Working Paper

Lifestyles and Energy Use in Human Food Chains

Gerhard K. Heilig

WP-93-14
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ABSTRACT

The supply of food is one of the most energy consuming tasks in a society. Even in highly industrialized countries more fossil energy is spent in the food sector than in industry. Usually some 30% of the overall fossil energy consumption is used just for feeding the population. This, however, includes *everything* - from the production of fertilizers and agricultural machinery to the fueling of irrigation pumps and drainage systems; from energy use in cultivation and harvesting, to energy consumption in processing, storage, transportation, and preparation of food.

Only a small - and declining - proportion of the total fossil energy consumption in the food sector is spent for food *production* - most of it (some 90%) goes to the processing, storage, conservation, transport and preparation of food. Contrary to conventional wisdom it is not the high-tech farmers who are responsible for the enormous energy consumption in the food sector. It is the food industries, food traders, restaurants and households which spend most of the fossil energy in the food system. This is the reason, why lifestyles are much more important for studying energetic efficiency in food chains than the frequently analyzed input-output rates in agricultural production.

This paper argues that the energy efficiency of food must be analyzed for whole **food chains** - including production, harvesting, slaughtering, processing, storage, transportation and preparation in the household.

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LIFESTYLES AND ENERGY USE IN HUMAN FOOD CHAINS

Gerhard K. Heilig

1. INTRODUCTION

Energy and food are linked in the most basic way. Life on earth utterly depends on the solar energy which is captured by plants and transformed into biomass. The unique capacity of plants to fix solar radiation and store it in the form of chemical energy is the first link in a long chain of transformations which in the end provides vital elements, minerals, vitamins, fats and proteins to both animals and humans. During the first 500,000 years our human-like ancestors, as gatherers and hunters, totally depended on the plant transformation of solar energy. As long as mankind lived in small family systems and scattered tribal units, the energy balance of nutrition was probably not bad. It was estimated that a "primitive" food gatherer who collected nuts within an average distance of 4.8 km from his home, invested some 2700 kcal in this effort - for walking, collecting the nuts, for the normal metabolism during leisure time, and other "non-working" activities. Since a typical return of this effort would be some 10,500 kcal in food energy, his energy balance would be quite positive.[1]

When the "homo sapiens" decided to camp in caves during the Older Paleolithicum some 60,000 years ago, he began to use *fire* for cooking food - but also for lighting and heating the cave, and as a means to drive away wild animals. Since the emergence of stable settlements in the early Neolithicum (some 8000 to 5000 years B.C.), fire was gradually used to clear land for agriculture, fertilize the soil (even if the Neolithic farmers might not have been aware of it), cook the food, and - probably - conserve meat and fish by smoking and drying. In the millenniums that followed the farmers slowly learned how to utilize energy sources other than the sun and the fire: they began to harness draught animals, use wind and water to power irrigation or to process harvests. Since 4100 B.C. agricultural societies thinly populated the alluvial lowlands between the Tigris and Euphrates rivers in the flood plains along the large Asian rivers.[2] Here a first agricultural revolution set the ground for the development of human societies and states. Yet the average agricultural productivity - and thus the food energy return - was quite low as compared to our present standards. During the next several thousand years agricultural technology

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[1] The example is based on calculations from: Lee, R.B. 1969. !Kung bushman subsistence: An input-output analysis. Pages 47-79 in A.P. Vayda, ed. *Environmental and Cultural Behavior: Ecological Studies in Cultural Anthropology.* Garden City, New York: Natural History Press; and Pimentel, D. 1984. Energy flow in the food system. In D. Pimentel and C.W. Hall, eds. *Food and Energy Resources.* Orlando: Academic Press, p. 3.

[2] Whitmore, T.M., B.L. Turner II, D.L. Johnson, R.W. Kates, and T.R. Gottschang. 1990. Long-term population change. Pages 25-39 in B.L. Turner II et al., eds. *The Earth as Transformed by Human Action. Global and Regional Changes in the Biosphere over the Past 300 Years.* New York: Cambridge University Press, with Clark University.

stagnated. In the 12th century European farmers still used ploughs which were similar to a prototype developed in Babylon 3000 years B.C.[3]

Between 1690 and 1700 in England, 1750 and 1760 in France, and 1790 to 1800 in Germany - some 30 to 50 years *before* the Industrial Revolution - the second ("modern") agricultural revolution in Europe set the ground for a new balance between people and land. Only since then farmers have used machinery fueled by *fossil* energy to plough the soil, power irrigation pumps, harvest and process the crops. The use of machines was a critical factor which contributed to lifting agricultural productivity to a much higher level. Through tractors, pumps, reapers, threshing machines, harvesters, and lorries it became possible to cultivate large, previously unusable areas and - even more important - to supply distant markets.[4] These technical devices, however, utilize only a most basic process of energy conversion to increase agricultural productivity: the transformation of fossil energy into *mechanical* power. The real breakthrough only came when biochemists learned how to optimize the growth of plants with the help of fossil energy, transformed into *chemical* energy in artificial fertilizers.[5]

Today, the supply of food, which once was a simple process of collecting and hunting, has evolved into a complex network of production activities, industrial processes, market and price mechanisms, trade arrangements, food policies and distribution channels. On each stage of this widely expanded food chain the consumption of fossil energy plays a significant role. This paper will identify some of the energy-related links in our food chains and show that social and cultural factors (such as lifestyles) heavily influence the overall energy efficiency of the food system.

For a systematic analysis of linkages between food, energy, and lifestyles it seems appropriate to distinguish four levels or domains:

- physical processes;
- (agricultural) technology;
- organizational arrangements, infrastructure, and logistics in food processing; and
- social and cultural conditions.

2. BIOPHYSICAL PROCESSES

The first energy-related link in a food chain is the conversion of solar energy into biomass. By means of photosynthesis green plants can transform solar radiation into chemical energy which they use for growth and sustenance. However, only a very small proportion of the solar radiation hitting the ground can be utilized in food plants. Four major factors are involved in the

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[3] Grigg, D.B. 1981. *Population Growth and Agrarian Change. A Historical Perspective.* Cambridge: Cambridge University Press.

[4] Binswanger, H.P. 1984. *Agricultural mechanization. A comparative historical perspective.* Staff Paper No. 673. Washington, D.C.: World Bank.

[5] Fussel, G.E. 1967. The agricultural revolution, 1600-1850. In M. Kranzberg and C.W. Pursell, eds. *Technology in Western Civilization. Volume I: The Emergence of Modern Industrial Society. Early Times to 1900.* London: Oxford University Press.

reduction of usable energy:[6] First, some 75% of the sun's radiation spectrum is unsuitable for photosynthetic transformation - the wavelength is either too long or too short. Second, another 10% of the useful radiation energy is not absorbed by the plants, but reflected from their surface. Third, the growing season is much shorter (usually only 4 to 5 months) than the sunshine period. And fourth, some 20% to 40% of the solar energy that is transformed by photosynthesis cannot be used for biomass growth, but is consumed for respiration. In addition to these general restrictions the energy efficiency of photosynthesis also varies by a wide margin between different kinds of plants.

2.1. Efficiency of Photosynthesis

We can find good and bad solar energy converters. Maize is one of the most productive food and feed crops; it has yields of about 7000 kg/ha of grain and 7000 kg/ha of biomass as stover. Converted to heat energy this equals 69×10^6 kcal which is equivalent to 1% of the solar energy reaching a hectare during the growing season (and 0.5% of the solar energy input per year). Potatoes, on the other hand, have a lower energy efficiency.[7] Their solar energy conversion ratio is only 0.4%.[8] Wheat production is even more energy inefficient: just 0.2% of the sunlight reaching the ground during a year is turned into biomass (see Table 1). So the conversion efficiency of maize is five times that of wheat. In general, however, the conversion efficiency of food and feed crops is much higher than that of the natural vegetation, which in the United States is estimated to be only about 0.1%.

Since few humans are pure vegetarians, the overall energy consumption in food systems not only depends on the level of efficiency at which plants can convert solar energy, but also on the energy losses in livestock production.

Table 1. Conversion efficiency of selected crops and natural vegetation.

		kcal per hectare per year
Solar Energy	100.0%	14×10^9
Maize	0.5%	69×10^6
Potatoes	0.4%	50×10^6
Wheat	0.2%	28×10^6
Natural Vegetation (oceanic/terrestrial)	0.1%	

Source: Pimentel, 1984, *op. cit.*

[6] These estimates were made by: Schmidt, A. 1986. Food and energy. In United Nations, Economic Commission for Europe: Biotechnology and Economic Development. *Papers from the Economic Commission for Europe Symposium on the Importance of Biotechnology for Future Economic Development,* June 1985, Szeged, Hungary. Oxford: Pergamon Press (published as Volume 38 Number 1 of the Journal *Economic Bulletin for Europe*).

[7] Energy efficiency, however, is not the only factor that determines the productivity of a food crop. While the solar conversion ratio of potatoes is relatively low, their overall productivity in moderate climate is rather high. The introduction of potatoes was a major factor which ended the times of famine in Central Europe.

[8] There is, however, some disagreement on the numbers among experts. Schmidt has published a higher estimate for the energy efficiency of potato production in Austria. See: Schmidt, *op. cit.*

2.2. Efficiency of Meat Production

Meat production is based on a *double* energy transformation: first, solar energy and nutrients in the soil are converted into biomass by green plants. When the plants are fed to animals the proteins, fats, carbohydrates, etc. in the fodder are transformed again into energy which fuels the growth and sustenance of the animal. However, only a small proportion of the energy consumed is used by the animal to build up fat and muscles, or to produce milk or eggs. A major share of the energy intake is spent on keeping up normal metabolism (stabilizing body temperature, keeping up blood circulation and breathing, etc.) and - simply - for moving around on the meadow.

The double energy conversion in livestock production is a biophysical process that inevitably brings about a relatively low energy efficiency in meat production. For Austria it was calculated that of 100 kcal used to produce *vegetable* food 83 are returned in the form of food energy - however, for 100 kcal input to *livestock* production only 6 kcal are returned in the form of meat. For the same energy content in food one has to input 14 times more energy in livestock than in food crop production systems.

Photosynthesis is the starting point of all food chains. Already at this basic biophysical level the choice of a specific food or feed crop with optimum solar energy fixation could (slightly) improve the overall energy efficiency of the food supply. More important, however, is the proportion of animal to vegetable food in our diet, due to the inherent energetic inefficiency in meat production. But the most important factors that determine a food chain's overall energetic efficiency are linked to "higher" levels in the system's hierarchy: to agricultural technology, to the logistics of food distribution, and to the patterns of food consumption. Let us look at some of these factors in detail.

3. AGRICULTURAL TECHNOLOGY

Probably the most fundamental difficulty of agriculture since its invention by Neolithic farmers is the inevitable exhaustion of the soil. After a few growing seasons yields usually begin to decline and gradually the output falls below the input of seeds. This is a "basic law" of agriculture and should not be confused with modern problems of soil degradation or over-utilization. The cause of the phenomenon is simple: plants not only use renewable substances from the soil (such as water) to build up their cells, but also extract minerals and other *non-renewable* chemicals. With each harvest a significant amount of these elements, incorporated in the plants, is permanently removed from the field. "When 7000 kg of corn is harvested an estimated 40 kg of nitrogen, 5 kg of phosphorus, and 6 kg of potassium are removed from each hectare of land."[9] In advanced production systems with high-yield food plants the nitrogen loss can be up to 100 kg per hectare.

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[9] Pimentel, 1984, *op. cit.*, p. 10.

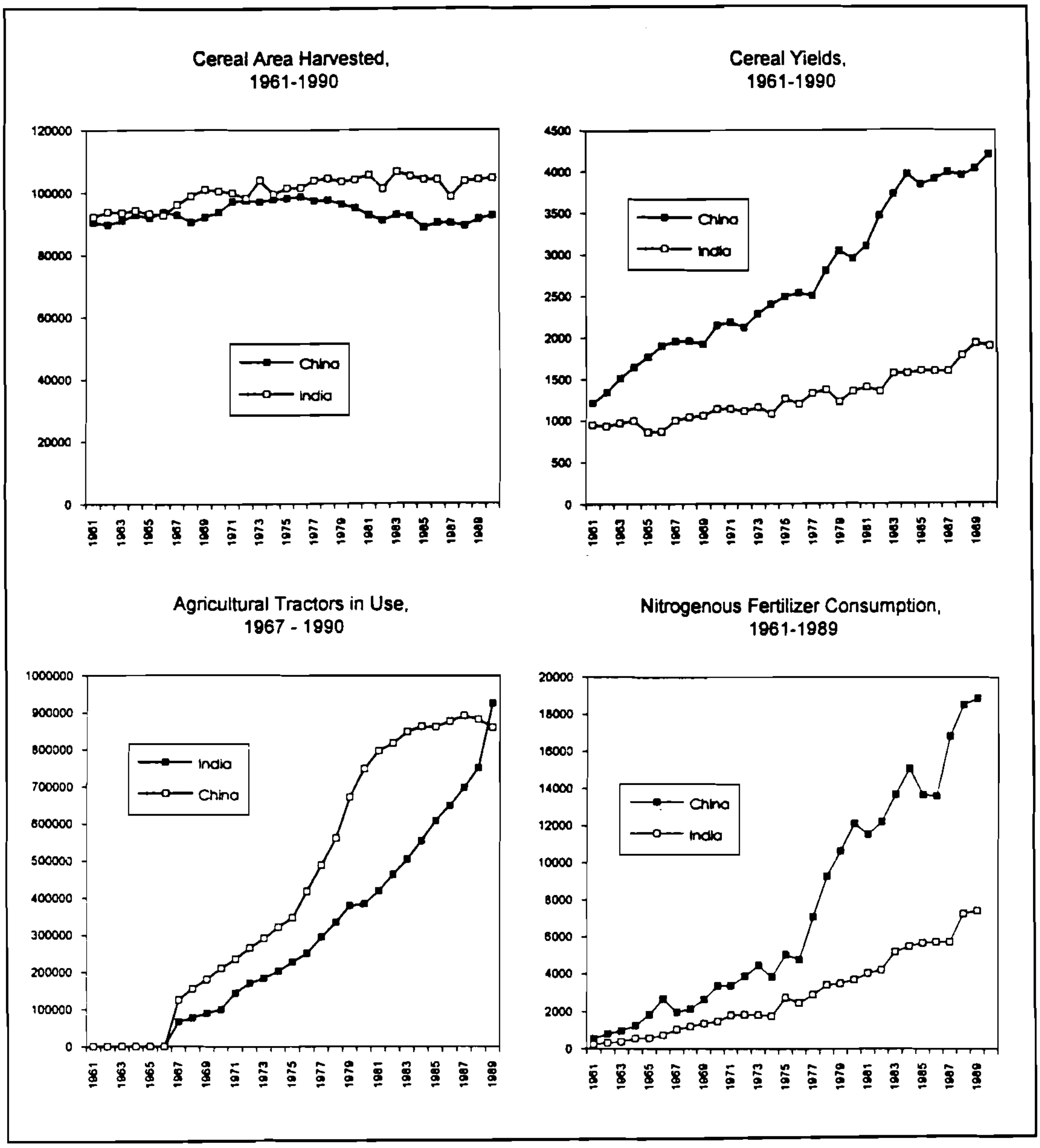

Figure 1. China and India: (a) central area harvested, (b) cereal yields, (c) agricultural tractors in use, and (d) nitrogenous fertilizer consumption.

There is no way to stop this gradual revocation of vital plant nutrients other than to recycle it to the soil. In a few agricultural areas this is done by natural phenomena, such as volcano eruptions[10] or floods which bring fertile mud to the fields.[11] Normally, however, the farmers

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[10] Ashes and lava from volcano eruptions are rich in minerals and other elements essential for plant growth.

[11] This is why agriculture emerged in the flood plains and deltas of large rivers, such as Tigris, Nile or Ganges. For more than 3000 years Egypt's agriculture was based on the Nile's floods which brought fertile mud to the fields. Today Egypt's farmers have to use enormous amounts of artificial fertilizers to compensate for lacking floods and to further increase yields.

have to use special techniques of re-fertilization, such as to rotate food crops and leguminous species (clover, alfalfa, or broad beans),[12] put manure on the field, or let it fall fallow for several years to let natural vegetation do the job.[13]

The most critical plant nutrients are nitrogens (N), phosphates (P_2O_5), and potash (K_2O). It is characteristic of modern agriculture that farmers have learned to solve the problem of "natural" soil degeneration by using *fossil* energy. Through the techniques of agrochemistry it became possible to produce plant nutrients in large quantities and recycle them to the soil. In combination with the breeding of new food crops ("high yield varieties"), artificial methods of pest and weed control, and the development of irrigation systems, this led to a multiplication of yields all over the world. Fossil energy has become the critical factor of modern agriculture (see Figure 1).[14]

3.1. Yields and Fertilizer Consumption

During the last decades farmers in Europe and Northern America achieved spectacular yields by optimizing the input of plant nutrients and crop sanitation by mechanizing cultivation, harvest and processing, and by adopting sophisticated crop rotation schemes. But this success story of modern agriculture is not restricted to the north. Most Third World countries could also increase food production: In China cereal production more than tripled between 1961 and 1989; in Indonesia it more than doubled. The growth was *not* achieved by expanding the area harvested, as it is often assumed, but by increasing the yields through agrochemistry and mechanization. The major factor was the enhancement of soil fertility through the input of "artificial"[15] fertilizers (see Table 2). Only between 1961/63 and 1983/85 the consumption of fertilizers grew tenfold in developed countries and doubled in the developing world.

In fact, fertilizer consumption can be seen as a global indicator which characterizes agricultural "regimes". Figure 2 shows the correlation between fertilizer consumption (in kg per hectare) and cereal yields (in kg per hectare) between 1961 and 1988 in Western Europe, less developed Africa, and in Asia.

- Africa, Asia and Western Europe represent entirely different levels of agriculture: cereal yield and fertilizer consumption differ by factors from 5 to 10. In 1988 the less developed countries of Africa had an average per hectare fertilizer consumption of some 11 kg and achieved cereal yields of some 1090 kg per hectare. Asian farmers on average applied some 115 kg of artificial fertilizers to their fields and achieved cereal yields of 2643 kg per

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[12] Crop rotation is a frequently used, traditional technique to recycle nitrogen to the soil. By planting sweet clover after harvest and plowing it under the next year, some 170 kg of nitrogen is added per hectare. The nitrogen fixation capacity of broad beans and alfalfa is estimated to range up to 600 kg per hectare. See: Smil, V. 1987. *Energy, Food, Environment. Realities, Myths, Opinions.* Oxford: Clarendon Press, p. 284.

[13] For a more detailed discussion see: Hayami, Y. and V.W. Ruttan. 1985. *Agricultural Development. An International Perspective.* Baltimore: The Johns Hopkins Press, pp. 45ff.

[14] Stout, B.A. 1990. *Handbook of Energy for World Agriculture.* London: Elsevier.

[15] The term "artificial fertilizers" is often used in a most degradative sense as "unnatural chemical substances". However, the most widely used substances, such as nitrogen, phosphorus, and potash, are natural components of fertile soils. They are "artificially" removed with each harvest. Proper fertilizer use only maintains the natural fertility of soils.

hectare. By contrast, farmers in Western Europe harvested more than 4500 kg of cereals per hectare, using 225 kg of artificial fertilizers.

Table 2. Changes in selected inputs to agricultural production. Source: PC-AGROSTAT, 1991.

Arable Land & Permanent Crops

Years	Developed Countries		Developing Countries	
1961/63	655,852		700,054	
1987/89	674,740		800,751	
Increase	**18,888**	**3%**	**100,697**	**14%**

Sources: FAO: PC-AGROSTAT; FAO Production Yearbook (in 1000 hectare)

Irrigated Agricultural Area

Years	Developed Countries		Developing Countries	
1961/63	38,219		104,176	
1987/89	63,109		166,991	
Increase	**24,890**	**65%**	**62,815**	**60%**

Sources: FAO: PC-AGROSTAT; FAO Production Yearbook (in 1000 hectare)

Nitrogenous Fertilizers

Years	Developed Countries		Developing Countries	
1961/63	10,430,275		2,650,089	
1988/89-1990/91	37,812,333		40,801,000	
Increase	**27,382,058**	**263%**	**38,150,911**	**1440%**

Sources: FAO: PC-AGROSTAT; FAO Fertilizer Yearbook (in 1000 metric tons)

Agricultural Tractors

Years	Developed Countries		Developing Countries	
1967/69	14,083,070		1,194,740	
1987/89	21,015,264		4,875,961	
Increase	**6,932,194**	**49%**	**3,681,221**	**308%**

Sources: FAO: PC-AGROSTAT; FAO Production Yearbook (numbers)

- The figure, however, not only indicates *regional* divergences in fertilizer input, but also *changes in time.* There is a clear trend within each of the three regions: as fertilizer consumption increased between 1961 and 1988, cereal yields also improved. In Asia per hectare fertilizer input grew by 106 kg, cereal yields by 1431 kg. In Africa input of artificial fertilizers rose by 9 kg, yields increased by some 387 kg. European farmers enhanced fertilizer input by 122 kg during the last three decades and increased average cereal yields by 2413 kg.
- While the correlation can be observed in all three regions, its strength differs greatly. For each kg increase of fertilizer input, cereal yields rose in Asia by 13.5 kg, in Africa by 43 kg, and in Western Europe by 19.8 kg. If we assume that fertilizer input is a major factor for rising soil productivity, Africa would gain most by an increase in fertilizer use. At the

extremely low level of fertilizer input that is typical for African agricultures,[16] each kilogram of additional fertilizer input would bring (and has, in fact, brought) great returns. In Asia, by contrast, the substantial increase of fertilizer input correlated only weakly with the slight increase of cereal yields; especially during the late 1980s.

- On a very high level of fertilizer input a substitution effect can be observed. During the 1980s cereal yields in Western Europe rapidly increased, while fertilizer input *stagnated*. Obviously the farmers managed to improve the productivity of their soils without increasing the input of fossil energy in the form of artificial fertilizers.

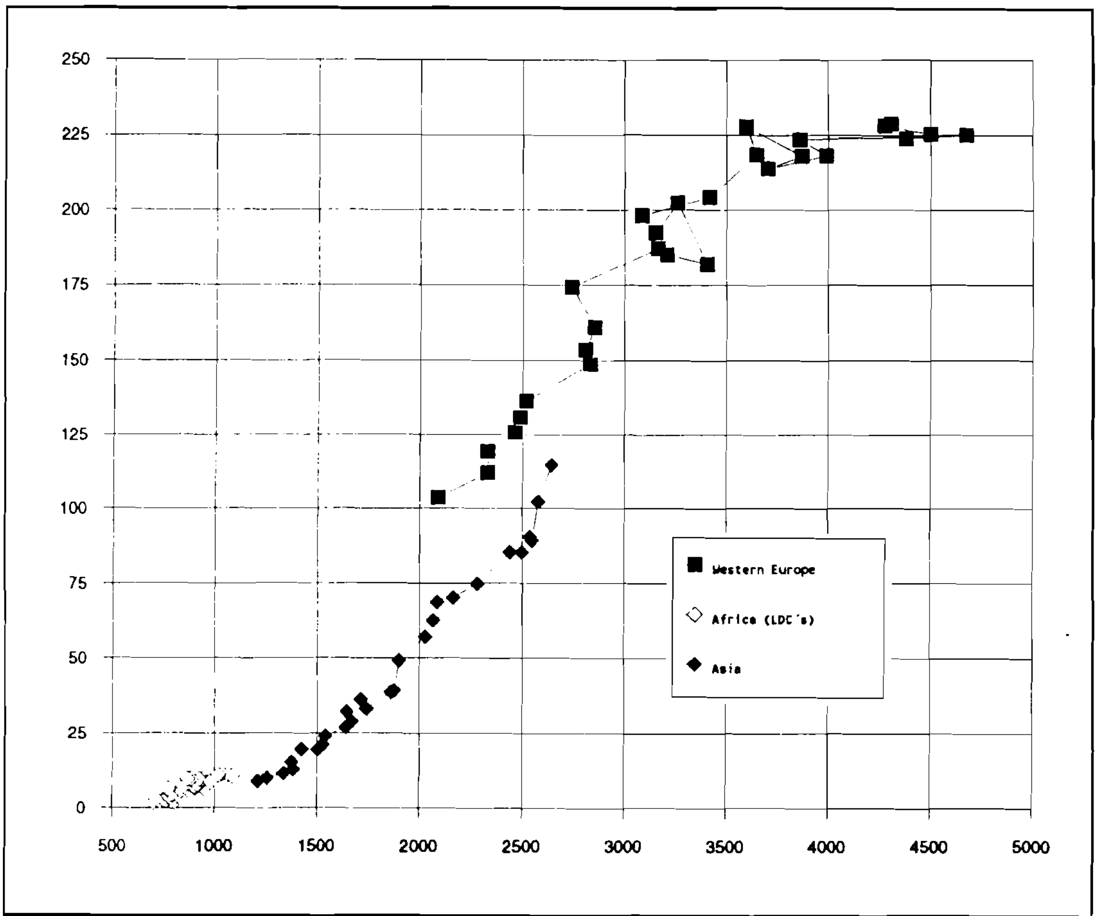

Figure 2. Western Europe, Asia, Africa (LDCs): Average fertilizer consumption (kg/ha) by average cereal yields (kg/ha), 1961-1988.

There can be no doubt that a whole range of factors other than fertilizer input can influence the productivity of soils. Climate conditions, such as average and peak temperatures, or the timing and amount of rainfall are very important. Also of great relevance is the "natural" quality of the soil, the availability of high yield seeds, access to irrigation, and farming know-how. But without the recycling of plant nutrients in the form of fertilizers made from fossil energy,

[16] The only exceptions are the North African countries of Egypt and Libya, whose farmers use very large amounts of artificial fertilizers, well comparable to West European standards.

no modern agriculture is possible. As a FAO report states: The "increase in fertilizer usage...was possibly the most potent single factor in raising productivity...".[17]

Table 2 shows selected inputs to agricultural production between the early 1960s and the late 1980s. Contrary to widespread belief the world crop area only slightly expanded from 656 to 675 million hectare in developed and from 700 to 801 million hectare in developing countries. There was also only a minor expansion of the irrigated area. Nitrogenous fertilizer input, however, more than tripled in the developed world (from 10.4 to 37.8 billion tons) and increased fifteen-fold in developing countries (from 2.7 to 40.8 billion tons). Obviously the major source of the worldwide surge in agricultural production was the *productivity gain* linked to agrochemistry. "Instead of being limited by shortages of nutrients and water, and harmed by competition from weeds and attacks by pests, modern crops could come closer to reaching their full yield potential."[18]

Agrochemistry has become a major factor in agricultural energy consumption. In advanced agricultures nitrogen fertilizers are the single largest sink of fossil energy. It typically accounts for no less than a third, but in some case up to 90 percent, of all external energy invested in production. However, it is very difficult to estimate the total amount of *fossil* energy that - directly and indirectly - goes into agriculture.

According to estimates from the early 1980s one needs approximately 14,700 kcal of fossil energy to produce one kilogram of nitrate fertilizer, 3,000 kcal for one kg of phosphorus and 1,600 kcal for one kg of potassium.[19] More recent calculations, however, are somewhat different: they estimate some 12,600 kcal for the production of one kg nitrate fertilizer, between 1,500 and 1,096,281 kcal for one kg of phosphatic fertilizers[20] and 1665 kcal for the production of one kg potassium.[21]

Worldwide, some 70% of the nitrogen fertilizers are produced from natural gas.[22] Today we need about one cubic meter of this gas to produce one kg of nitrogen fertilizer. The

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[17] Alexandratos, N., Ed. 1988. *World Agriculture: Toward 2000. An FAO Study.* London: Belhaven Press.

[18] Smil, *op. cit.,* p. 286.

[19] Lockeretz, W. 1980. Energy inputs for nitrogen, phosphorus, and potash fertilizers. Pages 23-24 in D. Pimentel, ed. *Handbook of Energy Utilization in Agriculture.* Boca Raton: CRC Press; and Pimentel, 1984, *op. cit.,* p. 11.

[20] The enormous range results from different processes for the production of phosphoric fertilizers and their base products. For the production of (ordinary or granulated) "superphosphates" from ground phosphate rock one needs only some 1,502 kcal of energy per kg fertilizer. However, to produce one kg of phosphoric acid from phosphoric rocks, one needs between 5,269 (wet process) and 30,729 kcal (acid-oxidation method). The most energy consuming process is the transformation of phosphoric acid into ammonium phosphates which needs some 1,096,281 kcal per kg. All data from: Brown, H.L., B.B. Hamel, and B.A. Hedman. 1985. *Energy Analysis of 108 Industrial Processes.* Philadelphia: Fairmont Press Edition, pp. 212-214.

[21] These estimates include both fossil and non-fossil energy consumption (such as electricity from water driven power plants). *Ibid.*

[22] Stout, *op. cit.,* p. 159.

worldwide nitrogen fertilizer production from natural gas consumes a little less than one percent of the total (global) energy consumption. Even in the developing countries, where agriculture is still a major sector, only 2.7% of their total commercial energy use is in the form of fertilizer. In other words, compared to the energy use in industries or households the energy consumption in agrochemistry is very small.[23]

It is true that a large proportion of fossil energy use in agriculture goes to the production of nitrogenous fertilizers - but total agricultural energy use, including fertilizers, averages only some 4% of overall commercial energy consumption. In absolute terms, the use of fossil energy for fertilizers is only minor. Thus, fertilizer production is a very good investment. By spending just roughly 1 percent of the world energy consumption in fertilizer production (and an additional 2 or 3% in agricultural mechanization, irrigation, transport, etc.) we have multiplied global food production and saved the lives of hundreds of millions of people.

The author is well aware that agrochemistry has its negative side. In some critical areas one can certainly identify environmental and public health risks of excessive pesticide and fertilizer use. However, these problems are small as compared to the consequences of agricultural stagnation. Without the application of artificial fertilizers and crop sanitation chemicals it would not have been possible to double or triple crop production during the last three decades in India, China, and several other Asian countries. There would be a food production deficit for hundreds of millions of people and widespread famines would flare up frequently - as it was the case before the "Green Revolution".[24]

3.2. Energy Output/Input Ratios in Selected Food Production Systems

In the U.S. agriculture energy input and yields in maize production dramatically changed between 1945 and 1985. While maize yields (measured in food energy output) more than tripled, the total energy input quadrupled. Overall energy efficiency - which is the ratio of energy output to input - declined from 3.4 to 2.9. However, it was not the overall energy consumption, but the pattern of energy use, which changed most. There was a sixteen-fold increase of energy input in the form of artificial fertilizers (from 233,000 to 3,744,000 kcal per hectare). The energy input for irrigation grew eighteen-fold (from 125,000 kcal to 2,250,000 kcal per hectare). On the other hand fuel consumption and labor input declined (from 1,428,000 to 1,278,000 and from 31,000 to 6,000 kcal per hectare, respectively). In 1985 the products of agrochemistry (fertilizers, insecticides, herbicides) accounted for some 40 percent of the total energy input to maize production; in 1945 their share was only 9.3 percent (see Table 3).

The heavy use of (fossil) energy in modern agriculture - mainly through the use of artificial fertilizers - is reflected in very low energy output-input rates in the production of certain food products. One needs, for instance, 5000 kcal of fossil energy to produce lettuce with a food energy content of just 1000 kcal. Such low returns are typical for many vegetables. Tomatoes need 1667 kcal of energy input for 1000 kcal output; and to produce cabbage with an energy content of 1000 kcal one needs 1250 kcal of fossil energy.

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[23] Smil, *op. cit.*

[24] See also: Pimentel, D. 1989. Impacts of pesticides and fertilizers on the environment and public health. Pages 95-108 in *Toxic Substances in Agriculture, Water Supply and Drainage.* Proceedings of the 2nd Pan-American Regional Conference, 1989.

Table 3. USA: Energy input in maize production, 1945-1985 (in 1000 kcal per hectare).[25]

	1945		1985	
Activity	kcal	in %	kcal	in %
Labor	31	1.2	6	0.1
Machinery	407	16.3	1,018	9.9
Draft animals	0	0	0	0
Fuel	1428	57.3	1,278	12.4
Manure	-	-	-	-
Fertilizers	233	9.3	3,744	36.3
Lime	46	1.8	134	1.3
Seeds	161	6.5	520	5.0
Insecticides	0	0	60	0.6
Herbicides	0	0	350	3.4
Irrigation	125	5.0	2,250	21.8
Drying	9	0.4	760	7.4
Electricity	8	0.3	100	1.0
Transport	44	1.8	89	0.9
Total	2,492	100	10,309	100
Yields	8,528		29,600	
Ratio: Input/Yields	3.4		2.9	

By contrast, the output-input ratio of energy in food and feed crop production is much better: by using 1000 kcal of fossil energy (for fertilizers, machinery, irrigation, etc.) US farmers can produce oats with an energy content of 5100 kcal, soya bean equivalent to 4500 kcal, and maize with an energy content of 3500 kcal. However, the most widely used food crops, wheat and rice, are relatively energy inefficient in modern production systems. To produce 2,022 kg of wheat with an energy content of 6,700,000 kcal, US farmers need 2,500,000 kcal of fossil energy (which is equivalent to an output-input ratio of 2.7 : 1). The returns in rice production are even less: US farmers need some 12,500,000 kcal of fossil energy input to produce 4,742 kg rice of 14,000,000 kcal energy content (output-input ratio: 1.1 : 1) (see Table 4).

The relatively high energy consumption in rice production is not a typical result of US energy wasting. According to estimates by Wen Dazhong and David Pimentel the energy output-input ratio of rice production in Dawa County, Liaoning Province, China, was also only 2.6 : 1, which is slightly *less* than the energy efficiency of US wheat production. B.S. Pathak and A.S. Bining conducted a study on energy use patterns in rice-wheat cultivation in three clusters of Pundjab villages, India. They found that energy consumption in rice production was much higher than in wheat production, primarily due to the high irrigation requirements of rice. They

[25] Adapted from: Pimentel, D., W. Dazhong, and M. Giampietro. 1990. Technological changes in energy use in U.S. agricultural production. Pages 305-321 in S.R. Glissman, ed. *Agroecology. Researching the Ecological Basis for Sustainable Agriculture.* New York: Springer Verlag.

calculated total output-input ratios for commercial energy of between 1.4 : 1 and 1.81 : 1 in rice production and between 3.02 : 1 and 3.45 : 1 in wheat production.[26]

Table 4. USA: Fossil energy inputs and outputs per hectare for selected crop and livestock production systems.

Crop / Livestock	Kcal Output / Kcal Fossil Input	Labor Input (man-hours)
Maize (United States)	3.5	12
Wheat (North Dakota)	2.7	6
Rice (Arkansas)	1.1	30
Beans, dry (Michigan)	1.3	19
Apples (East)	0.9	176
Oranges (Florida)	1.7	210
Potato (New York)	1.4	35
Lettuce (California)	0.2	171
Tomato (California)	0.6	165
Cabbage (New York)	0.8	289
Beef	0.04	2
Pork	0.02	11
Sheep (grass-fed)	0.01	0.2
Eggs	0.06	19
Catfish	0.03	55

Source: Pimentel, 1984, *op. cit.*

Low energy returns of rice are typical for all modern production systems - in the USA as well as in Asia. Only traditional systems of rice production are more energy efficient. In the Philippines output-input ratios of between 5.5 : 1 and 10.5 : 1 can be observed in traditional rice farming. Since these production systems have yields of only between 1250 to 2700 kg per hectare, growing population pressure will force the farmers to modernize in order to increase the yields; and this in turn will inevitably force them to increase fossil energy input.[27]

Considering the food preferences of - at present - some 3 billion Asians, the relatively high energy consumption in *modern* paddy rice production is an important factor for future energy use in food production systems. Since Asian populations are projected to increase by some 2 billion during the next 35 years (UN-medium variant), we have to expect a significant increase in energy consumption in agriculture, particularly for the production of fertilizers. On the other hand, this might be a good investment: one cannot eat fossil fuel, but one can eat rice and wheat.

[26] Pathak, B.S. and A.S. Bining. 1985. Energy use pattern and potential for energy saving in rice-wheat cultivation. *Energy in Agriculture* 4(3):271-278.

[27] Baozhao, Z. and Y. Kekuan. 1989. Energy input for rice production in China and approaches of increasing efficiency. Pages 916-920 in *Proceedings of the International Symposium on Agricultural Energy (89-ISAE)*, Beijing, China, 12-15 September 1989. Vol. II.

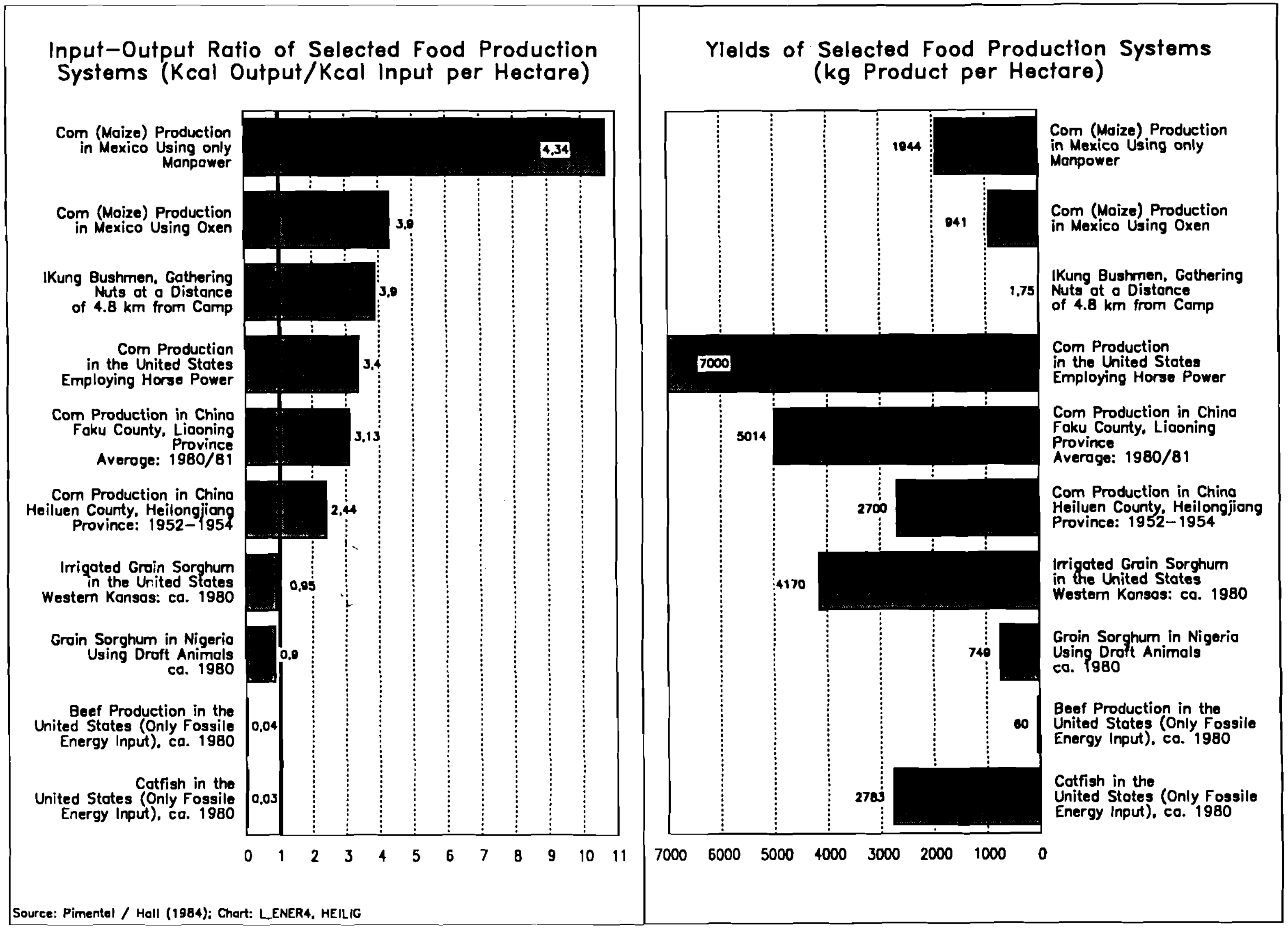

Figure 3. Input/output ratio and yields of selected food production systems. Source: Pimentel, D. and C.W. Hall, Eds. 1984. *Food and Energy Resources.* Orlando: Academic Press.

Unfortunately, many analysts have attached a negative image to the use of fossil energy in agriculture, implying that a low energy output ratio is bad, while a high one is good. In the name of energy conservation and environmental protection they propagate the ideology of traditional agriculture. One can find authors that make people believe the Third World could survive on shifting cultivation. But these analysts ignore the simple fact that without artificial fertilizers and pesticides there would be much less food around for the rapidly growing population. They should first answer the question of M. Slesser: "...what's wrong with using energy to get food?"[28]

3.3. Future Energy Requirement in Food Production

In 1990 the world grain production was 1,954.7 million tons - consisting of 595.1 million tons of wheat, 518.5 million tons of paddy rice and 841.0 million tons of coarse grain.[29] Using a recent food demand projection of the Organization for Economic Cooperation and Development (OECD)[30] the Indian agricultural expert S.K. Sinha has tried to estimate the global energy use in future grain production. For the year 2000 Sinha assumed a grain requirement of some 2,412.5 million tons - about 600 million tons of wheat, 634 million tons of rice and 1187 million tons of coarse grain. On the basis of US agricultural technology he estimated that one would need fossil energy equivalent to some 264.4 million tons of oil in order to achieve this output; however, based on Indian technology the energy requirement would be equivalent to only 92 million tons of oil.[31]

Unfortunately Sinha's projections were not very realistic. For example, he projected that the developing world would need some 1,016 million tons of grain by the year 2000. But in 1990 the developing countries already produced more than that (some 1,020 million tons of grain). Obviously, Sinha seriously underestimated the potential (and need) for increasing grain production in the Third World.

It is very difficult to project the future *overall* energy demand in agriculture; it partly will depend on a number of factors that are impossible to predict, such as a possible breakthrough in the bioengineering of new types of crop plants that can generate nitrogen or the development of new energy saving irrigation schemes. Most important, however, there could be worldwide shifts in dietary patterns (such as increasing preference for animal food) which would boost the demand for energy consuming feed crops. On the other hand one has to remember that worldwide only a few percentages of commercial energy are used in agriculture (*including* fertilizer production, irrigation, and farm mechanization). Much more fossil energy is used in the "later stages" of the food chain, such as food processing, transportation, and preparation (not to speak about the energy use in industry). Even a doubling of energy consumption in agriculture would be a relatively minor increase in absolute terms.

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[28] Slesser, M. 1986. Energy balance in agriculture: The developed world. In M.S. Swaminathan and S.K. Sinha, eds. *Global Aspects of Food Production.* Oxford: Tycooly International.

[29] FAO. 1990. *Production Yearbook,* Vol. 44.

[30] OECD. 1979. *Facing the Future.* Paris.

[31] Sinha, S.K. 1986. Energy balance in agriculture: the developing world. Pages 57-83 in M.S. Swaminathan and S.K. Sinha, eds. *Global Aspects of Food Production.* Oxford: Tycooly International.

4. PROCESSING, FOOD TRADE, AND LOGISTICS

Research on energy consumption in the food sector is usually restricted to production of *primary* food products, such as rice, wheat, potatoes, fish or meat. But we no longer live from hand to mouth. We very seldom eat plants as they come from the field or enjoy raw meat directly from a killed animal or fish. We rather prefer bread and cake, hamburgers and milkshakes, pork chops or "Wiener Schnitzel", cheese and potato chips, wine and beer. From Beijing to Jakarta, and from Lagos to Mexico City the people of the earth have developed sophisticated techniques of food preparation that often reflect a particular national lifestyle.

The transformation of basic food into meals usually involves numerous industrial processes - from the grinding of grain, to the freezing of vegetables, the canning of meat and fish, or the bottling of drinks. Food products are stored, transported to markets and distributed to households or restaurants. There they are transformed again into a near endless variation of dishes. Cooking food can be as simple as roasting a piece of meat on an open fire and as complex as preparing a "haute cuisine" meal with 12 courses (and substantial fossil and human energy consumption in the kitchen). In any case, each step in the long food chain from the farm to the market and from there to the table needs fossil energy - usually *much more* than what is necessary to produce the raw product.

Especially in the industrialized world the fossil energy inputs in processing, preserving, packaging, and transport of food are enormous. Altogether some 30% of the total energy consumption in developed countries is consumed in the food sector: 10% of this energy is used in agriculture and livestock production, but 90% is spent for transport, packaging and preparation of food.[32] For *producing* one unit of food energy (vegetable food plus meat) we need about 0.6 units of fossil fuel in the industrialized countries; but the processing, transportation, storage, and cooking of this food consumes at least another six units of fossil fuel per one unit of food energy.[33]

4.1. Preserving and Packaging

In the late 1970s David Pimentel calculated that "producing sweet corn on the farm uses only about 10% of the total energy used to produce, process, market, and cook a 1-kg can of sweet corn."[34] Freezing the food as a means of preservation is even more energy consuming. One needs approximately 7980 kcal/kg for freezing food as compared to 6560 kcal/kg for canning. A most energy efficient technique of preservation is salting. In former times this method was frequently used for safe storage of fish, meat and vegetables. According to Pimentel the process consumes only about 23 kcal per kilogram of meat (not counting the fossil energy for producing the extra bottle of beer, wine or mineral water necessary to stop the burning thirst after the consumption of over-salted food).

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[32] These are the most recent estimates available to the author. However, there are older calculations which estimated a somewhat smaller energy consumption in the food sector of around 20% (including 5% for food production) of the total fossil energy consumption in developed countries. See: Leach, G. 1977. *Energy and Food Production.* IPC, Guildford, p. 30; Cited from: Slesser, *op. cit.*

[33] Schmidt, *op. cit.*

[34] Pimentel, 1984, *op. cit.*, p. 19.

4.2. Transport

While the industrial processing and packaging of food by itself can consume up to ten times the energy that is necessary for production, its transport can use up even more. Consider the import of tropical fruits, coffee or tea to Europe! During the late 1970s David Pimentel tried to estimate the energy costs of food transport in the United States by assuming an average transport distance of 640 km and a proportion of 60% truck and 40% rail transport. He concluded that the energy input of transport was about 350 kcal per kilogram food. However, Pimentel himself was obviously not happy with this estimate, since he added the example of a lettuce transport by truck from California to New York. This required about 1800 kcal of fossil energy per kg lettuce, which is 36 times (!) the energy content of the food. Today it is even more difficult to give a general estimate of energy consumption in the food *transport* sector. There are many food products that virtually have travelled around the world before they are eaten by a consumer, such as Kiwi fruits from New Zealand sold in Europe, Egyptian bread baked with Canadian wheat flour, Argentinean sirloin meat that is consumed in European "Steak Houses", or South African oranges that can be bought in northern Sweden.

4.3. Logistics

It is one thing to bring potatoes to the market and another to ship food or food-components back and forth within a complex network of distributed processing, packaging and marketing sites. While the first activity can be called the transport component in the food chain, the second is a highly sophisticated organizational scheme to minimize costs in the food processing and marketing sector. It should be distinguished from the first kind of activity and called the logistics of the food system.

The energy consumption in international food trade is only the tip of the iceberg. The hidden form of energy consumption, which is associated with the complex network of material flows between interlinked processing, packaging and marketing units in modern food industries, is much more important. Sometimes these logistics are rather absurd. For example potatoes, harvested on German fields, are carried to Italy, where they are washed and packaged - only to be transported back again to be marketed in Germany. It is not unlikely that some of these potatoes - now as packaged potato chips - cross the Alps mountains for a second time from Germany to Italy. Milk and milk products are also transported excessively back and forth across large distances between European countries - supposedly to be brought to the most cost efficient dairy plant for being processed into butter, cheese, yoghurt, etc.

Only recently Austrian politicians protested at the European Community against the excessive and unnecessary food transports between Germany and Italy. They argued that the traffic on the transit routes through Austria could be significantly reduced, if these food transports were terminated. However, one has also to take into account that the concentration and specialization of food industries inevitably causes a certain redistribution of the raw product. A case in point is milk processing. In Europe, dairy plants have specialized to such an extent that some plants only produce a certain kind of milk product (such as yoghurt) while other plants elsewhere in Europe have specialized in other products. The material flows in the food industries are optimized according to *cost* efficiency and optimal allocation of production capacities, rather than according to *energy* efficiency. As long as fossil energy is relatively cheap, excessive transport of food products for optimal processing and marketing will continue.

The logistics of food is often ignored in food studies - probably because it is nearly impossible to sort out the complex network of ever-changing flows between farmers, processing industries, packaging sites, exporters and importers, wholesalers, retailers, and households.

5. SOCIAL AND CULTURAL ASPECTS

Eating is not only a matter of energy intake or protein supply, otherwise soya meat would have been a big success - as well as sea weed salads and synthetic food. There are at least five social and cultural components of food:

- People choose food according to taste and tastes are rather different. If people do not like the taste they often will not eat the food even if they are starving to death. There are numerous examples where people in the middle of a famine refused to eat "strange" food, such as eggs, fish, testines, animal blood, insects, snakes, frogs, snails, etc. It is often food that other people in other cultures would consider delicacies. Sometimes it requires substantial fossil energy input to achieve the right taste in food preparation - such as roasting coffee beans or smoking salmon.
- People eat with their eyes and within a typical social setting. Most of us, for example, prefer to drink wine from a glass (drinking it from the bottle would save the fossil energy that is required to produce and wash the drinking glass). Some of us prefer to eat at a nicely set table (there is substantial fossil energy spent for producing and washing the table cloth and the porcelain dishes).
- There is a religious and symbolic dimension of food: Nearly all religions have certain food taboos and rituals of eating. For Christians bread and wine is something special, Jews prefer kosher food, Moslems avoid pork and alcohol. Members of alternative lifestyles treat themselves with müsli and shiver from abhorrence at hamburgers with ketchup. Some environmental activists would never eat an Argentinean sirloin steak, because they think they would help to destroy the environment. This symbolic and ritual dimension of food has energetic consequences: It restricts the diet to types of food that often need more (or less) energy input than a broader range of food items would require.
- Food can be a drug. Especially in developed countries the number of people with pathological eating habits is substantial. It would be interesting to calculate the fossil energy consumption that is necessary just to produce the additional food for the people that simply eat and drink too much.
- Food has an entertainment aspect. There is a whole industry that produces - what could be called - "entertainment food". This is food which is usually not eaten because of its nutritional content, but because of its "fun and taste" features. Ice cream, candy bars, popcorn, candy floss, chocolate Santa Clauses, Easter bunnies, chewing gum, and the whole range of sweets for children are examples. They are not required for a healthy diet (just the opposite!), they are eaten for a special experience. A most recent trend in this industry is to combine food with toys ("Kinder-Überraschung").

Strangely enough, these social and cultural aspects of food are usually ignored in studies of energetic efficiency in the food sector. It is strange, because there can be no doubt, that - at least in developed countries - they are responsible for most of the fossil energy consumption in our food chains.

5.1. Global Trends in Food Preferences

In order to get a first overall impression of the global trends in food consumption patterns Table 5 was compiled. It shows the average food energy supply of major regions by selected categories (in kcal per caput per day) as well as the changes between 1961 and 1989.[35]

Worldwide there is a trend to better food energy supply: it increased by 19.8 percent. Both vegetable and animal products contributed equally to this increase. However, as is often the case with the global food situation, the overall trend is rather misleading. Broken down by major regions, a different pattern becomes visible:

- In less developed Africa there is a trend to vegetable food. While the food calorie supply based on animal products increased by only 2.2 percent between 1961 and 1989, the calorie supply of vegetable food grew by over 10 percent. This is rather remarkable, since Africa already has the highest proportion of vegetable food in overall calorie supply. Total calorie supply increased only slightly (by 9.6 percent) during the past three decades.
- There is an opposite trend in the Far East. While the overall calorie supply grew by some 37 percent, food calories based on animal products increased by over 144 percent. In 1961 these Asian countries, in fact, had *lower* food calorie supply from animal products than the developing nations of Africa (88 as compared to 135 kcal per caput per day). Today, the people in the Far East are supplied with 215 kcal per person per day of animal-based food, while in Africa only 138 kcal per caput per day are available.
- In Latin America the increase of calorie supply from animal products was over 20 percent, calories from vegetable products, however, only increased by 15 percent.
- The calorie supply in the developed world stems to a high degree from animal-based food. Roughly one-third of the total calorie supply (of 3417 kcal per caput per day) comes from animal products. Yet there is still a trend to more animal food. While the vegetable calorie supply increased by some 8 percent, calories from animal products grew by nearly 24 percent since 1961.

In parts of the Third World large sections of the population seem to become fond of a more "western" diet. They begin to dislike the - sometimes rather monotonous - food made out of traditional grains (such as sorghum, millet, or barley), pulses[36] and starchy roots.[37] In Latin America, for instance, the calorie supply of starchy roots declined by some 23 percent, in the Far East it decreased by more than 38 percent. Food calorie supply from pulses fell by 27 and 50 percent, respectively. The supply of eggs in terms of calories, however, doubled in Latin America and tripled in the Far East. But the most spectacular change was the enormous increase of meat consumption in the Far East: between 1961 and 1989 the calorie supply of meat and offals grew from 27 to 112 kcal per person per day (plus 315 percent).

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[35] The data can only give a crude estimate of real food consumption patterns, since they represent average per caput food supply in a given country. Nothing is said whether this supply is actually used for consumption.

[36] These include beans, peas, lentils, etc.

[37] These include potatoes, cassava, yams, taro, etc.

Table 5. Food energy (in kcal per caput per day) by food product category.

Category	WORLD 1961	WORLD 1989	WORLD Change in %	AFRICA(LDC's) 1961	AFRICA(LDC's) 1989	AFRICA(LDC's) Change in %	LATIN AMERICA 1961	LATIN AMERICA 1989	LATIN AMERICA Change in %	FAR EAST 1961	FAR EAST 1989	FAR EAST Change in %	NEAR EAST 1961	NEAR EAST 1989	NEAR EAST Change in %	MDC's 1961	MDC's 1989	MDC's Change in %
Grand Total	2262	2710	19.8	2030	2224	9.6	2359	2732	15.8	1784	2450	37.3	2225	2954	32.8	3034	3417	12.6
Vegetable Prod.	1901	2277	19.8	1895	2086	10.1	1965	2257	14.9	1697	2235	31.7	1984	2670	34.6	2191	2371	8.2
Animal Products	361	433	19.9	135	138	2.2	394	475	20.6	88	215	144.3	241	284	17.8	844	1046	23.9
Cereals	1123	1385	23.3	934	1042	11.6	948	1054	11.2	1149	1651	43.7	1408	1707	21.2	1133	996	-12.1
Wheat	416	532	27.9	154	230	49.4	330	375	13.6	184	463	151.6	859	1173	36.6	796	726	-8.8
Rice	401	577	43.9	89	146	64.0	206	265	28.6	676	954	41.1	148	204	37.8	130	120	-7.7
Barley	25	11	-56.0	43	35	-18.6	6	3	-50.0	28	6	-78.6	57	54	-5.3	16	6	-62.5
Maize	123	163	32.5	263	319	21.3	391	402	2.8	100	133	33.0	162	175	8.0	59	78	32.2
Rye	38	12	-68.4	0	0	0	1	0	-100.0	6	2	-66.7	25	4	-84.0	106	43	-59.4
Oats	5	4	-20.0	0	0	0	3	4	33.3	3	1	-66.7	0	0	0	11	11	0.0
Millet	47	37	-21.3	141	137	-2.8	0	0	0	67	42	-37.3	26	11	-57.7	8	3	-62.5
Sorghum	61	43	-29.5	200	149	-25.5	8	4	-50.0	81	44	-45.7	131	85	-35.1	1	3	200.0
Other Cer.	8	6	-25.0	43	25	-41.9	2	1	-50.0	5	5	0.0	0	0	0	6	5	-16.7
Starchy Roots	179	141	-21.2	431	446	3.5	170	130	-23.5	156	96	-38.5	36	61	69.4	174	132	-24.1
Sweeteners/1	197	237	20.3	72	110	52.8	377	439	16.4	96	132	37.5	142	277	95.1	350	438	25.1
Pulses	89	58	-34.8	95	91	-4.2	131	96	-26.7	122	61	-50.0	46	61	32.6	33	24	-27.3
Oilcrops	38	45	18.4	68	57	-16.2	26	17	-34.6	42	51	21.4	24	27	12.5	29	41	41.4
Vegetable Oils	113	214	89.4	111	170	53.2	121	301	148.8	57	130	128.1	118	304	157.6	196	366	86.7
Vegetables	37	46	24.3	22	24	9.1	22	26	18.2	31	40	29.0	45	59	31.1	53	72	35.8
Fruits	53	65	22.6	88	82	-6.8	109	115	5.5	21	32	52.4	124	138	11.3	71	94	32.4
Alcoholic Bever.	55	66	20.0	46	39	-15.2	53	68	28.3	11	28	154.5	6	7	16.7	133	173	30.1
Meat/Offals	136	201	47.8	65	57	-12.3	203	231	13.8	27	112	314.8	84	110	31.0	311	465	49.5
Animal Fats	74	65	-12.2	14	14	0.0	52	58	11.5	13	22	69.2	45	53	17.8	189	186	-1.6
Milk	115	113	-1.7	39	44	12.8	116	143	23.3	31	48	54.8	101	94	-6.9	263	276	4.9
Eggs	17	24	41.2	4	6	50.0	13	26	100.0	5	15	200.0	5	16	220.0	42	54	28.6
Fish, Seafood	17	27	58.8	11	16	45.5	9	15	66.7	10	18	80.0	4	9	125.0	34	59	73.5
Other Items/2	19	23	21.1	30	26	-13.3	9	13	44.4	13	14	7.7	37	31	-16.2	23	41	78.3

/1 Sweeteners + Sugar Crops

/2 Other Items include: Treenuts, Spices, Stimulants

Less developed Africa did not completely follow this trend. Here the food calorie supply from starchy roots and pulses *increased* (by 3.5 percent and 7.1 percent, respectively) while it declined in Latin America, the Far East and in the developed countries. The increase, however, was less than the growth of Africa's total food calorie supply. Sugar crops and sweeteners also became more important for the African food calorie supply: in 1961 they added 72 kcal to the overall food supply; in 1989 their contribution was 110 kcal per person per day. Among the large regions only the Near East (with its traditional preference for sweet food) had a higher percentage increase of calories from sugar crops and sweeteners. Most surprisingly, the developing countries of Africa had a significant increase of rice supply: between 1961 and 1989 the food calorie supply covered by rice grew from 89 to 146 kcal per person per day (plus 64 percent).

On the other hand traditional cereals, such as barley, rye, millet, or sorghum are losing ground as compared to wheat and rice. While in 1961 sorghum accounted for 200 kcal in the average African food calorie supply, it was only 149 kcal per person per day in 1989 (minus 26 percent). During the same period wheat increased its share from 154 to 230 kcal (plus 49 percent) and rice - as we have already mentioned - from 89 to 146 kcal (plus 64 percent). In the Far East the food calorie supply from sorghum declined from 81 to 44 kcal per person per day (minus 46 percent), and in the Near East it fell from 131 to 85 kcal per caput per day (minus 35 percent).

The energy implications of these trends are multiple and difficult to quantify. A shift to "modern" food crops, such as wheat and rice will most likely amplify the need for agricultural modernization (including the use of artificial fertilizers and irrigation); and this, in turn, will increase fossil energy consumption. Of even greater significance might be the rapid increase of meat supply in the developing nations of the Far East, which has *quadrupled* since 1961. (However, it should not be forgotten, that the average meat supply in the Far East today is still only one-fourth of that in developed countries.) Since the production of meat consumes much more fossil energy than that of food crops the energy consumption will increase even further.

5.2. Lifestyles and Food Consumption Patterns

Food habits all over the world have changed fundamentally since the time of our grandparents. Today, no one in Europe or Northern America is surprised to find fresh salads on the market throughout the year. We have become accustomed to eating bananas, grapefruits or oranges at Christmas and ice cream or milkshakes in the mid-August heat.[38] But this change in lifestyle is not restricted to the developed world. The citizens of Cairo, for instance, have developed a preference for white bread which can only be produced due to Egypt's enormous cereal imports. In many Third World cities the middle classes are increasingly becoming fond of "western" food. One can easily eat "hamburgers" in Guatemala City, drink "Coca Cola" in Java or have a bottle of beer in Arusha, Tanzania. But all this is only possible due to an enormous input of fossil energy in the food transport and processing sector.

We can conclude that there are three major trends in food preferences that have a direct impact on the logistics of the food system:

- Simple, traditional dishes which were prepared from raw products in the household tend to be replaced by refined, *industrially processed food*. The worldwide success of fast food

[38] Arthey, V.D. 1989. Fruits and vegetables. In C.R.W. Spedding, ed. *The Human Food Chain*. London: Elsevier.

restaurants and ready-to-eat packaged food (chocolate bars, potato chips, yoghurts, etc.) is a symptom of this trend.

- Food consumption patterns no longer follow the *seasonal circle.* Fresh fruits and vegetables are marketed throughout the year - either from glasshouse production or imported from parts of the world that currently have a growing season for the product.
- In developed countries there is a trend to *greater food variety* and even *"exotic" food* among certain groups of the population. Europe's food stores are filled with vegetables and fruits from the most distant places, such as mangoes, litchis, or papayas. This indicates that the food chains are expanding from local or regional to *international markets.*

These trends have already caused a shift in energy use from the production of food to its transport, processing, storage and preparation. As the typical "western" lifestyle expands to the Third World a significant increase in energy use in the food distribution and processing system can be projected. This will be *in addition* to what must be expected anyway due to the increase of food production for the growing population.

5.3. The Cultural Dimension of Animal Food

Cycling crops through animals to produce protein is extremely inefficient, both in terms of land and energy. According to a calculation of David Pimentel the production of a high animal protein diet consumes about three times the fossil energy that is needed for pure plant protein food. To produce a daily food energy intake of 3300 kcal one needs 33.900 kcal of fossil energy for a high animal protein diet, 18.900 kcal for a lacto-ovo diet that includes eggs, milk and milk products, but only 9.900 kcal for a pure vegetarian diet.[39] This calculation is based on the rather conservative assumption that the high animal protein diet includes 100 g of animal protein per day. There is, however, a large number of people who consume a substantially higher amount of animal protein per day. More recent estimates are even more pessimistic: they assume that producing animal food requires up to fourteen times more input of fossil energy than the production of vegetable food.

During the past few years food experts and environmental activists (not to speak about physicians and dietary advisers) have spoiled our appetite for meat and meat products. They widely published statistics and research reports which demonstrated that diets which are rich in animal protein and fats

- increase the probability of cholesterol-related diseases (ischemic heart diseases, stroke),
- trigger environmental destruction (cattle ranging in tropical forests, groundwater pollution due to excessive amounts of manure),
- change the pattern of agricultural production from food to feed crops, and thus
- plunder the world (food) resources at the cost of the hungry in the Third World.

In addition to the high energy and land waste in livestock production there are obviously a number of good reasons to decrease the consumption of animal protein. Why is it then that in most parts of the world (with the exception of Africa) the consumption of meat and meat products is *increasing?* This can only be understood if one considers the cultural dimension of animal food.

Many people in Northern America and Europe are accustomed to protein-rich diets of (red) meat and other animal products, such as sausages, milk, cheese, or animal fats. These diets

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[39] Pimentel, 1984, *op. cit.,* pp. 1-24.

are so typical that they often contribute to a people's definition of cultural identity. American "T-bone steaks", German "Würste", or French "cheese" are more than just categories of food. To a certain extent they represent a way of life. A large majority of Americans would hardly celebrate the 4th of July other than with a barbecue of pork-chops or spare ribs. And an American "Thanksgiving" would certainly not be the same without a turkey. It would also be difficult to find someone ordering "fish" and mineral water in a Bavarian village pub, instead of a solid joint of pork ("Schweinebraten") and a beer. French cheese is a matter of national pride and political relevance.[40]

This link between culture and (animal-based) food is not only typical for Europe and Northern America. There are several Third World countries where diets rich in animal protein are quite popular. The Balinese national food, for instance, is roasted "suckling pig"; the Chinese like "marinated duck" and numerous dishes made of pig meat and pig offals; in the Islamic world sheep meat is eaten not only at religious ceremonies. Even in India, which is usually considered the most typical vegetarian country, some seven percent of the total food calorie supply came from animal products (mostly milk) in 1989. In Somalia, which has a large population of nomadic cattle rangers, more than 30 percent of the total calorie supply was from animal products. Some twenty years ago, the diets of the Somalians consisted of even more animal protein: 42 percent of the food energy came from animal products, mainly milk. High animal protein diets are also typical for the following countries: Uruguay, Libya, Argentina, Kuwait, and the Republic of Korea. As Third World countries develop, a growing section of their population will be able to afford meat and other animal products more often. This will most likely increase the worldwide shift to animal-based food. China, for instance, has already increased its meat production between 1961 and 1988 from 3 kg per caput per year to 23 kg per caput per year.

5.4. Low-Calorie Food

The cultural dimension of food is not restricted to the traditional preference of certain (animal food) diets, the worldwide success of fast food restaurants, the widespread consumption of "exotic" food, or the year-round consumption of seasonal fruits and vegetables. Alternative lifestyles within the developed countries have emerged during the last decades that are linked to certain nutritional styles.[41] A recent trend is the fitness movement, symbolized by skinny joggers and slim aerobic dancers. Trimming weight is their credo, and "low-calory food" the means to achieve it.

From the perspective of fossil energy conservation, "low-calorie food" is a disaster. By using artificial sweeteners ("Nutrasweet"), water-oil emulations and some other "tricks" of modern food technology to reduce the natural calorie content of a given food product, the industry has managed to "create" special types of food for those who are eager to save calories. Very often these products combine extremely low calorie content with the most extensive, energy wasting packaging. A case in point are "low-calorie" soft drinks, such as "Coca Cola Light". The food "energy" delivered in the drink is a tiny fraction of the energy that is needed to produce it, blow the bottle, fill it, carry it to the food store, bring it home, and open it. There is a whole range of products in our supermarkets, from margarine and cheese ("Du Darfst") to sausages and

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[40] The French Ministry of Education has set up a course in primary schools where small children learn to savor the taste of French cheese (and that of other original French food, such as red wine or baguettes) in order to prevent them from falling prey to the global "junk-food" of hamburgers, french-fries and coca cola. The "taste training", as they call it, is reported to be very popular.

[41] Galtung, J. 1976. Alternative lifestyles in rich countries. *Development Dialogue* 1:83-96.

chocolates, where special food preparation technologies (with significant energy consumption) are used to *decrease* the energy content of the product. Instead of simply eating *less*, people in the developed world tend to eat *more* calorie-*reduced* food.

5.5. "Luxury Food"

A most interesting example of energy use in the food sector can be found in the marketing and consumption of "high prestige" food. A typical case is mineral water. This product is no longer a simple bottle of water with more or less mineral content. It has become a brand-name product, which is often carefully selected by consumers who expect to find their special type wherever they travel. Only recently an Austrian producer ("Vöslauer") proudly announced that he is shipping his water all over the world - from Canberra to New York. In its physiological effect the Austrian mineral water is probably not much different to similar water bottled in the United States or Australia. It is obvious that the enormous amount of energy used for shipping water around the world has nothing to do with its primary function of quenching thirst. It satisfies the desire for a certain lifestyle. Many types of "luxury" foods, from Russian "caviar" to Canadian salmon, that are distributed worldwide to first class hotels, restaurants, and food stores are using up unusually high amounts of fossil energy.

5.6. Is it Possible to Calculate the Energy Costs of (Dietary) Lifestyles?

The energy use in "low calorie food products" and in certain kinds of "luxury foods" indicates the need for a reorientation in energy analyses. The conventional approach of calculating energy output-input ratios for certain products is no longer appropriate. If the food energy content of a product is negligible in comparison to its fossil energy consumption in transport, packaging, and preparation, the widely calculated output-input ratios loose their meaning.

But this is not the only difficulty. While it is certainly necessary to consider all possible sinks of fossil energy in a food chain (and not only in the production of the primary product) in order to calculate the "real" energy consumption of a diet, we can easily find ourselves on rather uncertain ground. Should we, for instance, also include the fossil energy that is needed in advertising food? Should we include the energy consumption of hospitals for treating food-related diseases?[42] The consumption of "Vichy" mineral water imported from France and of locally produced wine might use up a similar amount of fossil energy (used in producing, bottling and transporting the product). But the health consequences of these "diets" could easily shift the overall energy balance to the side of the more "healthy" product by avoiding the energy costs of alcoholism.

This is not the place to further explore these questions. They should only create awareness for the fact that nutrition is a rather complex social, cultural, and economic phenomenon. Probably it will never be possible to find a general measure of energy efficiency in the food sector, since its definition severely depends on the scope and perspective of the research design. One thing, however, is certain: understanding the patterns of energy consumption in food chains would be much easier if fossil energy prices would better reflect the true costs of energy use.

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[42] Physicians and dietary specialists often argue that in the highly developed countries of Northern America and Europe more people are killing themselves with "fork and spoon" than by any other means.

6. CONCLUSION

This paper argues that the energy efficiency of food must be analyzed for whole **food chains** - including production, harvesting, slaughtering, processing, storage, transportation and preparation in the household. Its major results follow.

6.1. The Shifting Balance of Energy Use in Food Chains

The supply of food is one of the most energy consuming tasks in a society. Even in highly industrialized countries more fossil energy is spent in the food sector than in industry. Usually some 30% of the overall fossil energy consumption is used just for feeding the population. This, however, includes *everything* - from the production of fertilizers and agricultural machinery to the fueling of irrigation pumps and drainage systems; from energy use in cultivation and harvesting, to energy consumption in processing, storage, transportation, and preparation of food. Obviously, the 30% figure is a very rough estimate. It is extremely difficult - if not impossible - to take into account the energy consumption in each and every link of our widely expanded food chains. In rural parts of the Third World the proportion of fossil energy used in the food sector might well be close to 100 percent; in highly industrialized countries this proportion is probably less than 30%.

Only a small - and declining - proportion of the total fossil energy consumption in the food sector is spent for food *production* - most of it (some 90%) goes to the processing, storage, conservation, transport and preparation of food. Contrary to conventional wisdom it is not the high-tech farmers who are responsible for the enormous energy consumption in the food sector. It is the food industries, food traders, restaurants and households which spend most of the fossil energy in the food system. This is the reason, why lifestyles are much more important for studying energetic efficiency in food chains than the frequently analyzed input-output rates in agricultural production.

6.2. Agricultural Productivity

While only some 10% of the overall energy consumption in the food system is spent in food production, fossil energy is still very important for boosting agricultural productivity. It is the transformation of *fossil* energy into plant nutrients (fertilizers), weed killers (herbicides), and products for plant protection and pest control (pesticides, fungicides) that made it possible to increase "natural" soil productivity by a factor of 10 to 100 during the past 40 years. These technologies of agrochemistry became firmly established throughout the world's farming systems, including those of poor countries like China, Indonesia or India. To put it bluntly: during the past four decades we have transformed *fossil* energy into food to sustain a doubling world population. For this enormous productivity gain in food production it was necessary to spend roughly one percent (!) of the global fossil energy consumption for fertilizer production. It is hard to find a better investment for this fossil resource.

6.3. Diets and Lifestyles

The distinction between food production and non-agricultural elements in our food chains is essential to understand the true energetic efficiency of certain diets. For instance: while the energy efficiency of (red) meat *production* might be rather low as compared to the production of cereals, vegetables or fruits, its processing, packaging, and transport may not. A large proportion of (red) meat in Europe is produced and marketed locally; for fresh meat there is virtually no packaging, since it is usually cut and sold across the counter from one large piece.

It is easy to find popular vegetable food that uses up much more fossil energy than meat, such as Kiwi fruits harvested in New Zealand, flown to Europe, processed into a soft drink, filled into a glass bottle and distributed by lorry to thousands of local supermarkets.

"Health food" and *"low-calorie food"* - which are often considered modern alternatives to the "traditional" protein-rich diets of (red) meat, butter, milk and eggs - are often quite energy consuming. A diet of vitamin-rich, low-cholesterol food with a high proportion of fish, (exotic) vegetables and fruits might be among the most energy consuming nutritional lifestyles - especially if it includes industrially processed "low-calorie" soft drinks, yoghurts, mineral waters, etc. There is no doubt that the biggest waste of fossil energy in the food sector is linked to *"luxury food"* which is often transported halfway around the globe and requires a lot of energy for preparation and serving.

From the perspective of overall energy consumption it is only *locally* grown and *fresh* marketed cereals, vegetables and fruits that would be a true alternative to the energy-wasting diet of (red) meat, glasshouse produced vegetables, tropical fruits and heavily-packaged "fast food". However, many people in the developed world might find it rather difficult to return to a diet consisting of bread, porridge, millet gruel, vegetables of the season and a few local fruits.

APPENDIX: Selected Data on Energy Consumption in Human Food Chains

Table A1. Total commercial energy and commercial energy used in agriculture.

Region	Commercial Energy used in Agriculture		Per Caput Energy Consumption		Energy per Agricult. Worker	
	1972 % of total	1982 % of total	1972 kgoe	1982 kgoe	1972 kgoe	1982 kgoe
North America	3.9	4.0	7,609	6,492	18,929	25,744
Western Europe	5.4	6.8	2,654	2,682	2,453	4,387
Africa	5.0	5.4	117	125	20	26
Far East	6.5	14.1	131	113	33	72
Asian Centrally Planned Econ.	4.3	7.2	295	400	40	109
Latin America	3.8	3.8	628	785	194	286
World	4.2	5.0	1,260	1,248	252	344

Source: Stout, B.A. (1990): Handbook of energy for world agriculture. London, New York (Elsevier) p. 52

kgoe: Kg oil equivalent

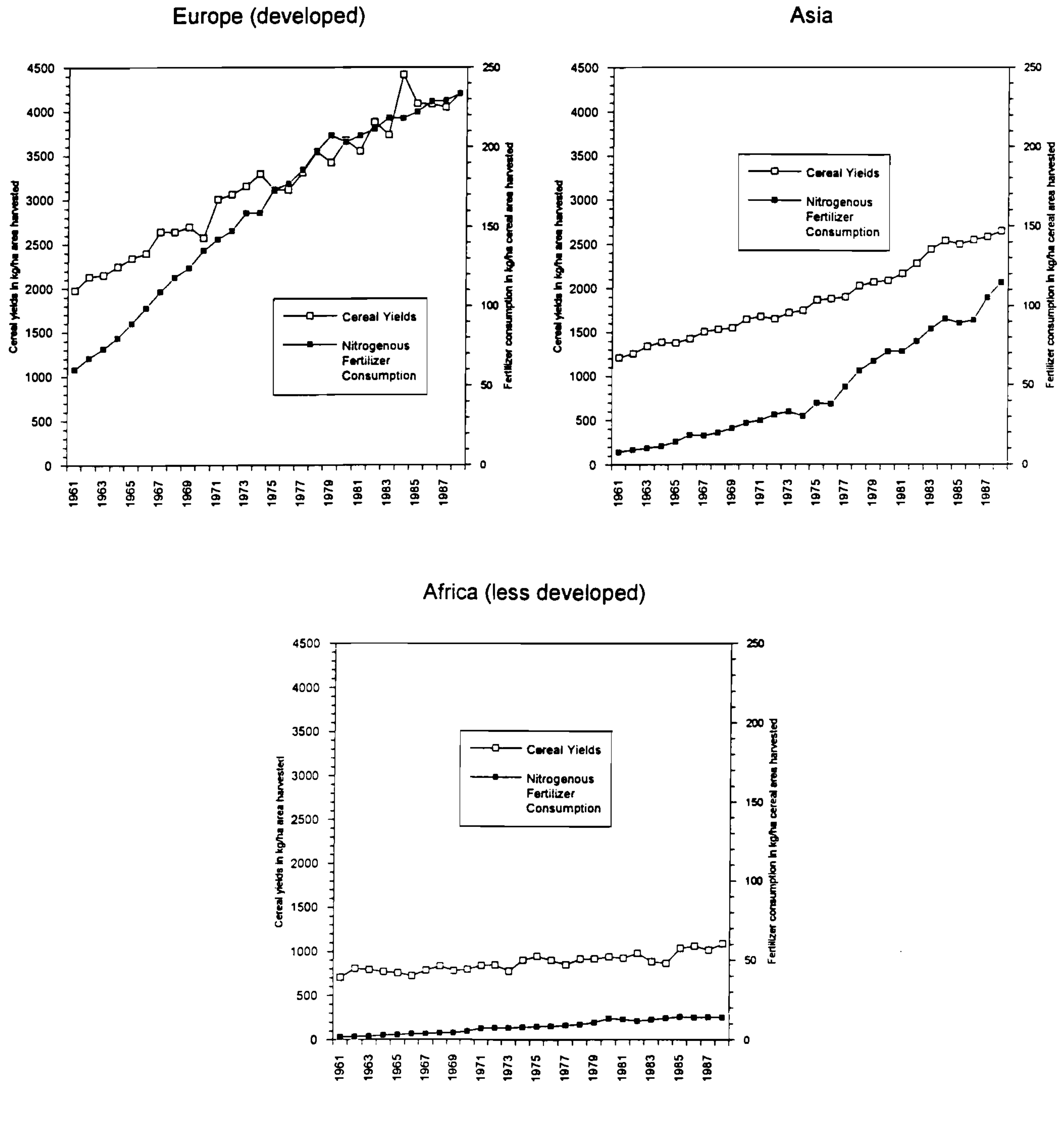

Figure A1. Cereal yield and nitrogenous fertilizer consumption in Europe, Asia and less-developed Africa.