P. Brimblecombe C. Pfister (Eds.)

The Silent COUNTDOWN

Essays in European Environmental History

With 37 Figures

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Dr. PETER BRIMBLECOMBE
School of Environmental Sciences
University of East Anglia
Norwich NR4 7TJ, United Kingdom

Prof. Dr. CHRISTIAN PFISTER
Historisches Institut
der Universität Bern
Engehaldenstrasse 4
3012 Bern, Switzerland

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The Early Loss of Ecological Stability in an Agrarian Region

C. Pfister[1]

1 "Solar" Agriculture: A Source of Economic Growth

The environment of a society is both natural and social; exchange of energy, materials, and information takes place within the sociosphere which is made up of other societies and their infrastructure, and also through processes of production and reproduction within the biosphere and its various ecologies which are all submitted to natural laws of evolution. In its broadest sense, human ecology provides the conceptual framework for the most realistic description of the complex links between people and nature. Ecology and ecosystems stress connectivity and mutual causality among the natural and human components. This approach emphasizes the two-way character of causality, although the relative influence in reciprocally causal relationships is never equal and may be very unequal (Kaplan and Manners 1972, quoted in Ellen 1982). One of the most important and elemental is the flow of energy. A web of energy and material relations allows the ecosystems approach to draw together the natural and human processes. This focus on common components in an interconnected system provides an important means of specifying how nature and society are in fact interrelated (Sack 1990).

Anthropologists have associated cultural development and economic growth with the control of progressively greater amounts of energy (White 1949; Cottrell 1970; Moran 1979). According to Ervin Laszlo (1987), a natural scientist, society has moved along an evolutionary axis, sparked by technology, toward the exploitation of increasingly dense and abundant energies. The economic dimension of ecological energetics has been discussed from the early 19th century (Martinez-Alier 1987) but until the work of Georgescu-Roegen (1971) it had not been couched into a coherent theory.

Debeir et al. (1987) have coined the term of *energy system*. An energy system includes not only the sources and the converters of energy and their efficiency, but also the social structures in which the converters are created and maintained and in which the energy is appropriated. Thus it is more than just an ensemble of producers, transformers, conductors, and reservoirs for calories or joules. In order to understand how it works, its social, technological, political, economic, and cognitive dimensions have to be taken into account.

[1]Historisches Institut der Universität Bern, Engehaldenstrasse 4, 3012 Bern, Switzerland

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Schnaiberg (1980) who discusses human and other biological systems in terms of energy, notices that one important area wherein human systems diverge from other biological systems is in the "creation and disposition of surplus energy". Whereas the ecosystem reaches a steady-state by permitting the growth of just enough species and populations to offset the surplus, societies, particularly industrial societies, tend to use the surplus to accumulate still more economic surplus in the future. The question then to be answered by environmental history is: when, where and why has this quest for accumulation begun?

In human history there have been three basic types of energy systems: (1) the unmodified solar system of hunter-gatherers; (2) the modified solar system of agricultural societies and (3) the fossil energy system of industrial societies (Sieferle, this Vol.). Up to the present, ecological analysis has focussed upon the transitional period between those systems and the period of precipitous environmental transformation in the last three decades, where major shifts in human relations with nonhuman nature are known to have occurred. (Sieferle, Deléage, this Vol.). Less attention has been paid to the energetic dimension of the modifications which are known to have occurred *within the solar energy system*, e.g., the invention of the harness and the water- mill, and the introduction of new crops and rotations in order to raise agricultural output (Sieferle 1982; Debeir et al. 1987). This latter innovation was at the origin of a fundamental shift in carrying capacity, the magnitude of which may be compared to the Neolithic Revolution.

Following a period of prolonged stagnation, the population of Europe grew by 90% between 1750 and 1850 (Köllmann 1965), i.e., over a period in which grain or guano could still not be imported in substantial quantities from overseas. The challenge of increasing agricultural production to feed 120 million additional people and of releasing much income and labour for secondary and tertiary industries was successfully met by an agriculture still lacking significant industrial inputs (Grigg 1980). The "new" agriculture came into practice in 17th-century Flanders and was then transferred to England. By the mid-18th century, it had already raised agricultural productivity quite considerably in this country (Slicher van Bath 1963; Jones and Woolf 1969). Continental Europe was somewhat slower to follow. In Denmark (Osterud 1978), in Hannover (Ulbricht 1980) and in some other regions of Germany (Abel 1978), and in Switzerland (Pfister 1984) the take-off dates from the late 18th century, in France from the early 19th century (Désert and Specklin 1976). Jones (1974, p. 128) suggests that "developments on the production side of agriculture were instrumental in bringing the earliest advanced countries to the brink of industrialisation". Bairoch (1976) mentions the growth of population and purchasing power, the demand for steel for agricultural implements, and the investment of "agricultural" capital into industry, which all were connected to the "agricultural revolution" as being the decisive factors for the success of the industrial revolution.

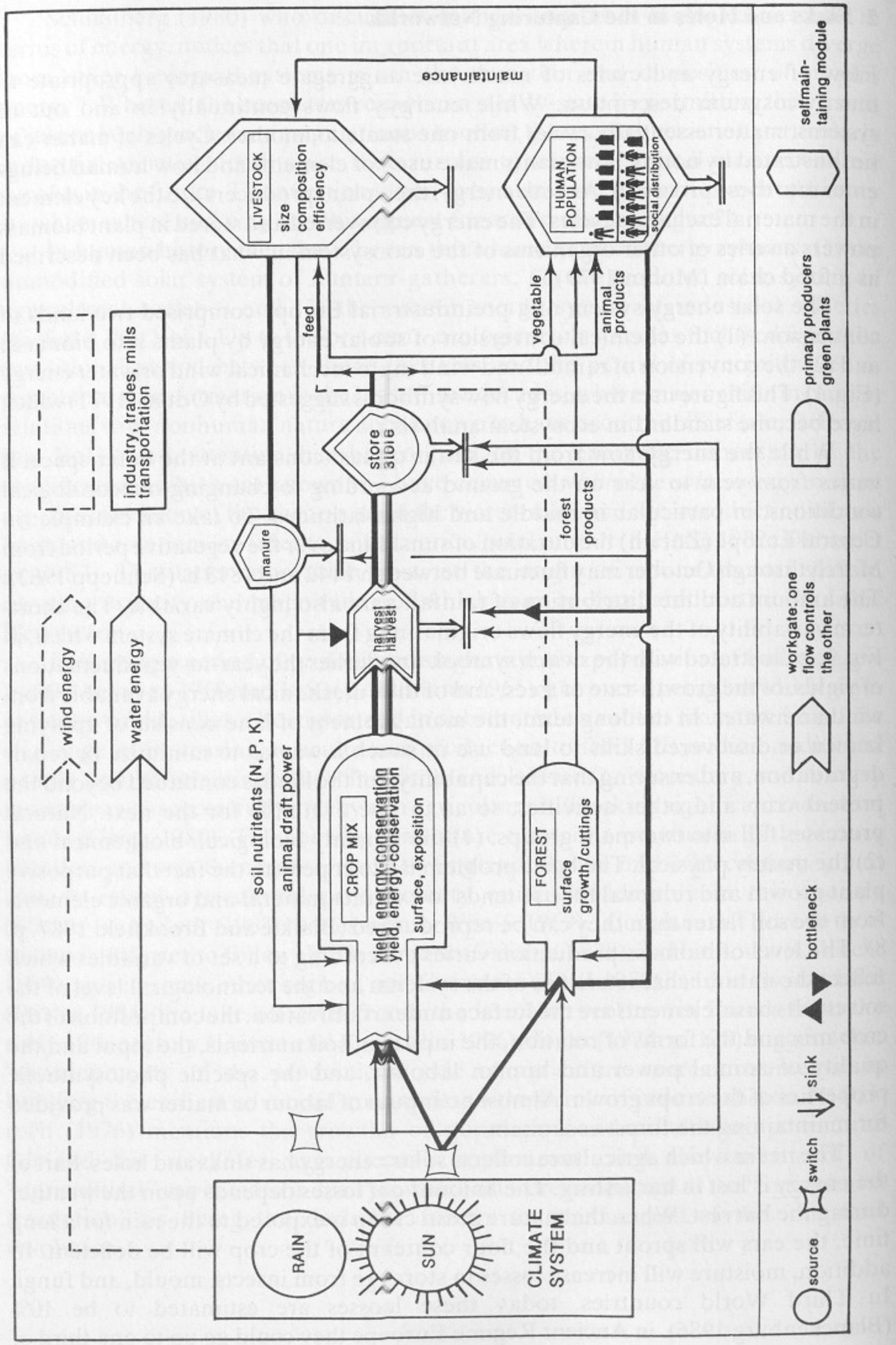
2 Sinks and Holes in the Capturing Network

Flow of energy and cycles of matter are aggregate measures appropriate to macroecosystem description. While energy flows continually in and out of systems, matter essentially cycles from one state to another. Cycles of matter can be illustrated by noting how plants make use of elements and how human beings enter into these processes. As with energy, the plant producers are the key element in the material exchange cycles. The energy converted and stored in plant biomass powers a series of other organisms of the ecosystem in what has been described as a food chain (Moran 1979).

The solar energy system of a preindustrial Europe comprised two kinds of conversion: (1) the chemical conversion of solar energy by plants into biomass; and (2) the conversion of rainfall and wind into mechanical wind or water energy (Fig. 1). This figure uses the energy flow symbols suggested by Odum (1971) which have become standard in ecosystem analysis.

While the energy flow from the sun is quasi-constant at the outer space, it varies from year to year on the ground according to changing meteorological conditions, in particular in middle and high latitudes. To take an example: in Central Europe (Zürich) the duration of sunshine over the vegetative period from March through October may fluctuate between 1142 and 1813 h. (Schüepp 1962). The amount and the distribution of rainfall are also highly variable. The short-term variability of the energy flows originating from the climate system which, in Fig. 1, is illustrated with the switch symbol, underlies the year-to-year fluctuations of yields, of the growth-rate of trees, and of the mechanical energy available from wind and water. In the long term, the management of land consists of applying known or discovered skills to land use in such a way as to minimize or repair degradation, and ensuring that the capability of the land is continued beyond the present crop and other activities, so as to be available for the next. Natural processes fall into two main groups, (1) the mainly biological/biochemical and (2) the mainly physical. The basic problem is to cope with the fact that purposive plant growth and removal for use tends to extract mineral and organic elements from the soil faster than they can be reproduced (Blaikie and Brookfield 1987, p. 8). The level of biomass production varies according to a set of variables which reflect the natural characteristics of the system and the technological level of the society. Its basic elements are the surface under cultivation, the composition of the crop mix and the forms of rotation, the input of soil nutrients, the input and the quality of animal power and human labour, and the specific photosynthetic properties of the crops grown. Almost no input of labour or matter was provided for maintaining the forest ecosystem.

The net in which agriculture collects solar energy has sinks and holes. Part of the energy is lost in harvesting. The amount of losses depends upon the weather during the harvest. When the mature grain crop is exposed to the rain for a long time, the ears will sprout and the flour content of the crop will be deficient. In addition, moisture will increase losses in storage from insects, mould, and fungi. In Third World countries, today these losses are estimated to be 10% (Blanckenburg 1986), in Ancient Régime Europe they could go up to one-third of



the harvest, when the harvest was not properly dried in the field. The amount of energy which is contained in the hay crop also depends primarily on the meteorological conditions. Hay which is repeatedly washed out by the rain loses up to 70% of its energy content. Prior to the early 19th century, when the productivity of the cows was still very poor, variations of energy in the feed had a profound impact upon milk yields (see Fig. 4; Pfister 1984). In order to minimize energy losses, agrarian societies had to use their working capacity and animal draft power to the fullest during the harvest peak. Often the number of hands decided whether the crop was sheltered in dry condition, or whether it got drenched.

Manpower and draft animal power, which were abundant during the slack season, were short during the harvest peak. In Fig. 1 this shortage is represented with a "bottleneck" symbol (created for this paper). Unequal access to basic resources is a fundamental property of human societies. Because it is often overlooked in the traditional ecological "per capita" approach to carrying capacity, adequate symbols have been inserted in the module which represents human population in Fig. 1. As for livestock, its composition, its size, and its yield are the important parameters which all mirror the quality and quantity of feed. In modeling ecosystemic relationships, the biomass which is put in for animal feed must match the known properties and yield of the livestock. The manure is a very valuable part of the produce, because it contains the essential soil nutrients (nitrogen, phosphorous, and potash) which could not otherwise be obtained in an agriculture lacking manufactured inputs. The amount of nutrients actually recycled depends on how much of the manure is actually collected, how long it is stored, and how it is managed. Poor recycling technologies were a basic cause for the inherent low productivity of "traditional agriculture".

Sieferle and Deléage (this Vol.) have argued that a "solar" economy is bound to a stationary state of production, consumption, and population, because the energy input of the sun is limited. This may be true for an agrosystem such as that of the Chinese, in which an appropriate crop mix, a high input of labour, and adequate recycling strategies have pushed the use of land, material, and manpower near the theoretical limit of carrying capacity. Most of the agrosystems in

Fig. 1. A model of the flows of energy and materials in solar energy agrosystems of Central Europe. The *sun* is the unique source of energy which powers the system. In temperate latitudes the energy input (radiation, water power) at the ground is variable according to weather conditions (*switch*). The energy content of the biomass collected and the soil nutrients are leaking out the agrosystem to some extent (*sink*). Losses in biomass are primarily caused by wetness patterns during the harvest period. Their magnitude depends partly from the animal draft power and the working capacity available (*bottleneck*). The product itself is unevenly distributed within the society. This is essential in considering carrying capacity.

During the 'agricultural revolution' the input of soil nutrients was increased by growing leguminous fodder crops (which obtain nitrogen from the air) and by improved recycling technologies (stall-feeding of cattle in summer and collecting liquid manure). As a consequence more biomass was harvested. Population and livestock expanded in a self-reinforcing process (*double lines*), whereas forest output remained constant

Ancient Regime Europe, however, were far from this limit. They had a wide margin within which the efficiency of the systems could be improved. The duplicate symbols in Fig. 1 express the fact that over the period under investigation, biomass production was manipulated through deliberate interventions in the material cycles and energy flows. The application and expansion of new technologies is contained within the institutional framework of a society. Institutions may be entitled to block, regulate, or unleash the introduction of technological innovations. These actions or non-actions are justified with reference to the set of values and norms which underlie the coherence of a society. In Ancient Regime Europe, institutions were more attuned at preserving the static flow of resources in favor of a closed group than at promoting economic growth. In most cases, new technologies involved modifications in the control of land and resources which interfered with the interest of the ruling classes.

Because the output of the systems was stagnating in the long run and variable in the short run, every agrarian society had to cope with three basic problems:

1. It had to find ways for adapting its numbers to the carrying capacity of the energy system, i.e., to prevent population from increasing to an extent that would have endangered the cohesion and the survival of society.
2. It had to preserve the energy converting property of the system from degrading, providing for certain inputs of human and animal work in order to get and harvest the biomass needed for food, heating, and cooking, and to maintain the installations which were transforming water-power into mechanical energy.
3. It had to protect its members from the effects of short-term climatic fluctuations by accumulating stocks of grain or large herds to provide food which could be consumed in periods of climatic hardship.

3 A Testing Ground for Ecological History

The quantitative analysis of energy flows within an agrosystem requires dependable data on agricultural energetics. The various flows of energy and cycles of matter must be identified and quantified, in order to get reliable estimates for the chemical transformation of solar energy into biomass and its gradual diffusion and loss through a food web (Moran 1979; Fluck and Baird 1980). This involves measuring a number of key variables such as land use, agricultural and forest production, water-power, losses through harvesting and in storage, livestock size and composition, and population size (Fig. 1).

Most of the variables needed to investigate agricultural energetics have been set up in the administrative context of the Swiss Canton of Bern. Before it became a member of the new Swiss Confederation in 1848, Bern was an independent republic of 6000 km² with a population of 400 000 (1850). Its territory roughly makes up one-seventh of the population and the surface of Switzerland. The canton is not an ecotope in the sense of a holistic land unit (Naveh and Lieberman 1984). It comprises "ecozones" at altitudes between 350 m and the line of permanent snow, such as a vine belt and a grain belt in the lowlands, a zone of mixed farming in the hills, and a dairy belt in the Alps (Pfister 1989). This diversity makes the canton an ideal ground for testing the complex interactions between population and its natural habitat. Moreover, it was basically self-sufficient, although items such as cloth, wine, coffee, and sugar were imported in exchange for cattle, timber, and cheese. In years of below-average harvests, grain was also imported. But it has been shown from the example of 1847 that shortage and hunger must be attributed to unequal distribution of the resources which were still sufficient to cover the demand of the population on a per capita basis (Pfister 1990).

This evidence for analyzing energy flows is being collected, verified, interpreted, and stored in a large data-bank called BERNHIST (Pfister and Schüle 1989). At present, only labour inputs have not yet been quantified. The ecosystem concept serves mainly as a didactic device to emphasize the interaction between living and nonliving components of a system, such as is has originally be used by Odum (1953). Boundaries are drawn according to the data available for the analysis.

For a long time, ecosystem research and modelling efforts have ignored historical change, with the exception of the chemist Martin Frissel (1977) who has compared the nutrient balance for dutch farms in 1800 and 1972. The present paper tries to shed more light on the transformations which have been brought upon by purposeful human interventions in the cycles of material from the period around 1760 –1890, i.e., during the final phase of the solar economy and the beginning of the transitional period from the solar to the fossil energy system.

For the first period from 1760–1885 evidence is available for the county of Büren (Stampfli and Frey 1987). This county of 88 km² is part of the so-called Kornland, where grain was the dominant crop within the three-field system. For the 1880's an energy balance is set up for the entire canton.

4 Dynamic Stability: The County of Büren Before 1760

Land use and productivity around 1760 are represented in the left part of Fig. 2. Net grain yields (seeds deduced) were only 850 kg/ha, estimated milk yields were some 1000 liters per cow and 250 liters per goat. A comprehensive starting point for analyzing the flows of energy and the circulation of matter is the question of limiting factors. Land was in excess – 35% of the area was only marginally used. A part of it, the commons, belonged to the community; approximately one-third of the arable land was laid fallow within the three-year rotation. Insufficient manuring is the reason which is most frequently given in the sources for the low productivity. This suggests a shortage of biologically available nitrogen which determines the production of nearly all food and the growing of plants used for other products in the vast majority of agricultural systems (Bolin and Arrhenius 1977; Postgate 1980). Manure was in short supply because the number of cattle was too low compared to the surface cultivated in grain. This was explained by a shortage of hay, which was a consequence of the small acreage of meadows in

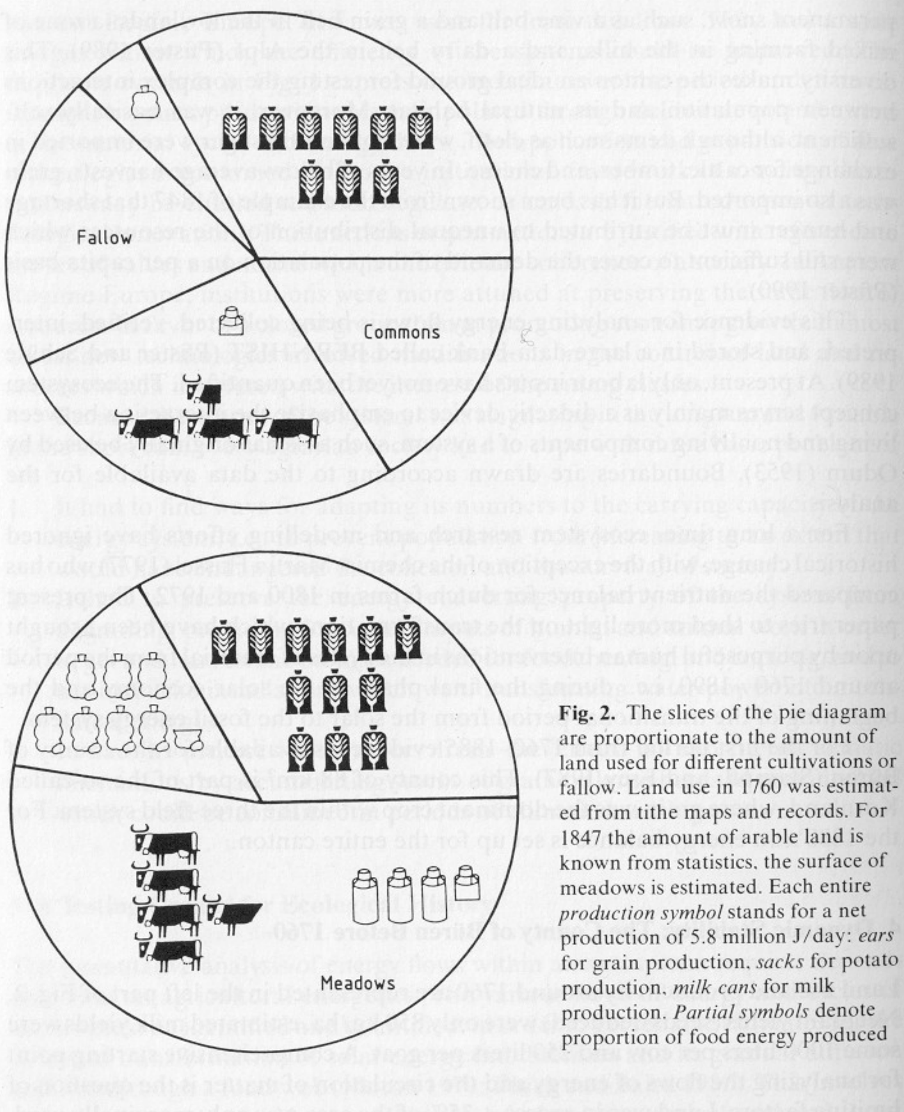


Fig. 2. The slices of the pie diagram are proportionate to the amount of land used for different cultivation or fallow. Land use in 1760 was estimated from tithe maps and records. For 1847 the amount of arable land is known from statistics, the surface of meadows is estimated. Each entire *production symbol* stands for a net production of 5.8 million J/day: *ears* for grain production, *sacks* for potato production, *milk cans* for milk production. *Partial symbols* denote proportion of food energy produced

proportion to the acreage of arable fields. This blockage has to be interpreted in the context of a political system which was tuned to maintain the status quo. Arable land could not be converted into meadows without the triple consent of the central authorities, the owners of the tithe, and the village community, who affected a loss in temporary pasture.

Moreover it has been estimated that only one-fifth of the dung and urine produced by the livestock was actually recycled to the fields (Table 1). In making this estimate, animals of different size had to be aggregated to cattle-units and the lower body weight of animals in the 18th century had to be taken into account in

Table 1. Land use, nitrogen inputs and food production in Büren country (88 km²)[a]

	1764		1847		1885	
	Land use	N-input	Land use	N-input	Land use	N-input
Cultivated surface	2750 ha	—	4000 ha	49 kg/ha	4552 ha	108 kg/ha
Manured surface	750 ha	25 kg/ha	4000 ha	49 kg/ha	4552 ha	108 kg/ha
Population	3640		7544		8162	
Cattle Units	3130[b]		4080		4985	
N from dung	48 t[c]	14 t(28%)	75 t[d]	60 t(80%)	116 t	93 t(80%)
N from urine	48 t[c]	5 t(10%)	75 t[d]	60 t(80%)	116 t	93 t(80%)
N from legumes[f]	—		77 t[g]	77 t	308 t	308 t
N total	96 t	19 t	227 t	197 t	540 t	494 t
Total net food produced yr^{-1}	17×10^{12} J		48×10^{12} J		54×10^{12} J	
Per capita food produced d^{-1}	13×10^{6} J		17×10^{6} J		18×10^{6} J	

[a] Without the parish of Pieterlen.
[b] Back projection from the proportion of 86 cattle-units per 100 people computed from the cattle statistic of 1790 (3602 cattle units).
Estimated nitrogen production per cattle unit:
[c] 1760 31 kg = 66.6% of the 46.5 kg obtained from the statistic of 1876 for cattle units of 370 kg each (Müller and Grete 1885).
[d] 1847 37 kg (80% of the values for 1876).
[e] Losses according to Krämer (1902).
[f] N production: 300 kg/ha (Postgate 1980).
[g] Assumed surface 226 ha (25% of the 1025 ha known for 1885).
[h] Seeds deduced.
Data: Stampfli 1987: Pfister and Schüle 1989.

estimating manuring capacity. The estimates obtained from the figures in Müller and Grete (1885) are in agreement with those obtained by Huggel (1979). Though it is known that the content of the dung and the urine in nitrogen (N), phosphorus (P) and potash (K) depends upon the quality of the feed, it was assumed that the quality did not change prior to the late 19th century. This has the advantage of not underestimating the manuring potential of a cattle unit in the 18th century.

Nitrogen losses are difficult to evaluate. It is known that the urine, which contained 50% of the nitrogen, trickled through to the loamy floor of the stable into the groundwater. In summer it was sprinkled on the common pastures which, however, were very poorly managed. The major part of the biomass was trampled down by the grazing animals. The dung was only properly collected during the 5 months when the animals were fed in the stable. For the remaining time it was wasted across the common pastures and on the streets. To make things worse: the manure which had been collected during the winter months was not brought onto the fields before the following autumn. During the whole summer, it was exposed to the sun and to the rain. This involved losses of nitrogen which may be estimated from experiments carried out at the station of Hohenheim in the early 1880's. The nitrogen content of manure which was exposed to the weather had dropped by

57% within a year, while losses in a sheltered box were only 32% (Müller and Grete 1885). For the 18th century the estimated loss of 35% for the period from early March to late September may rather be below than above the real figure.

All the available manure was applied to the winter crop within the three-field system (Table 1). It was estimated from the model that the nitrogen input in the case of Büren county was only 28 kg per hectare. The summer crop, grown in a second year of the rotation, was not manured. Accordingly, yields were considerably lower. In the third year of the rotation, fields were left fallow. This may be interpreted as a strategy for avoiding the risk of loosing scarce seed grain, because net yields might often have been negative without any input of nitrogen for 2 consecutive years. This practice is not at all related to the restoration of soil fertility as it is still described in many textbooks. On the contrary, soil fertility was further degraded, because the fallow land was ploughed repeatedly in order to suppress the weeds. The exposure of fallow soils to wind and rain resulted in a depletion of soil nitrogen by erosion (Bolin and Arrhenius 1977; Vogt, this Vol.).

To summarize the argument: the recycling of organic matter was inadequate, as a consequence, crop density and biomass production were low. From the ecological point of view, we have to evaluate the long-term stability and viability of the system, its *carrying capacity*. Ellen (1982, p. 41) has defined this term as being the "maximum population that a particular environment can support indefinitely without leading to degradation". If the term "support" is understood to mean providing enough nutrition for production and reproduction as well as enough energy for cooking and heating, this yields a workable definition. Stampfli and Frey (1987) have shown that in Büren county the per capita daily output per hectare was adequate according to the standards of the 20th century, despite the low productivity. To which extent the county could still cover the demand for timber and fuelwood may not be drawn from the sources. But it might have been partly imported from the zone of the hills, where acute shortages had not yet developed. The population which had been more or less stable for many decades did not press upon the resources in any case. Given the low intensity of land-use, many local ecosystems were still quasi-natural, particularly the marshes and along river margins. A broad genetic diversity of fauna and flora is described in contemporary reports. Man and nature may still have been in that kind of dynamic long-term equilibrium for which Waddington (1975) has coined the term "homeorhesis" (Naveh and Lieberman 1984, p. 61).

5 A Successful Management of Cycles and Flows

Economic history explains the take-off of European agriculture in the early 19th century in terms of market incentives, which became effective through the additional demand for food of a growing population. It is connected to the triumph of liberalism and individualism which removed the institutional and intellectual barriers to economic growth.

Ecological history raises the question how this take-off is associated to changes in the material cycles and energy flows, what the consequences were for the environment, and how they affected the long-term stability of the ecosystem. The transformations will be demonstrated from the example of Büren County (lower part of Fig. 2 and Table 1) which is typical for Central Europe. They involved expanding the cultivated area at the expense of the fallow and the commons, changing the crop mix, and increasing the input of soil nutrients and yields. In Büren County, most of the additional land had been converted to meadows. Net food energy had almost tripled. This was a consequence of a triple output of milk, of a fourfold expansion of the area cultivated with potatoes, and an 42% increase in grain yields. The doubling of population density and the 40% increase of per capita food output in 1847, compared to 1760, was the direct result of the modified energy flow. The transformation must be couched in the context of major human interventions in the nitrogen cycle. The strategic innovations involved a more efficient recycling of soil nutrients, a biological way for tapping the large reservoir of nitrogen contained in the air, a more productive form of converting solar energy into biomass, and the combination of those sources in cascades, chains, and couplings.

Attempts were made to fully exploit the dung potential of the livestock. Covered basins were built below the stables in order to collect the liquid manure. It was carried to the meadows, at first by men in a wooden pail on the back, later on special horsedrawn containers. The method became known in the twenties and thirties of the 18th century and was at first applied only in the German-speaking part of Switzerland. Propagated by farmers, and subsequently by the first agricultural scientists, it spread to other countries (Hauser 1974). Progress in stable-manuring farming was accomplished by keeping the livestock indoors all year round. As a consequence, more manure could be recycled to the fields and it was carried out more frequently, at least twice a year in spring and in autumn, which may have reduced losses to one-fourth (Table 1).

Leguminous fodder plants such as clover obtain nitrogen from the air by biological fixation. They were sown into the fields and fallows from the mid-18th century. A rapid diffusion from the late 1830's is described in the annual reports which the chief administrative officers in the districts had to submit to the cantonal government. For 1847 the acreage is not known. It has been set to 25% of the acreage known from 1885, not to overestimate the importance of this crop. In 1885 the energy yield of legumes was almost 50% higher than that of ordinary meadows and 25% higher than that of grain and vegetables (Fig. 3). This is attributed to a higher rate of photosynthesis (Kleiber 1967, p. 278). In 1885, legumes had become the dominant source of nitrogen (Table 1).

Through higher input rates of nitrogen, processes of positive self-amplifying feedback were induced. The shortage of nitrogen is an important reason why potatoes had not been grown in larger quantities before the early 19th century, although they had been known for almost a century by that time. The potato has a high demand for nitrogen – it takes 35 kg to produce 100 kg of tubers (Finck 1979, p. 308). It was only when the manuring gap was closed that the high energetic productivity of this crop (Fig. 3) was fully used. Part of the potatoes were fed to the livestock. As more animal feed was produced, the size of the herds was expanded, the animals were better fed, they were bigger in size, and produced

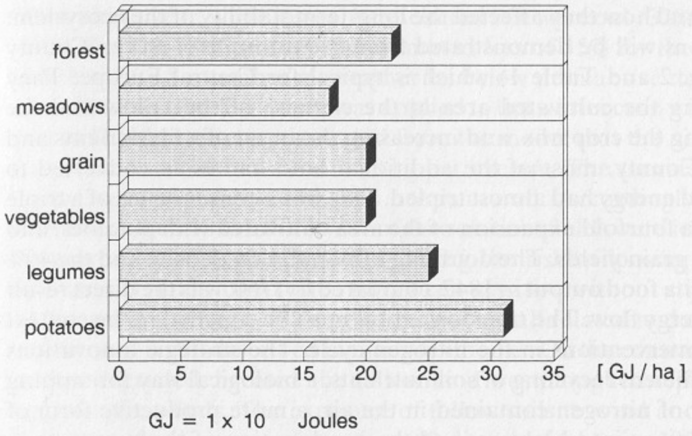


Fig. 3. Net yields of energy per hectare for different crops in the Canton of Bern in the 1880s. Land use and yield data have been obtained from agricultural statistics. For yield data a 5-year average was used. For grain and potatoes the amount required for seeds are deducted

more manure with a higher content in soil nutrients. Thus the production of animal feed and manure was mutually self-reinforcing. Compared to 1760, nitrogen inputs in the system may have been multiplied by ten in 1847 (Table 1). Given the weakness of some of the basic assumptions, this is a mere guestimate which nevertheless provides some rough idea on the magnitude of the transformations in the materials cycles which were involved in the growth process.

Milk production per animal increased out of proportion at the beginning of the take-off period, because the initial level of production had been very low. This is connected to the energetic properties of milk production. The maintainance of the metabolic rate of an animal requires a certain amount of nutrients which must be invested, before the first liter of milk may be obtained from it. The better the feed the higher the proportion of the nutrients which are converted into milk, therefore, the lower the energy input per liter. Within 100 years from the late 18th century the energy cost of milk was cut in half (Fig. 4). The relative abundance of milk had two consequences: (1) cheese manufacturing was introduced in most lowland communities in order to market excess production; and (2) nutrition became more rich in proteins, which may have improved resistance to disease and therefore promoted population growth and the capacity to work.

Population growth and the intensity of cropping were self-reinforcing in the first half of the 19th century. The cultivation of the fallow required a higher *input of work*. Labour-intensive crops such as potatoes were inserted in the rotation, greater amounts of manure were brought out, and a larger amount of biomass was harvested. Though population more than doubled from 1760–1847, most of the labour force was still engaged in agriculture or in trades connected to agricultural production in mid-century (Stampfli and Frey 1987).

When appropriate drainage technologies were available after 1850, the cultivated area was expanded at the expense of wilderness. Marginal land such as fallow, marshes, and hedges, which had been refuges for a broad variety of species,

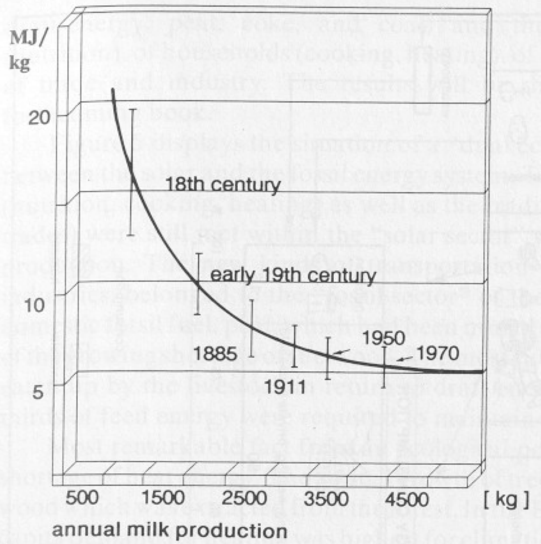


Fig. 4. The energetic efficiency of milk production. Input of net energy in 10^6 J as a function of the yearly average milk yield per cow. (Krämer 1888; Brugger 1979, 1985; Huggel 1979; Pfister 1984)

was diminished. The shift towards high-energy crops such as legumes and potatoes was intensified from 1847 to 1885. Given the imports of cheap grain by rail it paid to bear the high energetic losses which are involved in the production of meat and milk. Through the multiplying effect of herd size and legume production the rapid increase of nitrogen inputs into the agrosystem was maintained (Table 1).

Contemporary observers noted that the frequent application of liquid manure promoted the growth of grasses at the expense of Compositae and varieties of clover (Stebler and Schröter 1887). Though agriculture was still in its 'solar' phase, human interventions in the nitrogen cycle had already become important enough to change the floral composition of meadows. On the other hand, they were not yet sufficiently large to jeopardize human health, because the number of hogs or chicken, which a single farmer would support, were still related to the productive capacity of its farm. *Pollution agricole* only became an environmental hazard after the 1960's, when cheap imports of fodder and new technologies paved the way for large-scale industrial husbandry. In some areas in the Swiss Cantons of Lucerne and Bern, and in the South Oldenburg region, hogs and battery chicken have been so highly concentrated that the groundwater has become unfit for drinking from the seeping of nitrates (Thober et al. 1985). Nitrogen and phosphorus, which once had been limiting factors for agriculture, became a source of pollution.

6 Out of Balance: The Energy-System in the Canton of Bern in the 1880s

For the years 1885–89 the evidence contained in the BERNHIST data-bank allows setting up an energy balance for the entire canton. It includes the production of solar and fossil energy in different forms (biomass, water-power,

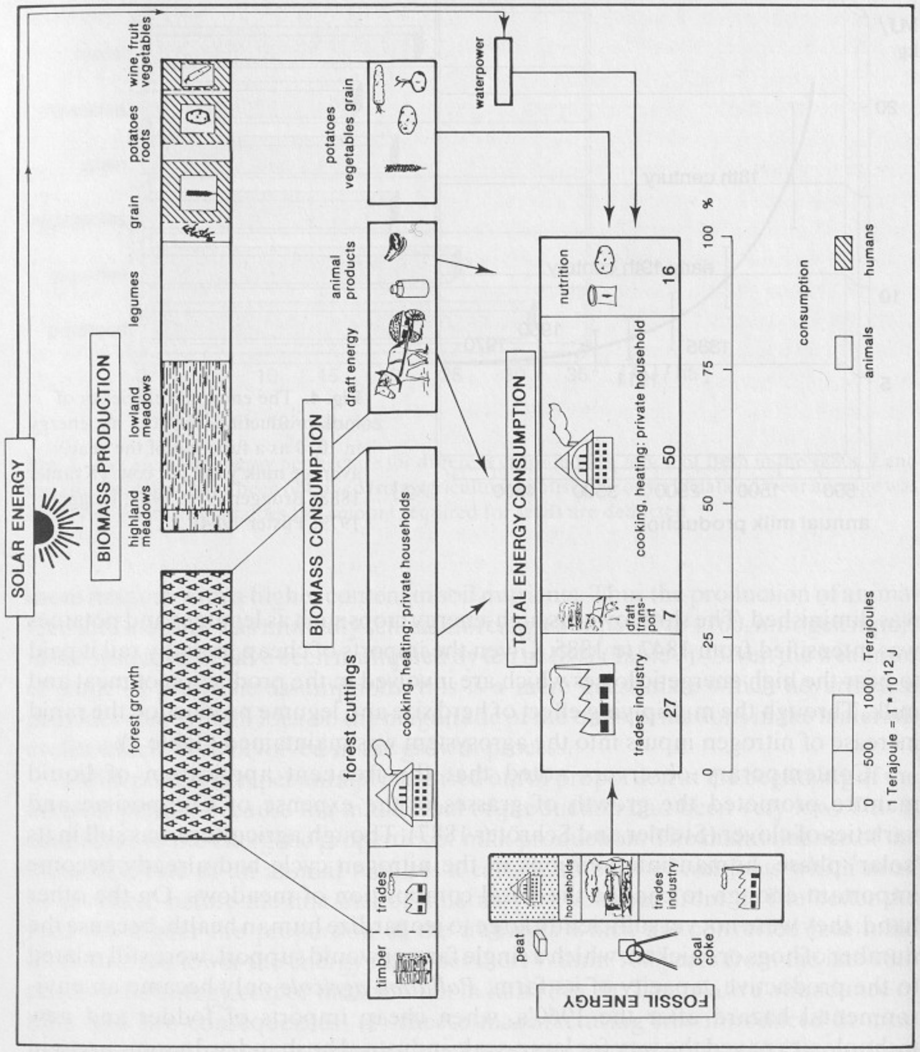


Fig. 5. The energy balance of the Canton of Bern around 1885. The data have been obtained from a variety of statistics taken in the 1880s. They were combined in a model (Pfister and Schüle, in preparation)

draft-energy, peat, coke, and coal) and the consumption of individuals (nutrition), of households (cooking, heating), of livestock, of transportation, and of trade and industry. The results will be discussed in greater detail in a forthcoming book.

Figure 5 displays the situation of a "dual ecology" in the transitional phase between the solar and the fossil energy system. The basic needs of the population (nutrition, cooking, heating) as well as the traditional occupations (agriculture, trades) were still met within the "solar sector" which comprised 72% of energy production. The new kinds of transportation and occupation, railroads and industries, belonged to the "fossil sector" of the economy. An exception is the domestic fossil fuel, peat, which had been mined from the 18th century as a result of the growing shortage of fuelwood. The most substantial part of the biomass was eaten up by the livestock in return to draft energy and animal products. Two-thirds of feed energy were required to maintain the metabolic rate of animals.

Most remarkable fact from an ecological point of view: there was an acute shortage of heat energy. The annual growth of trees hardly made up for half of the wood which was extracted from the forest. In the Bernese Oberland, where the per capita demand for heating was highest for climatic reasons, and where many trees were crippled by the teeth of goats, the annual growth of trees covered only 38% of the yearly consumption. It has been demonstrated from the example of Büren county how this energy crisis came into being. The agrosystems in the lowlands had been successfully attuned to feed the growing population, which in return provided the work energy for the more intensive cultivation. In contrast to earlier periods of demographic expansion, the take-off of the 19th century did not involve the clearing of forests. When enough feed became available from fields and meadows, forests in the lowlands were no longer used for pasture, which may even have improved their condition, although it took a long time before a sharp boundary between fields and forests came into being (Radkau and Schäfer 1987). However, the size and the yield of forests did not change significantly over the period. On the other hand, it may be inferred from the figures for 1889 that the demand for heat energy since the 18th century may have risen twice as fast than the demand for food as a result of population growth. In 1889, the annual consumption of fuelwood for cooking, heating, trades, and industry was 1.5 m^3 (10 GJ) per person, while the overall consumption of food energy was 4 GJ. Of course it must be considered that consumption per person may have somewhat declined in 1885, because in this year average household size was 0.5 persons larger than in 1760 and, according to Radkau and Schäfer (1987), new technologies for a more economical use of cooking and energy had been developed. But even assuming a consumption of 12 GJ per person in 1760, and taking the forest area and the yield of 1889, the annual growth of trees may have been adequate to meet the demand for firewood around 1760, when population size was 200 000, though local shortages had already developed. *The success of the measures which aimed at improving the carrying capacity of the agrosystems in the short term must therefore be considered to be the very reason why the ecosystem became unstable in the long term.* In order to maintain ecological stability, the areas under cultivation should have been reduced in favor of the area under forest when population began to grow. The threshold beyond which population density exceeded the carrying capacity of the forest may have been crossed around the end of the 18th century. The ongoing over-exploitation of the forests made the ecosystems more vulnerable for the impact of climatic extremes: soil erosion, landslides, and floods became more frequent during the 19th century (Der Hohe Schweizerische Bundesrath 1862). A similar dichotomy between food resources and fuel resources has developed in many parts of the Third World over the last few decades as a consequence of population explosion. China, for example, has become able to feed its population. However, the productive forest which was reduced by a third between 1949 and 1979 no longer meets the demand of the rural population for fuelwood (Aubert 1985). Today, nearly 60% of the wood removed from the world's forests is used to generate energy, overwhelmingly for cooking and keeping warm in the countries of the developing world. On the average, 0.45 m^3 of wood (2.9 GJ) is consumed per person, and up to 80% of their total energy requirements are supplied by wood (Williams 1990).

7 Concluding Remarks

Most of the "solar" agrosystems were far from optimal returns which could be expected from a careful management of the given resources. Through the application of soft technologies, the organization of feedback loops and energy cascade outputs could triple without any manufactured inputs. This inherent potential for growth has not been appropriately evaluated in most analyses, because the relevant hard data are not easily obtained. Moreover, yield figures, which are widely used as a yardstick for productivity, are often interpreted without considering the areas to which they refer and computing net returns (seeds deduced). Most fundamentally, the energetic content rather than market prices should be applied as a common denominator to measure and compare different kinds of agricultural produce in an ecological analysis, because the use-values of different agricultural products are not always related to their energy content (Martinez-Alier 1987).

Among those studies which attempt at measuring carrying capacity, the focus has been rather exclusively upon nutrition (e.g., Grigg 1980; Viazzo, this Vol.). Carrying capacity refers to long-term overall stability of human ecosystems and must therefore include the production and consumption of forestry resources. In most studies, it has been overlooked that per capita energy demand for cooking and heating rises much faster than that for nutrition as a result of population growth. It may be argued that the demand of private households for heat energy was one of the major constraints which have promoted the transition from the solar to the fossil energy system. It was met in the context of the railway network, which was itself operated by fossil fuel and allowed the import of coal and coke. For Sieferle (this Vol.) the development of a fossil energy system was a matter of *economic necessity*, unless a country would run the risk of economic marginalization. This is only half of the story. From the example of the canton of Bern, which may be typical in this respect, it must be inferred that the substitution of fuelwood by coal and coke was also an *ecological necessity*. If we disregard the use of nonrenewable energies, there were no alternatives left in the late 19th century for covering the energy needs of a population which had continuously grown for over 100 years, except by further plundering the forests. The price which had to be paid for economic growth was ecological instability. Of course, timber and fuelwood might have been imported from Scandinavia and Russia or from overseas, but it may be hypothesized that large segments of the population would not have been able to bear the price of transporting this bulky commodity over long distances. The rate at which the Bernese forests were exploited at the end of the 19th century suggests that, without the coming of fossil fuel, the Alps and the hilly regions of Central and Western Europe might have gone the way of the Mediterranean mountains, which became denuded and sterile as a consequence of deforestation.

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