CEPAL

Review

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UNITED NATIONS
ECONOMIC COMMISSION FOR LATIN AMERICA

SANTIAGO, CHILE/APRIL 1984

CEPAL

Review

Number 22 Santiago, Chile April 1984

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CEPAL REVIEW No. 22

Energy and the prevailing model of agricultural technology in Latin America

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In this article the author discusses some important issues related to the use of energy in Latin American agricultural production.

The increases made in the region's agricultural output in recent decades have been based on the intensified exploitation of areas which are already in use rather than on the use of new land, and in general this intensification has conformed to the pattern of agricultural development followed in the United States. Due to the large amount of energy inputs required for this type of development, however, it cannot be widely applied in other countries, and it has therefore become imperative to seek other approaches to agricultural expansion in Latin America.

Having stated the central problem in these terms, the author explores the possible technological options which could be applied; to this end, he first analyses the energy-related aspects of technological inputs, the energy productivity of the labour force and the environmental energy endowment. The possible technological options will depend upon the extent of intervention which has taken place in each climatic zone. Greater difficulties are involved in changing over those areas in which intervention has been more intensive, although a great deal can still be done to re-orient their use of energy; in areas where there has been less intervention, such as the humid tropics, exploitation could be based from the outset on approaches which are in keeping with the needs and potentials of the region.

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I

Introduction

The current debate on the energy problem in the rural sector tends to focus on an analysis of the possibilities for producing energy from the alternative sources available in this sector. There has been interest in research on the bio-energy which can be obtained from crops, the exploitation of forests and the processing of wastes. Efforts have also been directed towards using the energy produced by renewable or inexhaustible resources such as wind power, solar energy and water power.[1]

While it is of course very important to explore these possibilities, there is another facet of the energy problem relating to the situation and projections of agricultural development in Latin America which, because of its complexity, has hitherto been dealt with in a piecemeal and limited fashion; this aspect is the energy use in agricultural production in the ecosystems of Latin America. If we knew how the ecosystems are being artificialized,[2] how their environment-

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[1] An extensive body of literature exists on the subject. See, *inter alia*: FAO, *Energía para la agricultura mundial* (by B.A. Stout), Rome, 1980, 303 pp.; World Bank, *Alcohol production from biomass in the developing countries*, Washington, D.C., September 1980, 69 pp.; A Makhijani and Alan Poole, *Energy and agriculture in the Third World*, Ballinger Publishing Co., Cambridge, Massachusetts, 1975, 168 pp.; Fernando Homem de Melo, *A agricultura nos anos 80. Perspectivas e conflictos entre objetivos de politicas*, University of São Paulo, School of Economics and Administration, IPEA, March 1980, 61 pp.; P.H. Abelson, "Energy and chemicals from biomass", *Science*, Vol. 213, No. 4508, August 1981; D.E. Earl, *Forest, energy and economic development*, Clarendon Press, Oxford, 1975; EMBRAPA, *Programa nacional de pesquisa en energia*, Brazil, 1980, 27 pp.; UNEP, "New and renewable sources of energy. Information sources", INFOTERRA, Nairobi, Kenya, 1981, 320 pp.; Matthew S. Gamser, "The forest resources and rural energy development", *World Development*, Oxford, United Kingdom, Vol. 8, No. 10, 1980, pp. 769-780; United Nations, Report of the United Nations, Conference on New and Renewable Energy Sources (A/CONF. 110/11), New York, 1981; UNDP/Latin American Energy Organization (OLADE), "Plan de acción latinoamericano para el desarrollo de la energía no convencional", Latin American Seminar on Unconventional Energy Policies, Rio de Janeiro, November 1979; UNDP, *El PNUD y la energía, exploración, conservación, innovación*, Appraisal No.5, May 1981; UNEP/UNDP/OLADE, *Energy alternatives in Latin America*, Quito, October 1979; OLADE; *Programa latinoamericano de cooperación energética,* OLADE Document Series No. 15, Quito, November 1981.

[2] "Artificialization" of the ecosystem means the modification of its natural state by activities intended to produce

al endowments[3] and features are being managed, and what the specific characteristics of energy-related behaviour are, we would then have a better basis for introducing technological policies aimed at bringing new areas into use and achieving a more intensive utilization of renewable natural resources. Two great challenges facing the region are to incorporate vast expanses of tropical forests, many of them virgin, while also attempting to modify the harmful and ecologically costly systems which have been employed up until now, and to reverse the trend towards the deterioration of the arid and semi-arid zones, while also attempting to make the most of their special characteristics.

In order to accomplish these tasks, the social and economic factors which determine resource use will have to be altered, and this entails making substantive changes in the current development style as well as formulating different development strategies. Such strategies would have to incorporate the energy dimension in order to give rise to a form of self-sustained development which makes the fullest possible use of the environmental endowment.

The Latin American ecosystems which have not yet undergone structural changes and which retain all or most of their original features possess a relative capacity for utilizing energy; clearly, the main feature of such ecosystems, which are in or near a state of climax,[4] is the energy stored in their plant matter or biomass. On the other hand, the ways used to artificialize the ecosystems in Latin America tend to make poor use of both the environment's energy endowment and the natural systems for recycling its stored energy thus creating dependent agrosystems which require the aid of "injections" of energy or, as they are commonly know, "energy subsidies".[5] Most of these agrosystems are based on technology which gradually causes their deterioration while also generating a growing demand for energy for use in agricultural production.

These two factors form the basic problem in Latin American agriculture, i.e., how to artificialize the ecosystems —particularly the tropical, arid and semi-arid ones— in which ongoing agricultural activities are conducted, in such a way as to cause neither the loss of the energy stored in them nor the impairment of their capacity for procuring energy, while also allowing the concomitant creation of lasting agrosystems for the medium and long terms, which will not require increasing amounts of energy inputs for their maintenance, and which, in so far as possible, will be balanced through an appropriate use of the environmental endowment.

Consequently, the thesis advanced in this article is based on the need to design different agricultural development strategies which demand less energy, especially in its commercial forms, and which use energy more efficiently.

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certain goods and by the application of measures for its management, genetic improvement, the introduction of resources such as irrigation water, or inputs such as fertilizers and pesticides. These changes, which generally lead to specialization, result in the loss of the ecosystem's original stability.

[3] The term "environmental endowment" refers to the resources present in ecosystems (water, soil, climate) and the interaction between them, which can be put to use by man.

[4] The term "climax" designates that stage at which the ecosystem has attained its maximum physical expression by reaching a dynamic balance where mechanisms of self-control are in operation.

[5] Energy subsidies sustain artificialization through the use of fertilizers, pesticides and agricultural machinery.

II

The energy efficiency of the prevailing agricultural technology model

1. *Commercial, non-commercial, primary and usable energy*

Forestry, crop-farming and livestock production consume only a small percentage of all commercial energy: FAO has estimated the world average at 3.5%, and that of Latin America at 3.8%.[6] The system of agricultural production as a whole (including transport, agroindustry, etc.) consumes a much higher percentage of commercial energy, of course; the figures indicate that the entire chain, starting with food producers and ending with food consumers, absorbs an average of 20% of the commercial energy used.

There are very few data on Latin America, but some studies have shown that processing, transport, marketing and domestic consumption represent a higher percentage than production itself. Production absorbs between 3% and 3.5%; processing, transport and marketing use 5%-7%; and domestic consumption account for 4.7%. Taken together, the amount of commercial energy used in the food chain appears to fluctuate between 12.7% and 15.2%.[7]

This cursory analysis could lead to the recommendation of technological policies for agricultural production based on large energy subsidies on the grounds that the production systems do not use much energy. This is not the case, however. The adoption of agrosystems which misuse the environmental endowment results in missed opportunities for energy use; moreover, such new agrosystems commonly require increasing amounts of energy. Furthermore, this approach leads to the irretrievable loss of attributes of the ecosystem which could make it possible to practice a more viable type of agriculture from an ecological and economic standpoint.

The fact that agricultural production, and the rural sector in general, consume only a small percentage of commercial energy does not mean they do not use energy. Generally speaking, there is a large amount of primary energy present in nature (sunlight, biomass), although this does not necessarily translate into a large supply of usable energy (for transport and combustion, for example).[8] In agricultural areas, this type of energy is usually not commercial. In 1978 Revelle, as cited by D.V. Smith,[9] calculated that the primary energy consumed by peasant sectors in Bolivia amounted to 25 370 kcal per capita per day,[10] which is much higher than the average per capita consumption of Latin American cities. Human labour, animal power, the burning of plant matter, plant and animal wastes, and water power vary considerably fron one ecosystem and from one appropriation structure to another. Vast areas of Latin America which are inhabited by peasants exhibit considerable shortages of usable energy, above all in arid and semi-arid zones, but this does not mean that there is a meagre environmental endowment of primary energy. The situation varies and, although there is some correlation between primary and usable energy, there are many instances in which this correlation does not hold.

2. *Energy efficiency*

In recent decades, increases in agricultural output in Latin America have been based on the intensification of agriculture in areas already in use. Except in Brazil, where the expansion of the

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[6] FAO, *Energía para...*, *op. cit.*, pp. 51-52.

[7] FAO, *ibid.*

[8] The term "primary energy" refers to the total supply present before use, while "usable energy" is that which is actually involved in some process of change; this depends upon the efficiency with which it is converted.

[9] Douglas V. Smith, "Rural electrification or village energization?", *Interciencia*, Vol. 5, No. 2, Caracas, March-April 1980, pp. 86-91.

[10] The kcal has been adopted as a unit of measurement for this study; it is defined as 1 000 calories, or 1 000 times the amount of heat required to raise the temperature of 1 gram of water by 1 degree centigrade (from 15°C to 16°C).

agricultural frontier has been very great, 80% of the growth in agriculture during the 1970s was achieved through intensified farming and only 20% through the use of new land.[11]

With some notable exceptions, the intensification of agriculture has been achieved through the application of the technological model of the "Green Revolution", which grew out of the intense experimentation conducted in the United States; however, as C. and J. Steinhart point out, this is the most energy-inefficient food production system in the world.[12] This technology's persistence in Latin America, despite the changes which have taken place over the last decade, is closely related to the emergence of the agricultural development style which has come to predominate in the region. This style has become established through control of the demand for certain products on the basis of predetermined standards of quality, the structuring of input and product marketing systems, agricultural demonstration and extension activities which portray this technology as the "only" option for raising output, and the fact that State or private technical assistance is in the hands of professionals who have been trained to apply these exogenous technologies.

According to this model, agricultural modernization is regarded as being virtually synonymous with the technology used in the United States. However, as G.W. Cox and M.D. Atkins have stated, even the simplest analysis shows just how impossible it would be to feed the world population at the nutritional level of the United States using technology of this sort.[13] Pimentel *et al* have calculated, for example, that the energy inputs required in order to apply the type of agriculture used in the United States throughout the entire food system would amount to 1 250 litres of gasoline per capita annually. If these inputs were used to feed the world population at the nutritional levels of the United States and if the known oil reserves (as of the early 1970s) were used to supply the energy for this, those reserves would be depleted in 13 years. Similar calculations for Latin America yield equally discouraging results.

The problem becomes even more involved upon analysing the trends in the energy efficiency of food production. FAO projections for 1985-1986 indicate that agricultural energy consumption will have increased by 177% in the developing countries in comparison to the 1973 consumption.[14] The various studies conducted in order to estimate trends in energy efficiency focus on food production rather than crop-farming as a whole. Nonetheless, these data are representative of the overall situation.

In the United States in 1950, less than 1 commercial kcal[15] was needed to produce 1 biological kcal of food (conversion of the energy contained in food). In 1970, 2.06 commercial kcal was needed for every 1 kcal of food (see table 1). If non-food crops are figured into these calculations, the ratios are not altered significant-

Table 1

UNITED STATES: AGRICULTURAL ENERGY BALANCE, 1970
(10^{12} kcal)

Commercial energy inputs	
Irrigation	133
Fertilizers	150
Pesticides (not incorporated in irrigation)	12
Fuels	326
Machinery	101
Electricity	107
Total	*829*
Products in terms of food energy	
Consumption (200 × 10^6 persons at 1 095 × 10^6 kcal/person/year)	219
Residue from food production (20% more)	24
Exports (40 × 10^6 tons at 4 × 10^6 kcal/ton)	106
Total	*403*
Ratio - commercial energy inputs/food-product energy	*2.06*

Source: G.W. Cox and M.D. Atkins, *Agricultural Ecology, op. cit.*, p. 620.

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[11] ECLA, ECLA/FAO Joint Agriculture Division, "Veinticinco años en la agricultura de América Latina, rasgos principales, 1950-1975", *Cuadernos de la CEPAL* Series, Santiago, Chile, 1978.

[12] *C. Steinhart and J. Steinhart, Energy,* Duxbury Press, North Scituate, 1974.

[13] G.W. Cox and M.D. Atkins, *Agricultural Ecology*, Freeman, Ed., San Francisco, 1970, p. 626.

[14] FAO, *Energía para..., op. cit.*, p. 55

[15] Energy from commercial sources (oil, coal, hydroelectricity, nuclear plants).

ly, although it is possible that they may increase slightly due to the high level or artificialization of such crops as cotton.

In countries where crop-farming yields are not as high as in the United States, less energy is required to produce a unit of caloric energy, although the amount is rising steadily. Italy provides a good example of this pattern: in 1955, 0.46 commercial kcal was required to obtain 1 biological kcal; in 1965, this ratio had risen to 0.61 and more recently, in 1977, it had reached 1.01.[16]

From a physical/agronomic standpoint, the problem becomes more complex, not only because energy requirements increase as a result of the greater use of energy-intensive technologies, but also because there is a diminishing increase in yields (Mittcherlich's Law), which means that at higher rates of land productivity, the marginal increase is smaller. Energy efficiency is therefore progressively lower in highly artificialized areas using the same given technologies.

When this problem of diminishing yields is compounded by the economic problem of rising oil prices, the situation becomes even worse. According to Volpi[17] —to return for a moment to the case of Italy— the ratio of the petroleum equivalent needed to raise gross agricultural output by 1 000 pounds (1963) at producer prices was 1.21 in 1965 as compared to 1955. In 1977, as compared to 1965, this ratio had risen to 5.01.

Although, given the current economic situation, oil prices have not increased as much as expected, if there is an upward trend over the long term, then the ratio will progressively rise.

III

Energy inputs for agrosystems

1. *Technological inputs in terms of energy*

In order to explore the possible alternatives to the Green-Revolution technologies, the different relative magnitudes of the energy inputs used must be analysed and the ratios between them and the products involved, measured in terms of energy, must be compared.

In traditional extensive agriculture there is generally a low ratio between commercial energy inputs and the product (see table 2). Despite the fact that such agrosystems are not mechanized, the energy inputs vary considerably according to the animal labour added and the type of final product. In pasturage and mixed pasturage systems, the energy input is very low and the final product (animal production) is infinitesimal due to the conversion losses occurring in this type of production activity. Generally speaking, when the product of agricultural activities is of animal origin, the efficiency is low because the animals consume a great deal of energy in sustaining themselves and in moving about. In contrast, the manioc crop of Zaire is oustanding for its large energy product and great energy efficiency. The relatively low energy efficiency of wheat crops in India and of sorghum crops in Nigeria is accounted for by the heavy use of animal power and the low energy yields which result.

A comparative study of the years 1945 and 1970 shows how the use of inputs for maize crops in the United States has evolved (see table 3). Energy use rose 213%. Fertilizers (nitrogen, phosphorus and potassium), which totalled 8.06% in 1945, represented 36.45% in 1970. Nitrogen fertilizers had a particularly significant impact in this respect, in that their use rose by 1 500% so that they alone accounted for nearly one-third of all the energy inputs. Although the relative share of machinery and gasoline declined (from 78.17% to 42.01%), in absolute terms they increased by 133% and 47%, respectively. Lastly, it should be noted that the

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[16] Roberto Volpi, "Al servizio dello sviluppo agricola (Problemi attuali e prospettive dell'energia nel mondo)", *Política Internazionale*, No. 1, January 1981, pp. 41-48.

[17] Roberto Volpi, "Al servizio dello sviluppo...", *op. cit.* table 7.

Table 2

ENERGY INPUTS AND FOOD ENERGY OF SELECTED UNMECHANIZED AGROSYSTEMS
(kcal/ha/year)[f]

System	Food	Energy inputs				Energy product	Ratio: energy input / Energy product
		Human	Animal	Industrial	Total		
Pasturage							
Africa[a]	Milk, meat	5 100	—	—	5 100	49 500	0.104
Mixed pasturage Uganda[b]	Milk, meat grain	69 000	—	—	69 000	197 000	0.350
Rotated crops							
Guinea[c]	Mixed grains	1 390 000	—	—	1 390 000	22 780 000	0.061
Thailand[d]	Rice	340 000	—	6.000	346 000	6 220 000	0.056
Mexico[e]	Maize	659 200	—	16 500	675 700	6 843 000	0.099
Sudán[e]	Sorghum	193 300	—	16 500	209 800	2 970 000	0.071
Zaire[e]	Manioc	556 200	—	16 500	572 700	21 450 000	0.027
Irrigation by flooding							
Thailand[d]	Rice	124 000	10 000	18 000	152 000	5 730 000	0.027
Rice-paddy irrigation							
Thailand[d]	Rice	348 000	19 000	47 000	414 000	9 400 000	0.044
Permanent farming							
Mexico[e]	Maize	208 400	693 000	41 400	979 400	3 312 300	0.294
India[e]	Wheat	334 700	2 247 000	41 400	2 837 600	2 709 300	1.047
Philippines[e]	Rice	313 500	952 000	161 900	1 831 300	6 004 000	0.305
Nigeria[e]	Sorghum	63 100	2 555 000	41 400	2 722 200	2 471 700	1.101

Source: G.W. Cox and M.D. Atkins, *Agricultural Ecology, op. cit.*, p. 601.

[a] Brown, 1971.
[b] Odum, 1967.
[c] Rappaport, 1971.
[d] Hanks, 1972.
[e] Pimentel, 1974.
[f] The data represent measurements of energy inputs and products per hectare over a period of one year.

only input which decreased was the labour force (61%).

The study on maize indicates the general trend which exists in United States agriculture. An analysis of other crops might well show that, in some, this trend has become even more pronounced. A study conducted in 1971 in the United States comparing wheat, rice and potatoes (see table 4) points up significant differences in the amount of energy inputs used. In the case of rice, 44.88% corresponded to irrigation. As regards the other two crops, which do not use irrigation, machinery and fuel played an important role: 49.56% for wheat and 34.31% for potatoes. The combined figure for fertilizers (NPK) was also very significant: 28.71% for wheat and 45.79% for potatoes. Rice had the highest productivity with 21 039 480 kcal, but the high yield of unirrigated potatoes (19 712 000 kcal) was also noteworthy.

These studies corroborate the fact that systems involving large energy subsidies have a low energy yield.

Although quite different methods were used in arriving at a number of the calculations shown in table 5, their comparison indicates a rela-

Table 3

UNITED STATES: ENERGY INPUTS AND PRODUCTS FOR MAIZE, 1945 AND 1970

(kcal/ha/year)

Inputs	1945	Percentage	1970	Percentage	Percentage of each input compared to 1945
Labour	5 062.5	1.35	1 984.5	0.17	−61
Machinery	72 900.0	19.45	170 100.0	14.50	133
Gasoline	220 077.0	58.72	322 785.0	27.51	47
Nitrogen	23 814.0	6.35	381 024.0	32.47	1 500
Phosphorus	4 293.0	1.15	19 075.5	1.63	344
Potassium	2 106.0	0.56	27 540.0	2.35	1 208
Seeds	13 770.0	3.67	25 515.0	2.18	85
Irrigation	7 695.0	2.05	13 770.0	1.17	79
Insecticides	—	—	4 455.0	0.38	—
Herbicides	—	—	4 455.0	0.38	—
Drying	4 050.0	1.08	48 600.0	4.14	1 100
Electricity	12 960.0	3.46	125 550.0	10.70	869
Int. transport	8 100.0	2.16	28 350.0	2.42	250
Total	*374 827.5*	*100.00*	*1 173 204.0*	*100.0*	*213*
Energy product-maize	1 388 016.0		3 306 744.0		

Source: Based on Pimentel *et al*, *American Association for the Advancement of Science*, 1973

Table 4

UNITED STATES: ENERGY INPUTS AND PRODUCTS FOR WHEAT, RICE AND POTATOES AROUND 1971

(kcal/ha/year)

	Wheat		Rice		Potatoes	
	Amount	Percentage	Amount	Percentage	Amount	Percentage
Labour	6 531	0.14	16 328	0.11	32 655	0.38
Machinery	1 037 400	21.63	1 037 400	7.11	1 000 000	11.54
Fuel	1 339 800	27.93	2 153 250	14.76	1 971 420	22.77
Nitrogen	1.284 800	26.78	2 358 400	16.17	2 601 280	30.03
Phosphorus	54 230	1.13	-	-	818 235	9.45
Potassium	37 400	0.80	147 400	1.01	546 920	6.31
Seeds	552 750	11.52	813 120	5.57	269 500	3.11
Irrigation	–	–	6 545 880	44.88	–	—
Insecticides	26 620	0.55	135 520	0.93	135 520	1.56
Herbicides	–	–	135 520	0.93	135 520	1.56
Fungicides	–	–	–	—	135 520	1.56
Electricity	370 500	7.72	–	–	765 700	8.84
Drying	–	–	1 070 597	7.34	–	—
Transport	86 450	1.80	172 900	1.18	250 000	2.89
Total	*4 796 481*	*100.00*	*14 586 315*	*100.00*	*8 662 270*	*100.00*
Energy product	8 428 200		21 039 480		19 712 000	

Source: Based on tables prepared by Pimentel *et al* , *American Association for the Advancement of Science*, 1974; G.W. Cox and M.D. Atkins, *Agricultural Ecology, op. cit.*, p. 608.

Table 5
TOTAL INPUTS, ENERGY PRODUCTS AND ENERGY EFFICIENCY OF AGROSYSTEMS
(kcal/ha/year)

Agrosystem	Total energy input	Energy product	Input product
Pasturage, Africa[a]	5 150	49 500	0.104
Cleaning and rotational fallowing, Mexico[b]	675 700	6 843 000	0.099
Permanent farming, Mexico[b]	979 400	3 331 230	0.294
Permanent farming, India[b]	2 837 760	2 709 300	1.047
Maize, United States[c]	1 173 204	3 306 744	0.355
Wheat, United States[b]	4 796 481	8 428 200	0.569
Rice (irrigated), United States[b]	14 586 315	21 039 480	0.693
Apples, United States[d]	18 000 000	9 600 000	1.875
Spinach, United States[d]	12 800 000	2 900 000	4.414
Tomatoes, United States[d]	16 000 000		1.616

Source: Prepared by the author on the basis of data provided by Pimentel, Brown and Pimentel and Pimentel.

[a] Brown, 1971.

[b] Pimentel, 1974.

[c] Pimentel, 1973.

[d] Pimentel and Pimentel, 1979.

tionship between a high level of energy consumption and inefficient energy use, as may be seen in the case of fruit and vegetable crops. This correlation is not very high, because there are instances of non-mechanized farming having very inefficient ratings due to the use of animal power, whose energy cost is quite high. Although there is also a high correlation between large subsidies and large yields, this is not always the case, because large yields can be obtained with relatively small subsidies —resulting in high rates of energy efficiency— by rotating crops and by allowing land to lie fallow. What is certain is that when the technological package associated with mechanization is used, its energy supply is almost entirely commercial in nature. When animal power is used, only a part of the energy used is commercial. The energy cost of maintaining the animals is very high, but the cost in terms of commercial energy is usually low. Finally, it should be noted that the methods used to calculate the energy value (in kcal) of non-permanent pasturage and crop-farming systems do not provide details about the "harvest" from the ecosystem or, in other words, the use made of the energy stored up by the ecosystem during its formation, corresponding to the energy extracted over and above its recovery capacity.

In connection with animal foods, it is particularly interesting to analyse the energy efficiency of protein production, which is obviously very low because the plant-to-animal conversion of energy represents one more step in the trophic web[18] and because energy inputs are needed to maintain the breeding herd.

Table 6 shows the different ratios between the inputs of fossil fuels (oil and coal) and the protein produced. The most inefficient ratio is that of intensive cattle raising, where 1 kcal of protein requires an energy subsidy of 77.7 kcal. The least inefficient ratio is that of egg production (13.1:1).

2. *The energy yield of the labour force*

The questions raised about the technologies of the Green Revolution may be answered with

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[18] Trophic webs are produced by the interrelationship between predators and their prey. A large amount of energy is lost at each level.

Table 6
UNITED STATES: PROTEIN PRODUCT AND FOSSIL-FUEL ENERGY INPUTS, PER HECTARE/YEAR
(kcal/ha/year)

Animal product	Protein product	Fossil-fuel energy input	Fossil-fuel input / Protein product
Milk	238 468	8 561 000	35.9
Eggs	729 771	9 560 000	13.1
Poultry (broiler)	463 032	10 233 000	22.1
Pork	260 226	9 212 000	35.4
Beef (intesive)	203 925	15 845 000	77.7
Lamb and mutton (extensive)	679	11 000	16.2

Source: Prepared by the author on the basis of data provided by Pimentel *et al*, *American Association for the Advancement of Science*, 1975.

arguments relating to the high yields of the labour force (see table 7). This type of agriculture is marked by a high energy return per worker; for example, in United States wheat cultivation, 1 man/month produces 1 204 029 kcal and the figure for the maize crop is 275 562 kcal, whereas in Mexico the yield is only 4 800 kcal. A considerable input of commercial energy is involved, however. While the maize crop requires a subsidy of 97 767 kcal per man/month in the United States, in Mexico the subsidy is insignificant (242 kcal). If the commercial energy consumed is subtracted from the commercial energy produced and the yield per man/month is calculated, the figure will be greater for highly artificialized crops. For example, the net commercial yield for maize is 177 795 kcal per man/month, whereas in Mexico it is only 4 558. These conclusions should be accepted with some reservations, however, since the balance is negative in many crops. Thus, the commercial energy balance of a fruit (apples) per man/month is -48 000 kcal and for the vegetable crop (spinach) it is -176 786 kcal.

Table 7

RATIO OF THE LABOUR FORCE TO COMMERCIAL ENERGY, THE ENERGY PRODUCT AND THE NET ENERGY BALANCE

(Ha/year)

Country	Product	Commercial energy input (kcal) (1)	Gross commercial product (kcal) (2)	Net energy balance (kcal) (3) = (2)-(1)	Labour force (man-hours/ year) (4)	Commercial energy input/ labour force (1) : (4)	Gross commercial product/ labour force (2) : (4)	Commercial energy balance/ labour force (3) : (4)
Africa	Pasture	—	49 500	49 500	17	—	2 912	2 912
Mexico	Maize crop, cleaning and rotational fallowing	66 825	6 843 000	6 675 330	2 297	29	2 979	2 906
Mexico	Maize (permanent farming)	167 670	3 331 230	3 163 560	694	242	4 800	4 558
India	Wheat (permanent farming)	167 670	2 709 300	2 541 630	1 115	150	2 430	2 279
United States	Maize-mechanized	1 173 204	3 306 744	2 133 540	12	97 767	275 562	177 795
United States	Wheat-mechanized	4 796 481	8 428 200	3 631 719	7	685 212	1 204 029	518 817
United States	Rice-mechanized	14 586 315	21 039 480	6 453 165	17	858 019	1 237 616	379 598
United States	Apples	18 000 000	9 600 000	−8 400 000	175	102.857	54 857	−48 000
United States	Spinach	12 800 000	2 900 000	−9 900 000	56	228 571	51 786	−176 786
United States	Tomatoes	16 000 000	9 900 000	−6 100 000	165	96 970	60 000	−36 970

Source: Prepared by the author on the basis of data provided by Pimentel *et al* , (1973), (1974): Pimentel and Pimentel (1979), and Brown (1971).

IV

The options for Latin America

1. *The environmental energy endowment*

The prevailing development style in Latin America not only damages the environment but also, because of its tendency to copy exogenous technologies, misuses the enormous environmental endowment of the region's ecosystems.[19] Before analysing the specific characteristics of Latin American ecosystems, some comments are called for regarding the energy efficiency of plants, which are the basis for the harnessing of solar energy through photosynthesis. Only a small part (less than 5%) of the solar energy reaching plants is converted into biomass. Herbivores, which utilize more concentrated energy sources, use 90% of the plant matter they consume for their sustenance.[20] As energy moves through the trophic sequences of ecological communities, major losses take place in the form of respiration. In natural ecosystems, however, organism —unlike machines— sustain themselves, meet the need for storage, reproduce and tend to diversify in the interests of future survival.[21] Because of this, solar energy inputs in "mature" natural ecosystems tend towards a maintenance level, and their net energy production is consequently nil.[22] Agriculture, in the process of artificialization, attempts to transform these ecosystems into more simplified agrosystems in order to extract biomass (which is measurable in terms of energy). If the many ecosystems which have not yet undergone structural changes are to remain undamaged, or if attempts are made to simplify them while taking advantage of certain features, then these systems must be managed in such a way that, as the energy levels pass from "maintenance" levels to given levels of "net production", other features are also preserved, such as stability and flexibility.

Clearly, the resource represented by the environmental energy endowment cannot be made the sole object of a one-sided analysis, but instead must be studied as an integral part of the ecosystem. Nonetheless, it should be recognized that Latin America exhibits a high degree of solar radiation due to the large percentage of the region that is situated in the tropics and to its exceptional altitudes. Nearly three fourths of the territory receives 16 kcal/cm^2 of radiation in the best month and 12-16 kcal/cm^2 in the worst.[23] Moreover, in the tropics the temperature/humidity ratio in terms of the production of biomass approaches the optimum.

The fact that almost all the territory of Latin America has a relatively even number of hours of daylight and of darkness means that producer and consumer functions in the region exhibit a certain degree of homogeneity. This produces large expanses of foliage where dry matter accumulates on top of the soil. As a result, the plants have abundant leaves and relatively scanty roots.

The ratio between photic energy and temperature is quite adequate in vast sectors of the region, and full advantage tends to be taken of the process of photosynthesis in these areas.

The adequate supply of environmental energy combines with a large water supply in the humid tropics to bring about a high level of productivity in terms of biomass. Margaleff estimates that tropical forests where the biomass

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[19] See Nicolo Gligo, "Estilos de desarrollo, modernización y medio ambiente en la agricultura latinoamericana", *Estudios e informes de la* CEPAL series, No. 4, June 1981; Jaime Hurtubia, "Ecología y desarrollo: evolución y perspectivas del pensamiento ecológico", in *Estilos de desarrollo y medio ambiente en la América Latina*, Fondo de Cultura Económica, Serie Lecturas No. 36, Mexico, 1981, pp. 158-204; "La evolución del pensamiento ecológico", E/CEPAL/PROY. 2/R.45, October 1979; and E.P. Odum, *Ecología*, Nueva Editorial Interamericana, 1972.

[20] Joshua Dickinson, "Perspectivas ecológicas sobre el desarrollo", *Interciencia*, Vol. 6, No. 1, Caracas, January-February 1981, pp. 30-38.

[21] Jaime Hurtubia, "La evolución del...", *op. cit.*, p. 42.

[22] "Net energy production" means the amount of energy in excess of the point of equilibrium, which thus permits energy to be stored up.

[23] UNDP/OLADE, "Requerimientos futuros de fuentes no convencionales de energía en América Latina", Quito, June 1979, p. 80.

ranges from 3 200 to 40 000 gr/carbon/M^2 have a net production of between 1 000 and 1 500 gr/carbon/m^2 per year.[24] FAO calculations indicate that these ecosystems have a photosynthetic yield ranging from 3 to 10 gr/m^2/day of gross dry organic matter.[25] The net production of these ecosystems is no doubt higher than that of any other in absolute terms, but in terms of energy efficiency, ecosystems with less biomass expend less in the form of respiration and are therefore more efficient in converting solar energy into net energy. This fact should be taken into consideration when exploring the possibilities for improving areas with a low level of biomass per unit of surface area. Such is the case in areas far from the tropics, where the average solar radiation is low but where the conversion of solar energy into gross output is more efficient during the growing season, especially in the long days of summer. Net production in relation to gross production is also more efficient in these areas due to the fact that there are fewer organisms performing respiration.

Something similar to what occurs in the humid tropics happens in the arid or semi-arid zones. The high temperatures cause the plants to spend more of their gross energy output on respiration.[26] In this case, water is the major constraint, while solar radiation is extemely plentiful.

2. *Energy as a factor in technological policies for the agricultural development of Latin America*[27]

a) *The degree of artificialization of the ecosystems*

The degrees of ecosystem intervention present in the region cover the entire spectrum from virgin areas to highly artificialized single-crop farming using equal or sometimes even greater amounts of energy inputs than in the developed countries.

In virgin ecosystems and in the those with a low degree of artificialization which have not undergone major structural changes, a type of treatment can be applied which involves a technological policy based on a full understanding of the functions and features of the ecosystems and is aimed at making proper use of the environmental endowment.

A considerable part of the attributes of the more artificialized areas which have undergone major structural changes have been lost. The great majority of these changes are irreversible, although some situations other than the natural state do exist where some of these attributes are developed. In such cases, the ecosystem functions quite differently from the way in which it originally did. In general, traditionally agricultural areas that have been in use for several decades have been converted into a type of agrosystem which requires energy subsidies in order to produce. As the productivity of these areas increases, the yield of additional energy inputs diminishes, i.e., the higher their productivity, the more difficult it is to raise it.

Nevertheless, there are different types of subsidies for these ecosystems in terms of the use of organic fertilizers. Lockeretz *et al* conducted an in-depth comparative study of farms using energy-intensive production systems based on the application of inorganic fertilizers versus those using organic fertilizers.[28] They reached the conclusion that there was no difference in the net returns of the farms: the total output of the farms using organic fertilizers was only 55%-77% of that of the farms using inorganic fertilizers, but the energy costs were much lower for the "organic" farms (only about 30% of those of the "inorganic" farms).

In view of these circumstances, one might well ask why there continues to be an insistence on policies which promote inorganic fertilizers

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[24] Ramón Margaleff, *Ecología*, Ediciones Omega, Barcelona, 1974, p. 465-951.

[25] FAO, *Energía para...*, *op. cit.*, p. 105.

[26] Eugene P. Odum, *Fundamentals of ecology*, W.B. Saunders Company, Philadelphia, 1971, p. 45.

[27] ECLA, Development and Environment Unit (with the assistance of Sergio Alvarado), "Estilos de desarrollo, energía y medio ambiente: Un estudio de caso exploratorio", in *Estudios e informes de la CEPAL* series, No. 28 (E/CEPAL/G. 1254), July 1983. This document explores the outlook as regards the oil crisis and the pressing need to modify demand.

[28] W. Lockeretz, R. Klepper, B. Commoner, M. Gertler, S. Fast, D.O. Leary and R. Biobaum, *A comparison of the production, economic returns, and energy intensiveness of corn belt farms that do and do not use inorganic fertilizers and pesticides*, Washington University Centre for Biology and Natural Systems, St. Louis, 1975.

almost exclusively. The answer must be sought in the distinguishing factors of the style: specialization in the supply of certain inputs, the role of transnationals in marketing technological inputs, agricultural experimentation "induced" by biased technological models, and a technocratic propensity towards maximizing land productivity.

On the other hand, radical changes can also be introduced in order to reduce the consumption of commercial energy within schemes for raising production through the use of the classical technological package. In this connection, Johnson *et al*, as cited by G.W. Cox and M.D. Atkins, studied the possibility of maintaining a high level of production per unit of surface area with less energy-intensive technologies. The study was intended to show that energy could be saved, basically in mechanization, while using the same technological model. It was demonstrated that an input/product ratio of 1.81:1 could be lowered to 0.99:1 with no more than a 4% drop in production. Such savings could only be obtained up to a certain threshold, however, since when the ratio was reduced to 0.67:1, output was 47% lower.[29]

b) *The challenge posed by the humid tropics*

The extensive areas in Latin America which are only partially settled offer different options depending on the role assigned to them in the near and not so near future. The repeated failures which have been met with in settling these areas suggest the advisability of making sweeping changes in the development strategies for these lands. An energy-focussed analysis of the expansion of the agricultural frontier is of special interest in this connection.

The first major topic of discussion is the problem of the energy stored as biomass.[30] This is accumulated over centuries until the climax point is reached, when it tends to stay at a dynamically stable level. This biomass tends to be destroyed through the cutting of timber for use in industry or as a fuel, and it is also often burned as a quick and inexpensive way of preparing the soil for agricultural use. One way or another, the ecosystem is damaged in terms of energy, because a significant portion of the foliage cover and, thus, its capacity for photosynthesis, are destroyed. The first major challenge, therefore, is to preserve some measure of the ecosystem's capacity to transform and accumulate energy.

From the standpoint of forestry production, the yearly growth of mature forests is extemely low because the photosynthetic functions are in balance with the respiratory functions. Stands in the process of growth as well as tracts of exploitable forest currently exist in Latin America, however, and an annual potential growth rate can be estimated which would be equal to the capacity for accumulating energy. J.I. Leyton[31] calculates that there are over 506 million hectares of humid tropical forests in the region, with total reserves of between 50 600 million and 75 900 million cubic metres (100-150m^3/ha), plus exploitable stock in the process of formation amounting to 30 400 million cubic metres (60 m^3/ha), with a potential total annual growth rate of between 508 million and 1 016 million cubic metres (1-3 m^3/ha/year).

The other major problem connected with these ecosystems is how to use technology to change them in a way which will allow the environmental endowment to be utilized without causing damage. This consideration suggests the following general principles:

i) The "anatomy" or "architecture" of the ecosystems of the humid tropics must be preserved, since its alteration results in a large loss of stored energy and converts them into unstable agrosystems which require energy subsidies.

ii) In the course of artificialization, the loss of inertia or stability should be avoided in order to allow the capacity for energy accumulation to be retained.

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[29] G.W. Cox and M.D. Atkins, *Agricultural Ecology, op. cit.*, p. 625.

[30] UNEP defines biomass as the total volume of living matter present at any one time within a given population or area. See *El estado del medio ambiente: temas seleccionados*, 1983 (UNEP/GC.11/4), 21 February 1983.

[31] José I. Leyton, "Manejo y utilización del bosque húmedo tropical", FAO, Technical meeting on Latin American forests, Mexico City, 11-15 February 1980.

iii) A moderate degree of artificialization permits a healing process to take place as a function of the elasticity of the ecosystem.[32]

iv) If a process of specialization takes place which involves the elimination of some species, they should be replaced by exogenous species which fulfill equivalent functions.

Based on these principles, the energy orientation of technological policies should be as follows:

i) To make recommendations relating to energy efficiency and to establish land use systems whose subsidy requirements are small.

ii) To orient forestry, crop-farming and stock raising practices towards management techniques which preserve the structure and basic features of the ecosystem concerned; this means avoiding the substitution or elimination of the forest cover except when agricultural production can be sustained over the long term.

iii) To adopt new developments in genetic techniques aimed at increasing the efficiency of photosynthesis. The vast possibilities offered by genetic engineering in this field could lead to great technological breakthroughs. The genetic pools in the humid tropics should provide the basis for such improvements.

iv) To minimize the use of chemical techniques and mechanization in the working of farmland. These measures affect genetic efficiency.

v) To improve or introduce means of achieving greater bilogical nitrogen fixation.

It will become increasingly possible to put the above guidelines into practice as greater and greater compatibility is attained between short-term land productivity and medium- and long-term natural resource conservation. In order to do so, strategies will have to be devised which take into consideration *all* the policies relating to the settlement of the humid tropics, rather than only those relating to agricultural production.

c) *The challenge posed by the arid and semi-arid zones*

From an energy standpoint, the following considerations are important as regards the establishment of technological policies for arid and semi-arid zones:

i) Ecosystems in arid and semi-arid zones usually become unstable when man-made changes are introduced, and therefore deteriorate rapidly.

ii) Generally, despite the large environmental energy endowment, the limited water supply prevents or reduces photosynthesis, and this results in a low level of biomass per unit of surface area.

iii) Structural changes can be made in the ecosystem with fewer complications than in the humid tropics.

In Latin America these areas have been subject to various modifications. Firstly, there have been major changes in the irrigated tracts, where a total structural transformation has been brought about by the fact that, once the limiting factor of water has been overcome, the environmental energy endowment has been heavily utilized. In fact, water works are one of man's major opportunities for achieving total environmetal management.[33] Much still remains to be done in connection with irrigation in order to promote energy conservation. In irrigated farming, the need to save water has led to the introduction of overhead or drip irrigation systems which use energy, and new techniques should therefore be directed towards making savings in these systems. Secondly, new harvesting techniques and the use of soil topdressing to improve its water retention capacity can help produce a significant energy savings.[34]

The technological problems relating to energy production and use in arid and semi-arid zones are not seen in irrigated tracts, however, but rather in the drylands. In the zones with a potential for irrigation, the problem is usually an economic-financial one, but once water and distribution systems become available, there are various well-known technologies for bringing such zones into production.

The situation in the non-irrigated areas of Latin America is a very difficult one because

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[32] The healing process means the ecosystem's capacity to recover by closing the wounds inflicted upon it.

[33] Axel Dourojeanni and Terence Lee, "Aspectos ambientales de la gestión de grandes obras de infraestructura" (E/CEAPI/PROY. 6/R.2), 24 September 1981.

[34] FAO, *Energía para..., op.cit.*, p. 258

most of them have been subjected to overexploitation. The scant supply of biomass per unit of surface area, combined with the vulnerability of these ecosystems, have often set in motion detrimental processes which have commonly resulted in desertification. "In some cases, the proportion of photosynthesized energy is very low due to the lack of water, but in others, it is due to the inefficiency of farming practices."[35]

The first challenge to be met in these areas is therefore to halt the processes which are doing damage. In order to do this, the energy analysis incorporated in technological policies should be oriented towards the following measures:

i) To ascertain man/land relations, basic needs and the per capita supply of resources with a view to determining what pressures are exerted on the resources and avoiding excessive rates of extraction;
ii) To draw up energy balance sheets for the artificialized areas in order to determine the rates of extraction;
iii) To make use primarily of technologies designed to ensure proper crop rotation, crop combinations and planting times;
iv) To establish farming systems for sloping terrain which reduce the energy inherent in the topography and allow it to be put to use.[36] One example would be the re-introduction of terracing and similar practices.

The second major challenge to be met in these zones is the reclamation of damaged areas and lands which are in the process of desertification. Energy considerations suggest the following recommendations as a means of giving technological policies a more comprehensive orientation:

i) Ascertaining the nature of degradational trends on the basis of energy flows and relating them to economic and social conditions;
ii) Establishing an agrosystem which duplicates some of the basic features of the ecosystem at its point of climax and which will lead to the most efficient possible conversion of solar energy through photosynthesis;
iii) As part of such reclamation, photosynthesis should interact with the land's water retention capacity so as to break the vicious circle of overexploitation and deterioration in order to allow the accumulation of energy and water. Supporting policies should therefore be established which will allow energy to be accumulated by preventing its extraction during the first few years;[37]
iv) Genetic technologies should have top priority within the reclamation effort in order to boost efficiency;
v) Management technologies should be established in co-ordination with new man/land relations which avoid the overexploitation of resources;
vi) A type of management should be established in which stock-raising has an integral function.

The third major challenge to be dealt with in such non-irrigated zones is to incorporate areas which are used very little because they are marginal or sub-marginal. This is of special importance in the Andean zone, where upper ecological levels are in use on a very extensive basis. The energy-related approach in this regard should be oriented towards the following considerations:

i) A type of farming which gives ecological considerations a prominent place and which uses technology to cope with environmental constraints in order to allow the resources of the environment to be properly utilized should be established. Within this context, energy should be regarded as a factor of supply;
ii) The causes of marginality are to be found in the limitations of the ecosystems. Incorporation of marginal lands should therefore be done cautiously and gradually in order to conserve the small amount of energy which has been accumulated;[38]

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[35] Roberto Nava, Roberto Armijo and Juan Gastó, "Ecosistema, la unidad de la naturaleza y el hombre" *Serie Recursos Naturales*, Universidad Autónoma Agraria Antonio Narro, Saltillo, Coahuila, Mexico, 1979.

[36] This is the energy produced by differences in slope, and usually leads to erosion.

[37] An interesting study on this subject was conducted by the University of Cajamarca, in Peru. See "Experiencia del programa de desarrollo rural integral silvoagropecuario de Cajamarca-Perú" (E/CEPAL/PROY. 6/R.37), February 1982.

[38] In regard to the agricultural outlook, see "Estudio agroclimatológico de la zona andina" (FACO/UNESCO/WMO), Technical paper, Rome, 1975.

iii) Genetic technologies should be given priority in order to produce a beneficial type of artificialization and to cancel out the costs involved in energy extraction. The first step should be the introduction of plants whose genetically-controlled metabolic characteristics give them a high water yield. Both the current genetic contribution and the possibility of further improving shrub-like forage species should be carefully studied.

iv) In this regard, some of the factors which should be borne in mind are: research aimed at improving the photosynthetic mechanisms of carbon fixation; genetic engineering using cultures of cellular tissue which may have an effect on water/energy efficiency; the selection of plants for greater efficiency under adverse water and temperature conditions; and greater nitrogen fixation and its regulation through photosynthesis;[39]

v) The specific features of certain areas make them suitable for certain types of stock-raising which have a great potential. In this connection, advantage should be taken of the natural selection which has produced highly energy-efficient animals such as the camelidae. Their improvement and development may permit the utilization of ecosystems where there is a scarcity of water and energy resources.[40]

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[39] Kuwait Foundation for the Advancement of Sciences (KFAS), *Advances in food-producing systems for arid and semiarid lands*, Academy Press, New York, 1981, p. 126.

[40] See Alejandro Colomés, "Producción pecuaria y desarrollo de la ganadería de la vicuña en la ecorregión andina" (E/CEPAL/PROY. 6/R.40), Santiago, Chile, March 1982.