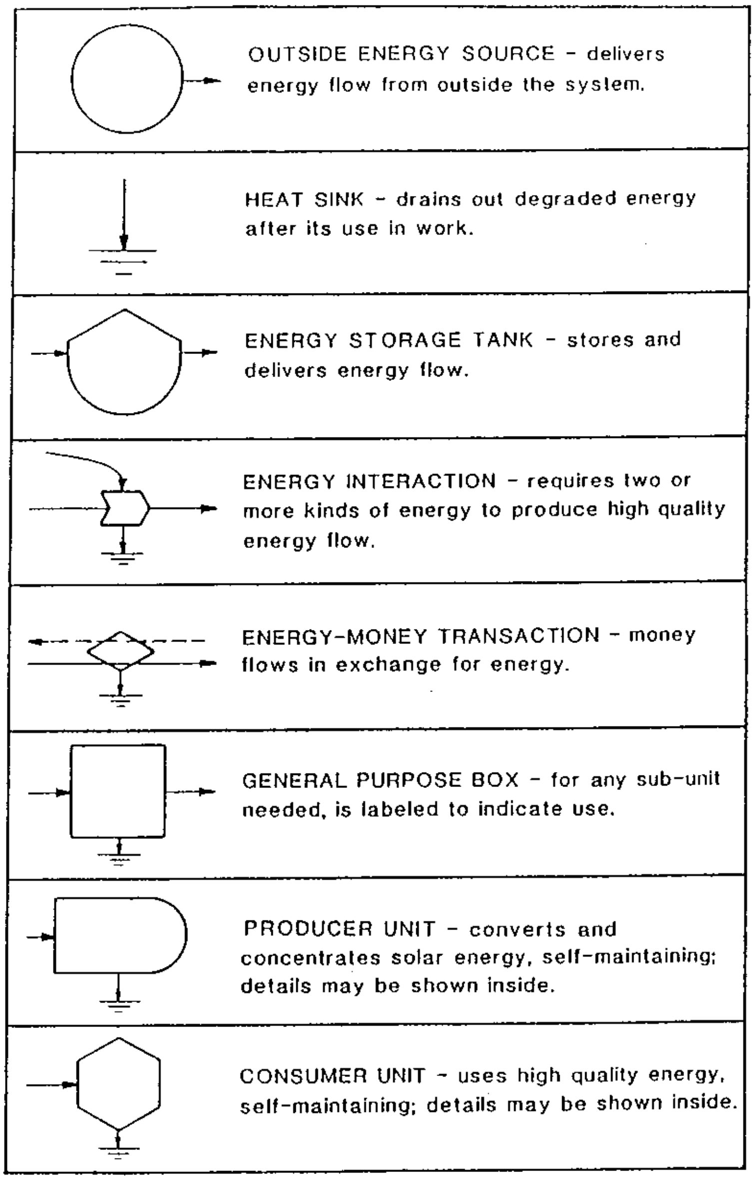
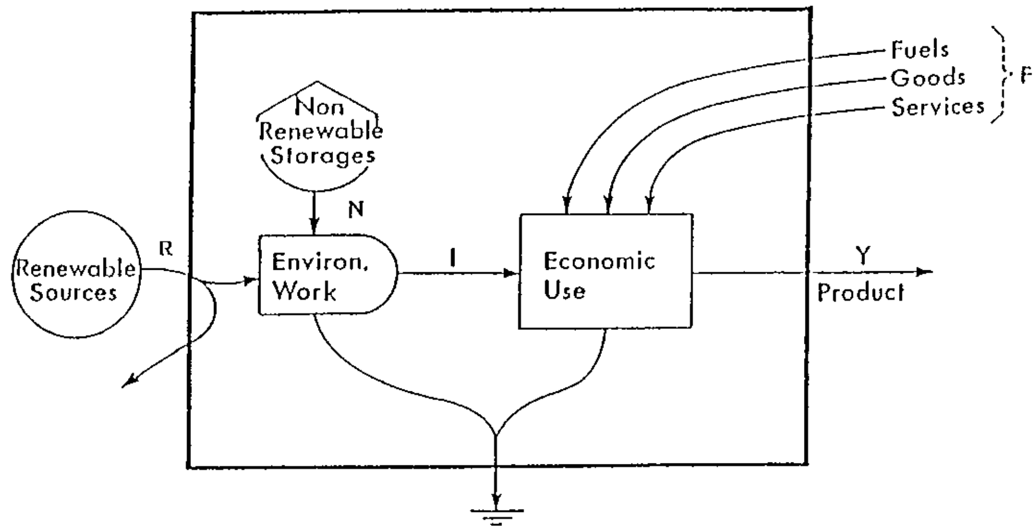


Figure 2. Symbols of the energy language used to represent systems (Odum, 1983).



I = N + R

Y = I + F

Net Emergy Yield Ratio = Y / F

Emergy Investment Ratio = F / I

Environmental Loading Ratio= (F + N) / R

Figure 3. Emergy diagram illustrating computation of emergy yields and use ratios.

process is economical as utilizer of the economy's investments in comparison to alternatives. 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, 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.

The *environmental loading ratio* (Figure 3) is the ratio of purchased and nonrenewable 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 *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, such as rain, nonrenewable resources used such as fuel reserves and organic matter in soil, imported resources and imported goods and services. Rural countries have a higher emergy/dollar ratio because more of their economy involves direct environmental resources inputs not paid for. The term *macroeconomic value* (Tables 1 and 2) 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 product or process contributes more to the economy. It has been proposed (G.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.

Finally, the *empower density*, i.e. the emergy flow per unit area (with the units solar emjoules per m2 per unit time), is a measure of spatial concentration of emergy within a process or system.

4. EMERGY BASIS OF ITALIAN AGRICULTURE

The inputs and products of Italian agriculture are represented schematically in Figure 4, as a production process combining solar energy, fertilizer nutrients, soil, land, labor and capital to yield products and by-products of food and fiber. This agricultural system is embedded in the larger systems of biosphere and Italian economic process.

The resource basis of Italian agriculture is presented in Table 1. It includes the main renewable and nonrenewable environmental sources (sunlight, rain, earth cycle, topsoil) as well as the nonrenewable inputs purchased from the main

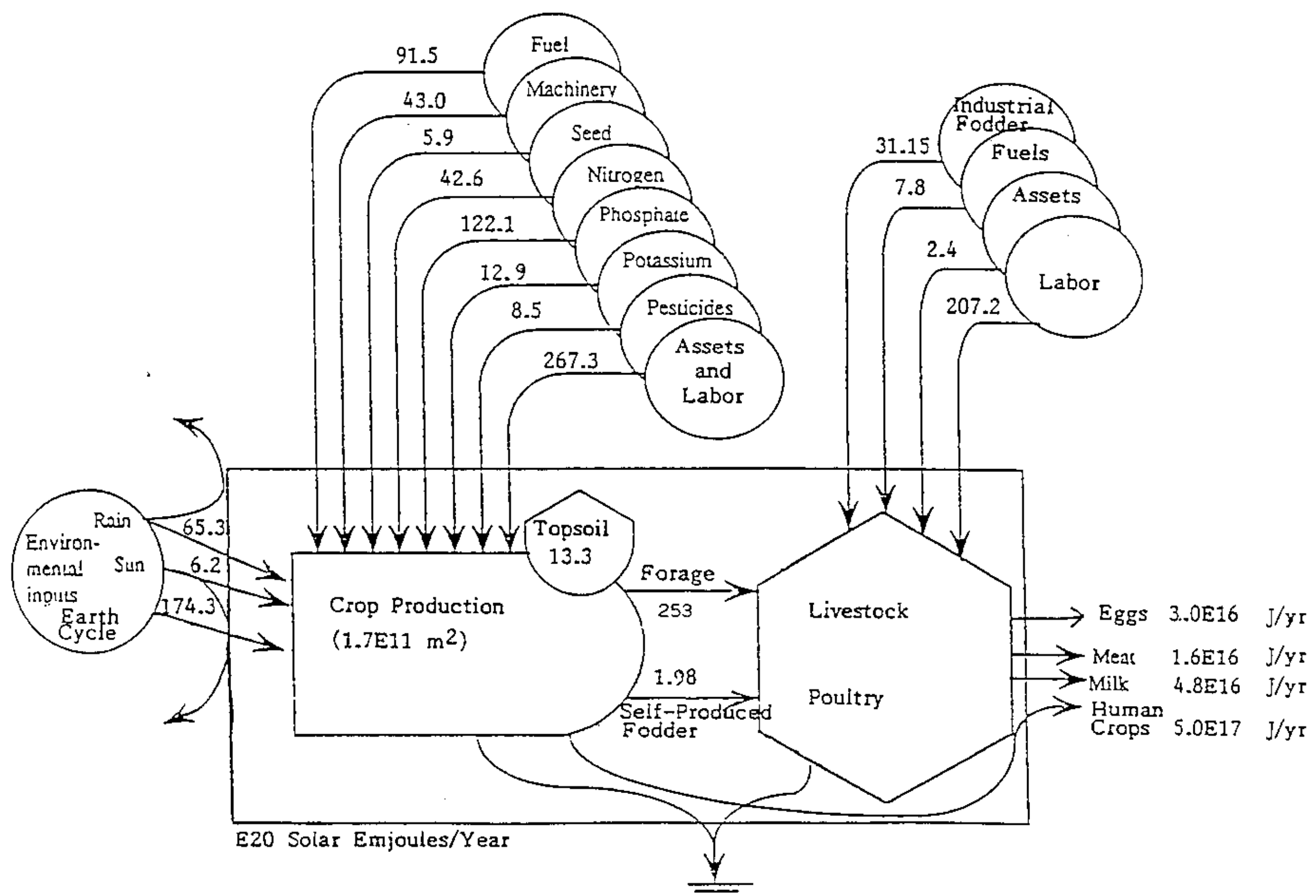


Figure 4. Overview diagram showing emergy inputs to crop and livestock production in Italy. Product flows are in joules/year.

Table 1.
Emergy Analysis of Resources Basis for Italian Agriculture, 1989.

Note	Item	Raw Units		Solar Transform. (sej/unit)	Ref. Transf. (*)	Solar Emergy (E20 sej)	Macroeconom. Value (#) (1989 US $) 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	C	262,46	17,98
13	Labor, livestock	2,80E+15	J	7,38E+06	C	206,88	14,17
GOODS AND ASSETS FOR CROP PRODUCTION							
14	Potash fertilizers, K2O	4,37E+11	g	2,96E+09	B	12,94	0,89
15	Nitrogen fertilizers, N	9,23E+11	g	4,62E+09	A	42,64	2,92
16	Phosphate fertil., P2O5	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	B	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	3,57E+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

(*) References for transformities are given in Appendix A; footnotes in Appendix B.
(#) Emergy divided by 1,46E+12 sej/$ (Emergy/dollar ratio of Italy, 1989) [D].

economy (electricity, fuels, seeds, fertilizers, pesticides, mechanical equipment, labor and assets). The analysis includes the two subsystems of crop and livestock production; the first one directly provides emergy to the second in the form of forage, while other kinds of fodder come from outside, after being processed in the industrial system.

An emergy analysis of the production of selected crops was performed and the results are schematized in Table 2, giving the total emergy input and solar transformities for each crop. An example is given in Table 3, emergy analysis of forage. Table 2 also summarizes the total production of agricultural and livestock subsystems as well as the total emergy inputs and transformities.

A summary of the emergy flows is given in Table 4 and diagrammed in Figure 5, while Table 5 shows the indices of emergy use calculated for a better overview and evaluation of the whole process. Particular care is needed when adding items from the two subsystems (see Table 4), in order to avoid double counting.

Finally, the net emergy yield ratio, the emergy investment ratio, the environmental loading ratio and the empower density were calculated for the crops of Table 2 and results are compared in Table 6.

5. DISCUSSION

The crop production subsystem in Italian agriculture required 8.5E22 sej/yr, while livestock subsystem was supported by 5.0E22 sej/yr. The sum of the two items *without double counting* (Table 4, item 7c), gives the total emergy driving Italian food production, estimated at 10.8E22 sej/yr (Figure 5). System's area was chosen as total cultivated land, when analyzing crop production; it was total area of assets plus hectares cultivated with forage, when livestock subsystem was considered.

A very large contribution to Italian food production comes from goods (mostly chemicals and machinery) and human labor. Free renewable sources to crop production were evaluated (items 1 to 4, Table 1) as well as rural nonrenewable sources from within the system (item 5, Table 1). 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% nonrenewable emergy (Ulgiati *et al,* 1992), so it is possible to assign 9.5% of human labor emergy to renewable sources and the remaining part to nonrenewable sources supporting agricultural process in Italy. Thus renewable (environmental and 9.5% labor) emergy accounts for 31% of total emergy driving the process of crop production.

Emergy in topsoil that is used up (organic matter slowly renewable) cannot be considered a renewable source in the time range under study. Yet it is a free resource and therefore is treated somewhat differently from other purchased non renewables. Free emergy inputs (environmental and topsoil; R1 and No1 in Table 4) accounts for 30% of total emergy used in Italian crop production.

A complete and detailed evaluation of renewable environmental as well as free nonrenewable emergy sources driving the livestock subsystem (R2 and No2, items 1b and 2b in Table 4) is still in progress. Crop production subsystem provides feed stuff to animal production, mostly in the form of forage (items 22 to

Table 2.
Emergy Analysis of Selected Crops and Products in Italian Agriculture, 1989.

Note	Item	Raw Units		Solar Transform. (sej/unit)	Ref. Transf. (*)	Solar Emergy (E20 sej)	Macroeconom. Value (#) (1989 US $) 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	Emergy, crop prod. (item 7, Table 4)					846,32 sej	
16	Emergy, livestock (item 7, Table 4)					502,78 sej	
17	Transform. crops (item 8, Table 4)			1,04E+05	sej/j		
18	Transform. livestock (item 9,Table 4)			3,17E+06	sej/j		

(*) References for transformities are given in Appendix A; footnotes in Appendix B.
(#) Emergy divided by 1,46E+12 sej/$ (Emergy/dollar ratio of Italy, 1989) [D].

Table 3.
Emergy Analysis of Forage Production per Hectare, Italy.

Note	Item	Raw Units		Solar Transform. (sej/unit)	Ref. Transf. (*)	Solar Emergy (E14 sej)	Macroecon. Value (#) (1989 US $)
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	6,82E+07	J	200000	A	0,14	9,34
6	Lubricants	1,42E+08	J	66000	A	0,09	6,43
7	Diesel	4,60E+09	J	66000	A	3,04	207,89
8	Gasoline	2,51E+08	J	66000	A	0,17	11,33
9	Labor	8,32E+07	J	7,38E+06	C	6,14	420,33
GOODS AND ASSETS							
10	Potash Fertilizers, K2O	3,17E+04	g	2,96E+09	B	0,94	64,19
11	Nitrogen Fertilizers, N	3,59E+04	g	4,62E+09	A	1,66	113,54
12	Phosphate Fertil., P2O5	4,10E+04	g	1,78E+10	A	7,29	499,25
13	Pesticides	5,82E+07	J	66000	A	0,04	2,63
14	Mechanical Equipment	3,27E+08	J	66000	B	0,22	14,76
15	Seeds	4,24E+07	J	66000	A	0,03	1,92
PRODUCTION							
16	Forage Harvested	4,34E+10	J				
17	Total Emergy					34,70	
18	Solar Transformity			79951	sej/j		
19	Total Hectares	7,86E+06	Ha				

(*) References for transformities are given in Appendix A; footnotes in Appendix B.
(#) Emergy divided by 1,46E+12 sej/$ (Emergy/dollar ratio of Italy in 1989) [D].

Table 4.
Summary Flows for Italian Agricultural System, 1989.

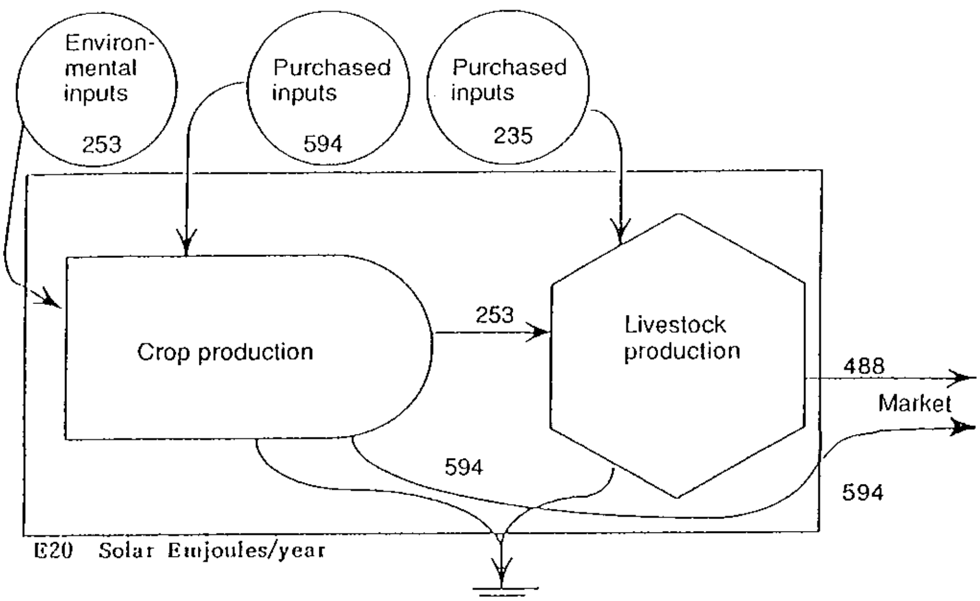
Item	Name of the flow	Expression	Solar Emergy (E20 sej/y)	Unit
1	Renew. environmental sources:			
	Crop production	R1	239,62	sej/yr
	Livestock production	R2=		
		=40.9% of total feed stuff+...	116,76	sej/yr
	Whole system, w. d. c.	R= R1+...(n.e.)	239,62	sej/yr
2	Dispersed non renew.rural sources:			
	Crop production	No1	13,26	sej/yr
	Livestock production	No2=		
		=2.2% of total feed stuff+...	6,46	sej/yr
	Whole system, w. d. c.	No= No1+...(n.e.)	13,26	sej/yr
3	Fuels in crop production	F1	70,52	sej/yr
	Fuels in livestock production	F2	1,94	sej/yr
	Whole system	F= F1+F2	72,46	sej/yr
4	Electricity in crop production	E1	21,02	sej/yr
	Electricity, livestock production	E2	5,89	sej/yr
	Whole system	E= E1+E2	26,90	sej/yr
5	Goods in crop production	G1	239,44	sej/yr
	Goods in livestock production	G2	288,07	sej/yr
	Whole system, w. d. c.	G	259,51	sej/yr
6	Labor in crop production	L1	262,46	sej/yr
	Labor in livestock production	L2	206,88	sej/yr
	Whole system	L= L1+L2	469,33	sej/yr
7	Total Emergy in crop production	U1	846,32	sej/yr
	Total Emergy in livestock, w. d. c.	U2	502,78	sej/yr
	Total Emergy, w. d. c.	U	1081,10	sej/yr
8	Transformity, crop production	U1/crops energy	1,04E+05	sej/j
9	Transform. livestock production	U2/livest.energy	3,17E+06	sej/j
10	Transf. whole system	U/total energy	1,30E+05	sej/j

w. d. c.= without double counting
n. e. = not evaluated

Table 5.
Indices using Emergy for overview of Italian Agriculture, 1989.

Item	Name of the index	Expression	Solar Emergy Flows (*) and Ratios
1	Empower density in crop prod.	U1/tilled area	5,01E+11
	In livestock production	U2/area for livestock	6,39E+11
	Whole system	U/total area	6,40E+11
2	Renewable emergy in crop prod.	C1= R1+0.095L1	2,65E+22
	In livestock production	C2=R2+0.095L2	1,36E+22
	Whole system, w. d. c.	C= R+0.095L	2,84E+22
3	Renewable/total in crop prod.	C1/U1	0,31
	In livestock production	C2/U2	0,27
	Whole system	(R+No+L)/U	0,28
4	Non renew. emergy in crop prod.	D1= No1+F1+E1+G1+0.905L1	5,82E+22
	In livestock production	D2= No2+F2+E2+(assets)+ +55% of total feed stuff+0.905L2	3,66E+22
	Whole system, w. d. c.	D	7,79E+22
5	Purchased emergy in crop prod.	M1=F1+E1+G1+L1	5,93E+22
	In livestock production	M2=F2+E2+(G2-R2-No2)+L2	3,80E+22
	Whole system, w. d. c.	M	8,28E+22
6	Purchased/total in crop prod.	M1/U1	0,70
	In livestock production	M2/U2	0,75
	Whole system, w. d. c.	M/U	0,77
7	Free emergy in crop production	R1+No1	2,53E+22
	In livestock production	R2+No2	1,23E+22
	Whole system	R+No	2,53E+22
8	Free/Total in crop production	(R1+No1)/U1	0,30
	In livestock production	(R2+No2)/U2	0,25
	Whole system	(R+No)/U	0,23
9	Net emergy yield ratio, crop prod.	Emergy yield/purchased emergy	1,43
	In livestock production	Emergy yield/purchased emergy	1,32
	Whole system	Emergy yield/purchased emergy	1,31
10	Environm.loading ratio, crop prod.	(U1-R1)/R1	2,53
	In livestock production	(U2-R2)/R2	3,31
	Whole system	(U-R)/R	3,51
11	Emergy investm.ratio, crop prod.	M1/(R1+No1)	2,35
	In livestock production	M2/(R2+No2+...)	3,08
	Whole system	M/(R+No+...)	3,28

(*) Flows in items 2-4-5-7 are in sej/yr; flows in item 1 are in sej/m2/yr.
n.e.= not evaluated
w. d. c.= without double counting



Y1 = Solar Emergy of Crops
= (253 + 594) E20 = 847 E20 sej/yr.

Y2 = Solar Emergy of Livestock
= (235 + 253) E20 = 488 E20 sej/yr.

Y3 = Total Solar Emergy to the System, without double counting
= (253 + 594 + 235) E20 ~ 1.1 E23 sej/yr.

Figure 5. Summary diagram of energy flows.

Table 6.
Net Emergy Yield Ratio and other Indices for Selected Crops in Italian Agriculture.

Item	Crop	Solar Transformity (E4 sej/j)	Emergy Invest. Ratio	Environmental Loading Ratio	Net Emergy Yield Ratio	Empower Density (E11 sej/m2)
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**		**1,62**	**9,33**		**41,40**

24, Table 1). The renewable environmental component in forage production (rain, earth cycle; Table 3) was 40.9% of total emergy used, while non renewable rural emergy (topsoil; Table 3) accounted for 2.2%. Therefore R2 (item 1b, 2able 4) and No2 (item 2b, Table 4) were evaluated respectively as 40.9% and 2.6% of total (mostly forage) feed stuff provided to livestock. Grazing is a minor practice in Italy and it was included in forage production. Thus the renewable emergy contribution to livestock subsystem accounts for 27% of total emergy flow. Nonrenewable emergy other than rural in forage production was 55% of total input: this percent was used in calculating total nonrenewable contribution to livestock (item 3b, Table 5).

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. However, some indices in Table 5 may be sensitive to their inclusion or exclusion.

Environmental loading ratio for Italy as a whole is 9.47 (Ulgiati *et al*, 1992), much more than the same ratio for crop production, which is 2.5, and for livestock subsystem, which is 3.3. Careful review of the production processes listed in Table 6 shows that some crops contribute more to environmental stress (the environmental loading ratio for sunflower is 27.8, for oranges 11.8, for fruits 9.37) while others are largely under the national average of Italy.

Empower density is very large for sunflower (40.8E11 sej/m2/yr, Table 6), close to the national average of emergy use in Italy (42.0E11 sej/m2/yr). It is less for the other crops. The average for total crop production is 5.0E11 sej/m2, while it is 6.4E11 sej/m2 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 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.

Solar transformities for total average crops and average meat production as well as for selected crops were evaluated (Table 2). A hierarchy of Italian food production results (i.e. there are large amounts of low transformity foods produced and a smaller amount of higher transformity foods). Since transformity is both an index of quality and a measure of a product's effect when used in real self-organizing systems, the presence of very high transformity and emergy investment ratio for sunflower raises several questions. Is this product a necessary part of some other systems, which in their contribution as a whole justify such a large purchased input per unit area of land? Is this product a luxury, a result of free market diversion of resources? Is this product something that will be eliminated when resources are scarcer? A supplemental analysis is required.

Finally, the global net emergy yield ratio (Table 4) of Italian crop production was calculated as 1.43. While Italian agriculture is a net emergy yielder, the relatively low ratio indicates that it cannot be considered as a primary energy source. Some crops (Table 6) show similar or higher ratios (rice, forage), while others show ratios very close to 1 (sunflower, oranges, sugar beet). Because these last agricultural crops use almost as much emergy from the economy as they yield to it, they contribute little to the economy. However, 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.

As oil, gas and related products become scarcer and more precious, their value as emergy sources will be reduced and the importance of agriculture as a potential net emergy provider will increase. As oil and gas prices approach their real value, agriculture will have to rely less on these inputs. Fuels, chemical fertilizers and pesticides will have to be replaced by the optimal 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.

6. 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, Roma, Italy, 389 pp.

Lotka A.J., 1922. A contribution to the energetics of evolution. Proc.National Academy of Sciences, U.S., 8, 147-155.

Odum H.T., 1983. Systems Ecology. An Introduction. John Wiley & Sons Publishers, New York, 644 pp.

Odum H.T., 1984. Energy Analysis of the Environmental Role in Agriculture. In 'Energy and Agriculture', Advanced Series in Agricultural Sciences 14, Stanhill G. editor, Springer-Verlag, Berlin, 24-51.

Odum H.T., 1988. Self organization, transformity and information. Science, 242, 1132-1139.

Odum H.T., 1991. Emergy and biogeochemical cycles. In: Ecological Physical Chemistry, C.Rossi and E.Tiezzi editors, Elsevier Science Publishers, Amsterdam, 25-56.

Odum E.C. and Odum H.T., 1985. System of Ethanol Production from Sugarcane in Brazil. Ciencia E Cultura, 37(11), 1849-1855.

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 and Texas Department of Agriculture, Policy Research Project Report, Number 78, University of Texas, Austin, Texas, 178 pp..

Pillet G., 1991. Shadow pricing for natural resource good and services, using the emergy method. In International Commodity Market Models-Advances in methodology and applications, O.Guvenen, W.Labys and J.B.Lesourd editors, Chapman and Hall, London.

Samperi M., Napolitano C., De Laurentis D., Mariani T. and Pellicano A.G. 1989. Bilanci energetici in Abruzzo. Final report for ENEA-CNR-'Energetics 2' Target project , Contract n.86.02622.59, 55 pp.

Scienceman D., 1987. Energy and Emergy. In: Environmental Economics (pp.257-276), Pillet G. and Murota T. editors, Roland Leimgruber, Geneva, Switzerland, 308 pp.

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), pp.115. Roma, Italy.

Ulgiati S., Odum H.T. and Bastianoni S., 1992. Emergy Use, Environmental Loading and Sustainability. Proceedings of the International ISEE Conference 'Investing in Natural Capital. A prerequisite for Sustainability', University of Stockholm, Sweden, August 3-6, 1992.

APPENDIX A

References for Transformities

A) - Odum H.T., 1992. Emergy and Public Policy. Part I-II, Environmental Engineering Sciences, University of Florida, Gainesville, USA.

B) - Brown M.T. and Arding J., 1991. Transformities Working Paper. Center for Wetlands, University of Florida, Gainesville, USA.

C) - This study.

D) - Ulgiati S., Odum H.T. and Bastianoni S., 1992. Modelling Interaction between Environment and Human Society in Italy: an Emergy Analysis. In 'General Systems Approaches to Alternative Economics and Values', Vol.II, pp.1121-1133; Linda P.Peeno Editor; published 1992 by International Society for the Systems Sciences, College of Business, Idaho State University, Pocatello, Idaho 83209, USA.

APPENDIX B

Footnotes to Table 1; references for footnotes 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 (J/y)= (land area)(avg. insolation)(1-albedo)=
=(1.69E+11 m^2)(1.09E+2 Kcal/cm^2/y)(E+04 cm^2/m^2)
(1-0.20)(4186 J/kcal)=
= 6,17E+20 J/y

2 RAIN CHEMICAL POTENTIAL:

Land Area =	1,69E+11 m^2	[1]
Rain (average)=	0,99 m/y	[3]
Evapotransp.Rate=	0,43 m/y (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/y

3 RAIN, GEOPOTENTIAL ENERGY:

Area =	1,69E+11 m^2	[1]
Rainfall =	0,99 m/y	[3]
Average elevation=	340,00 m	[7]
Runoff rate =	0,56 m/y (56.4% of total rainfall)	[3]

Energy= (area)(runoff rate)(water density)(avg. elevation)(gravity)
= (1.69E+11 m^2)(0.56 m/y)(1000 kg/m^3)(340 m)(9.8 m/s^2)
= 3,15E+17 J/y

4 EARTH CYCLE (steady state uplift balanced by erosion)

Heat flow per area =	3,00E+06 J/m2/y	[A]
Land area =	1,69E+11 m2	[1]

Energy (J/y) = (land area)(heat flow per area)
= (1.69E+11 m2)(3.00E+6 J/m2/y)
= 5,07E+17 J/y

NON RENEWABLE SOURCES FROM WITHIN THE SYSTEM

5 NET LOSS OF TOPSOIL

Farmed Area	1,69E+11 m2	[1]
Erosion rate =	2,00E+02 g/m2/y	[8]
% organic in soil =	3,00E-02	[A]
Energy cont./g organic=	5,00E+00 kcal/g	[A]

Net loss = (farmed area)(erosion rate)
= (1.69E+11 m2)(200 g/m2/y)=

= 3,38E+13 g/y

Energy of net loss (J/y) = (net loss)(% org.in soil)(5.4 Kcal/g)(4186 J/kcal)
= (3.38E+13 g/y)(0.03)(5.0 kcal/g)(4186 J/kcal)=
= 2,12E+16 J/y

APPLIED ENERGY AND LABOR

6 ELECTRICITY USED FOR CROP PRODUCTION
Total use = 2,92E+09 Kwh/y [1,3]
Energy = (2.92E+9 Kwh/y)(3.6E+6 J/Kwh)
= 1,05E+16 J/y

7 ELECTRICITY USED FOR LIVESTOCK
Total use = 8,18E+08 Kwh/y [1,3]
Energy = (8.18E+8 Kwh/y)(3.6E+6 J/Kwh)
= 2,94E+15 J/y

8 LUBRICANTS, CROP PRODUCTION
Total Use= 1,20E+07 Kg/y [1]
Energy content per Kg= 7,53E+07 J/Kg [5]
Energy (J/y) = (total use)(Energy content per Kg)
= (1.20E+7 Kg/y)(5.00E+7 J/Kg)
= 9,04E+14 J/y

9 DIESEL FOR CROP PRODUCTION (included fodder production for livestock)
Total Use= 1,85E+09 Kg/y [1]
Energy content per Kg= 5,15E+07 J/Kg [4]
Energy (J/y) = (total use)(Energy content per Kg)
= (1.85E+9 Kg/y)(5.15E+7 J/Kg)
= 9,53E+16 J/y

10 DIESEL FOR LIVESTOCK (fodder production is not included)
Total Use= 5,71E+07 Kg/y [1,5]
Energy content per Kg= 5,15E+07 J/Kg [4]
Energy (J/y) = (total use)(Energy content per Kg)
= (5.71E+7 Kg/y)(5.15E+7 J/Kg)
= 2,94E+15 J/y

11 GASOLINE
Total Use= 1,93E+08 Kg/y [1]
Energy content per Kg= 5,53E+07 J/Kg [4]
Energy (J/y) = (total use)(Energy content per Kg)
= (1.93E+8 Kg/y)(5.53E+7 J/Kg)
= 1,07E+16 J/y

12 LABOR FOR CROP PRODUCTION
Energy input:

Total man-days applied=	3,40E+08 working days (not trained labor)	[1,4,5]
Daily metabol. energy=	2,50E+03 kcal/day per person	[A]
Total energy applied per person per year=	7,13E+05 Kcal/person/yr (285 working days/year)	
=	2,98E+09 J/yr/person	

Total energy input=
= (total metabolic energy/person/day)(total man-days applied)(4186 J/Kcal)
= 3,56E+15 J/y

Emergy per person = 2,20E+16 sej/y (Italy, 1989) [D]

Solar Transformity of labor=
= (Total emergy/yr/person)/(Total app lied energy/yr/person)=
= 7,38E+06 sej/j

13 LABOR FOR LIVESTOCK

Energy input:

Total man-days applied=	2,68E+08 working days (not trained labor)	[1,4,5]
Daily metabol. energy=	2,50E+03 kcal/day per person	[A]

Total energy input=
=(total metabolic energy/person/day)(total man-days applied)(4186 J/Kcal)
= 2,80E+15 J/y

GOODS AND ASSETS FOR CROP PRODUCTION

14 POTASH FERTILIZER

K2O content= 4,37E+11 g/y [3]

15 NITROGEN FERTILIZER

N content= 9,23E+11 g/y [3]

16 PHOSPHATE FERTILIZER

P2O5 content= 6,86E+11 g/y [3]

17 PESTICIDES/ Commercial Products

Total Use= 1,95E+08 Kg/y [3]

Pesticides used and energy for their production:

Anticryptogamics=	1,06E+08 Kg/y	[3]	;	5,60E+07 J/Kg	[4]
Herbicides=	2,88E+07 Kg/y	[3]	;	9,10E+07 J/Kg	[4]
Insecticides=	3,59E+07 Kg/y	[3]	;	5,30E+07 J/Kg	[4]
Fytohormones=	2,47E+07 Kg/y	[3]	;	1,00E+08 J/Kg	[4]
Total energy=	1,29E+16 J/y			(oil equivalents)	

18 MECHANICAL EQUIPMENT

Total equipment used=	6,42E+11 g/y	[4]
Energy for production of machinery=	9,20E+07 J/Kg	[4]
Total energy for machinery=	5,91E+19 J/y (oil equivalents)	

19 SEEDS [2]

Cereal seeds=	3,25E+08	Kg/y
Potato=	7,65E+07	Kg/y
Vegetables=	1,11E+07	Kg/y
Oilseeds	1,52E+06	Kg/y
Sugar Beet=	1,15E+06	Kg/y
Tobacco=	7,70E+03	Kg/y
Forage=	3,11E+07	Kg/y
Total use of seeds=	4,46E+08	Kg/y

Average energy for production of seeds=
2,00E+07 J/Kg [4]

Total energy for seeds= (total use)(Energy for production)
8,93E+15 J/y (oil equivalents)

20 ASSETS FOR CROP PRODUCTION
(Total assets and energy embodied for production and maintenance) [4]
Greenhouses= 2,00E+04 Ha; 2,50E+11 J/Ha/y
Plastic mulch= 2,00E+04 Ha; 7,80E+10 J/Ha/y
Total energy in assets= 6,56E+15 J/y (oil equivalents)

GOODS AND ASSETS FOR LIVESTOCK

21 ASSETS FOR LIVESTOCK
(Total assets and energy embodied for production and maintenance) [4]
Stables= 8,50E+03 Ha; 4,20E+11 J/Ha/y
Total energy in assets= 3,57E+15 J/y (oil equivalents)

22 FORAGE [1]
Forage crops= 1,04E+11 Kg/y
Pasture= 8,68E+09 Kg/y
Total forage= 1,13E+11 Kg/y
Energy content/unit= 7,25E+02 Kcal/Kg [5]
Total energy content= (Total fodder)(Energy content per unit)
= (1.13E+11 Kg/y)(725 Kcal/Kg)(4186 J/Kcal)
= 3,16E+17 J/y

23 INDUSTRIAL FODDER
Total used= 1,18E+13 g/y
Energy for production= 4,00E+03 J/g [1]
Total energy required= (total used)(Energy requirement) [4]
= 4,72E+16 J/y (oil equivalents)

24 SELF-PRODUCED FODDER (production in the farm)
Total used= 7,49E+11 g/y
Energy for production= 4,00E+03 J/g [1]
Total energy required= (total used)(Energy requirement) [4]
= 3,00E+15 J/y (oil equivalents)

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

SELECTED CROPS

1 RICE

Total production=	1,25E+09	Kg/y	[1]
Energy content per Kg=	3,00E+03	Kcal/Kg	[5]
Total energy content=	3,74E+12	Kcal/y	
=	1,56E+16	J/y	

2 FORAGE

Total production=	1,49E+11	Kg/y	[1]
Energy content per Kg=	7,25E+02	Kcal/Kg	[5]
Total energy content=	1,08E+14	Kcal/y	
=	4,52E+17	J/y	

3 SUGAR BEET

Total production=	1,70E+10	Kg/y	[1]
Energy content per Kg=	6,67E+02	Kcal/Kg	[5]
Total energy content=	1,13E+13	Kcal/y	
=	4,74E+16	J/y	

4 CORN

Total production=	6,44E+09	Kg/y	[1]
Energy content per Kg=	3,50E+03	Kcal/Kg	[5]
Total energy content=	2,25E+13	Kcal/y	
=	9,44E+16	J/y	

5 WHEAT

Total production=	7,88E+09	Kg/y	[1]
Energy content per Kg=	3,30E+03	Kcal/Kg	[5]
Total energy content=	2,60E+13	Kcal/y	
=	1,09E+17	J/y	

6 FRUITS (Apples, pears, peaches, plums ed apricots)

Total production=	4,34E+09	Kg/y	[1]
Energy content per Kg=	5,50E+02	Kcal/Kg	[5]
Total energy content=	2,39E+12	Kcal/y	
=	9,99E+15	J/y	

7 VINEYARD

Total production=	9,64E+09	Kg/y	[1]
Energy content per Kg=	6,80E+02	Kcal/Kg	[5]
Total energy content=	6,55E+12	Kcal/y	
=	2,74E+16	J/y	

8 ORANGES AND LEMONS			
Total production=	2,82E+09	Kg/y	[1]
Energy content per Kg=	4,40E+02	Kcal/Kg	[5]
Total energy content=	1,24E+12	Kcal/y	
=	5,19E+15	J/y	
9 OLIVE			
Total production=	3,07E+09	Kg/y	[1]
Energy content per Kg=	1,70E+03	Kcal/Kg	[5]
Total energy content=	5,22E+12	Kcal/y	
=	2,18E+16	J/y	
10 SUNFLOWER			
Total production=	2,78E+08	Kg/y	[1]
Energy content per Kg=	6,10E+03	Kcal/Kg	[5]
Total energy content=	1,69E+12	Kcal/y	
=	7,09E+15	J/y	
11 ALMOND			
Total production=	1,02E+08	Kg/y	[1]
Energy content per Kg=	1,60E+03	Kcal/Kg	[5]
Total energy content=	1,63E+11	Kcal/y	
=	6,80E+14	J/y	

TOTAL PRODUCTION

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

Energy (J/y) = 1,95E+14 Kcal/y * (4186 J/Kcal)

= 8,16E+17 J/y

13 LIVESTOCK PRODUCTION (meat, eggs, milk)

Total meat=	3,45E+09 Kg/y	[1]
Total milk and cheese=	1,05E+10 Kg/y	[1]
Total eggs=	6,52E+09 Kg/y	[1]

a) Meat: [1]

Total protein content= (Total prod.)(0.22 organic) [A]

Energy (J/y) = (Total production)(0.22)(1000 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)

= (3.45E+9 Kg/y)(1E+03 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)(0.22)=

= 1,59E+16 J/y

b) Milk & Cheese (cheese produced in the farm): [1]

Total protein content= (Total prod.)(0.22 organic) [A]

Energy (J/y) = (Total production)(0.22)(1000 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)

= (1.05E+10 Kg/y)(1E+03 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)(0.22)=

= 4,83E+16 J/y

c) Eggs: [1]
Total protein content= (Total prod.)(0.22 organic) [A]
Energy (J/y) = (Total production)(0.22)(1000 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)
= (6.52E+9 Kg/y)(1E+03 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)(0.22)=
= 3,00E+16 J/y

d) Total Production = 2,05E+10 Kg/y [1]
Total protein content= (Total prod.)(0.22 organic) [A]
Energy (J/y) = (Total production)(0.22)(1000 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)
= (1.54E+10 Kg/y)(1E+03 g/Kg)(5.0 Kcal/g)(4186 J/Kcal)(0.22)=
= 9,42E+16 J/y

14 AGRICULTURAL RESIDUES
(Estimated an average 1:1 main product/residue weight ratio)
Total weight= 7,65E+10 Kg/y [1]
Average energy content = 2,00E+03 Kcal/Kg of residue
Energy (J/y) = (total weight)(Average energy content)(4186 J/Kcal)
= 6,40E+17 J/y

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

RENEWABLE RESOURCES

1 SOLAR ENERGY:
Land Area = 1,00E+04 m^2
Insolation = 1,09E+02 Kcal/cm^2/yr [3]
Albedo land = 0,20 (% given as decimal) [6]
Energy (J/y)= (land area)(avg. insolation)(1-albedo)=
= (1.00E+4 m^2)(1.09E+2 Kcal/cm^2/y)(E+04 cm^2/m^2)
(1-0.20)(4186 J/kcal)=
= 3,65E+13 J/y

2 RAIN CHEMICAL POTENTIAL:
Land Area = 1,00E+04 m^2
Rain (average)= 0,99 m/y [3]
Evapotransp.Rate= 0,43 m/y (43.6% of total rainfall) [3,6]
Energy (land) (J/y)= (area)(Evapotranspired rainfall)(Water density)(Gibbs no.)
= (1.00E+4 m^2)(0.43 m)(1000 kg/m^3)(4.94E+03 J/kg)
= 2,12E+10 J/y

3 EARTH CYCLE (steady state uplift balanced by erosion)
Heat flow per area = 3,00E+06 J/m2/y [A]
Land area = 1,00E+04 m2
Energy (J/y) = (land area)(heat flow per area)
= (1.00E+4 m2)(3.00E+6 J/m2/y)
= 3,00E+10 J/y

NON RENEWABLE SOURCES FROM WITHIN THE SYSTEM

4 NET LOSS OF TOPSOIL

Farmed Area	1,00E+04 m2	
Erosion rate =	2,00E+02 g/m2/y	[8]
% organic in soil =	3,00E-02	[A]
Ener. cont. per g organic=	5,00E+00 kcal/g	[A]

Net loss = (farmed area)(erosion rate)
= (1.00E+4 m2)(200 g/m2/y)=
= 2,00E+06 g/y

Energy of net loss (J/y) = (net loss)(% org.in soil)(5.4 Kcal/g)(4186 J/kcal)
= (2.00E+6 g/y)(0.03)(5.0 kcal/g)(4186 J/kcal)
= 1,26E+09 J/y

APPLIED ENERGY AND LABOR

5 ELECTRICITY

Total use = 1,89E+01 Kwh/y [1,3]

Energy = (1.89E+1 Kwh/y)(3.6E+6 J/Kwh)
= 6,82E+07 J/y

6 LUBRICANTS

Total Use=	1,89E+00 Kg/y	[1]
Energy content per Kg=	7,53E+07 J/Kg	[5]

Energy (J/y) = (total use)(Energy content per Kg)
= (1.89 Kg/y)(5.00E+7 J/Kg)
= 1,42E+08 J/y

7 DIESEL

Total Use=	9,64E+01 L/y	[1]
Energy content per litre=	1,14E+04 Kcal/L	[5]

Energy (J/y) = (total use)(Energy content per L)*4186 J/Kcal
= (9.64E+1 L/y)(1.14E+4 Kcal/L)(4186 J/Kcal)
= 4,60E+09 J/y

8 GASOLINE

Total Use=	5,93E+00 L/y	[1]
Energy content per litre=	1,01E+04 Kcal/L	[5]

Energy (J/y) = (total use)(Energy content per L)*4186 J/Kcal
= (5.93 L/y)(1.01E+4 Kcal/L)(4186 J/Kcal)
= 2,51E+08 J/y

9 LABOR

Energy input: [5]

Total man-hours applied= 63,60 hours/y, mostly not trained labor

Man-days= (Total hours)/(8 working hours per person per day)
= 7,95 Man-days per Ha per year

Daily metabolic energy= 2,50E+03 kcal/day per person [A]
= 1,05E+07 J/day

Total energy input= (Total man-days)(Daily metabolic energy)(4186 J/Kcal)
= 8,32E+07 J/Ha/y

GOODS AND ASSETS

10 POTASH FERTILIZER
K2O content= 3,17E+04 g/y [3]

11 NITROGEN FERTILIZER
N content= 3,59E+04 g/y [3]

12 PHOSPHATE FERTILIZER
P2O5 content= 4,10E+04 g/y [3]

13 PESTICIDES (Commercial Products)
Total Use= 6,40E-01 Kg/y [3]
Pesticides used and energy for their production:

Anticryptogamics	0,00E+00 Kg/y	[3]	5,600E+07 J/Kg	[4
Herbicides	6,40E-01 Kg/y	[3]	9,100E+07 J/Kg	[4
Insecticides	0,00E+00 Kg/y	[3]	5,300E+07 J/Kg	[4
Fytohormones	0,00E+00 Kg/y	[3]	1,00E+08 J/Kg	[4]
Total energy=	5,82E+07 J/y		oil equivalents	

14 MECHANICAL EQUIPMENT
Total Use = 7,80E+04 Kcal/y [5]
(production, depreciation and maintenance)
Total energy for machinery= (energy embodied in oil equivalents)(4186 J/Kcal)
= 3,27E+08 J/y

15 SEEDS [2]
Total use= 4,24E+00 Kg/y
Energy for production of seeds=
1,00E+07 J/Kg [4]
Total energy for seeds= (total use)(Energy for production)
4,24E+07 J/y (oil equivalents)

16 FORAGE PRODUCTION

Total =	1,43E+04	Kg/Ha	[1]
Energy content per Kg=	7,25E+02	Kcal/Kg	[5]
Total energy content=	1,04E+07	Kcal/Ha	
=	4,34E+10	J/Ha	

17 TOTAL SOLAR EMERGY
Sum of items 2 to 15.

18 SOLAR TRANSFORMITY
Transformity= (Total solar emergy input)/(Total energy output in the product)
= 8,00E+04 sej/j

APPENDIX C

References for data

1) - ISTAT, Istituto Nazionale di Statistica, 1990. Annuario Statistico Italiano. Roma, Italy.

2) - ISTAT, Istituto Nazionale di Statistica, 1990. Statistiche dell'Agricoltura, Zootecnia e mezzi di Produzione. Roma, Italy.

3) - ISTAT, Istituto Nazionale di Statistica, 1991. Statistiche Ambientali. Roma, Italy.

4) - 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, Roma, Italy, 389 pp.

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), pp.115. Roma, Italy.

6) - Henning Dieter, 1989. Atlas of the Surface Heat Balance of the Continents, Gebruder Borntraeger, Berlin, Germany, pp.402.

7)- Istituto Geografico De Agostini , 1975. Calendario Atlante. Novara, Italy.

8) - Triolo L., 1989. Energia Agricoltura Ambiente. Libri di base, Editori Riuniti, Roma, Italy.