The Energy System – A Basic Concept of Environmental History

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The imminent ecological crisis, perceived during the last 20 years in Europe and in America, offers a challenge not only to explain the present problems, but also to understand their historical evolution. There are great advantages in the historical reconstruction of ecological conditions and ecological crises in the past: we can observe them over longer periods of time, we are not obliged to offer "solutions", and we can look upon social systems and social values as functionally integrated parts of a human-ecological whole, not being obliged to share opinions, values or interests of the past. On the other hand, it will be necessary to integrate the results of different natural scientific disciplines into historical explanation, from whence severe problems of interdisciplinary cooperation are to be expected.

For history as an academic discipline, this means that a new set of viewpoints and methods has to be incorporated into conventional wisdom and procedures. In my opinion, the main challenge of environmental history lies in a change of point of view: from anthropocentrism to the ecosystem concept. The language of "ecosystem" can be used as a heuristic concept, which allows the use of models of explanation, developed within the framework of general system theory, for the explanation of complex life processes. Concepts such as "self-regulation", "balance", "resilience", or "feedback" must thus be understood as mere heuristic devices, not as essential qualities of "nature".

As we can learn from the science of ecology, the basic characteristics of ecosystems are flow of energy and circulation of materials. The biosphere can be seen as an energetically open system, operating through a flux of energy, which allows the synthesis of biomass, converting it into motion and maintaining the metabolism of organisms. Complexes with high information content can thus be organized and transmitted. Matter and materials are circulating within the system, while energy flows through it, building its motor.

"Balance" and "stability" of ecosystems are mere matters of perspective and time horizon. Ecosystems usually maintain certain levels of organization and regularity, showing a measure of resilience when confronted with disturbances. In the long run, however, the systems are not stable or balanced, but evolving. From the usual historical and anthropomorphic point of view, nature appears as a balanced and unchanging entity, because the evolution of ecosystems takes place in periods of time not accessible to elementary human experience.

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The special role of humankind results from its specific "strategy" of survival: cultural evolution. Changes of behaviour and ecologically relevant characteristics do not any longer exclusively result from the process of variation and selection of genotypes, as in all other species, but can be produced by neural ways of information processing, transmitted by symbolic communication. The "Darwinian" method of evolution is replaced by a "Lamarckian" method, allowing an enormous acceleration of human cultural evolution, when compared with the normal inert pace of molecularly fixed biological evolution. It is this difference from whence man's potential as a highly disturbing factor within his natural environment results. Cultural evolution allows a velocity of change, orders of magnitude faster than that which happens within the time frame of biological evolution. Both are not synchronized. In the biological arms race, other species (apart from microorganisms and certain generalists) have no chance against man.

The critical unit of human ecology is not the human race, but different types of human culture. In the process of cultural evolution, certain patterns evolve, which contain an intrinsic social logic of development. "Man" as a biological species is only a formal requirement of human cultural systems, which evolve with a momentum of their own and win characteristics which can not simply be deduced from their "human" elements. The subject of ecological history, therefore, is the relationship between cultural formations and their specific ecological niche, which is moulded by them, but which also sets certain limits for their progression.

This interaction of cultural systems and ecosystems can be demonstrated by the example of socially modified energy systems. In ecological anthropology, it has become usual to analyze the flow of energy within certain types of societies, in analogy to the flow of energy in natural ecosystems (cf. White 1943, 1959; Cottrell 1955; Kemp 1971; Rappaport 1971; Adams 1975, 1978; Hardisty 1977). As any other natural species, man has to participate in the natural flow of energy. This is necessary, firstly because he can only maintain his physical structure and can only win the potential to move and to work, when he successfully converts energy for his purposes. Furthermore, the social/cultural/institutional framework of his existence can only be built up and maintained, when large amounts of energy can be mobilized. This is far more than what is needed for his physical metabolism in a narrow sense.

For this reason, it makes sense to analyze certain types of societies from the point of how they organize their energy flows, and which amounts of energy they use. Usually, three stages of social evolution and three types of energy use can be distinguished:

1. Hunter/gatherer societies and an unmoulded solar energy system;
2. Agricultural societies and a progressively moulded solar energy system;
3. Industrial society and a fossil (or nuclear) energy system.

"Primitive" hunter/gatherer societies participate in the natural flow of energy analogous to other predator species, without severely modifying it. They use solar energy, which has been fixed by the photosynthetic process of green plants or has

been converted into the biomass of herbivores. They use energy primarily through their metabolic process, which allows them to convert the chemical energy of their food into mechanical energy, enabling them to work. In this continual conversion process, temperatures and levels of energy density are low, with the exemption of the use of fire being the same as an accelerated conversion of energy chemically fixed in biomass into heat. The use of fire allows them to change the physical and chemical structure of food, making things digestible, which were not so while uncooked. Moreover, fire helps to create a microclimate, allowing existence in habitats to which man is not physiologically adapted. Thus primitive man can live in quite different regions of the world, spreading from the tropics to the Arctic regions of the high north.

Agricultural societies are also limited to the use of solar energy, but they succeed in changing the flow of energy considerably. This is the basic strategy of agriculture itself, i.e., clearing the land, tilling the soil, fighting noxious weeds and vermin, breeding new varieties of animals and plants, and changing the geomorphological structure of the earth such as building terraces, irrigating, draining etc. Agriculture makes it possible for more people to live on a certain space than under the conditions of hunting and gathering. The resulting higher density of human populations is the direct result of the modified energy flow: since the amount of solar energy, which reaches a certain area, is given, and since the energy density of this solar energy is rather low, it has to be collected and concentrated by plants over a period of time. A human society which succeeds in monopolizing the greatest amount of energy flowing into its biosphere for its own purposes can afford to be more populous than a society which has to share this energy with other life forms. Thus the removal or extermination of useless and noxious animals and plants has to be one of the basic characteristics of agriculture.

Agricultural societies have a high potential for innovation. The higher density of population allows them to develop social differentiation and division of labour, producing a surplus. Specialized trades can emerge. Certain groups can be set free from physical labour, enabling them to concentrate on fields of knowledge. Social and political power are concentrated, mobilizing resources for certain cultural purposes, such as the building of cities, pyramids, and cathedrals. Civilized agricultural societies develop a peculiar "anthroposphere", growing into the biosphere, with the tendency to out-grow it (cf. Boulding 1985). The social-institutional organizations steer the energy flow through the whole system in such a way, that a new world of artefacts arises, stabilizing the culture and winning a momentum of its own. In this process of innovation and development the whole population can grow, and so can the per capita consumption of energy.

Most important for developed agricultural civilizations is, that they succeed in using new methods of converting solar energy beyond the traditional conversion by human or animal labour. The first thing is the use of wind, mainly for sailing, so that transportation over long distances becomes possible. The next thing is the use of water power, allowing the mechanization of simple work processes such as milling or hammering. But all these methods of energy use remain within the narrow framework of a traditional solar energy system: man participates in the natural flow of energy, which he can skillfully modify. But he

is not able to use more energy than is *continually* flowing through the ecosystem. He can use the stored biomass of forests, but in the long run he can not use greater amounts of energy than are flowing into the system during the same period of time from its only source: the sun.

This is the reason why agricultural societies are faced with a fundamental dilemma, stemming from their basic ecological condition: on the one hand, they can develop rather complex social and cultural systems with sophisticated mechanical devices, resulting in a peculiar dynamic of economic and demographic growth. On the other hand, they are fundamentally restricted within the framework of a continual energy flow. Over a certain period of time, they can not, on the whole, use more energy than is delivered by the sun. Moreover, since this energy is flowing in over an area, they must always spend large amounts of materials and labour to collect and concentrate this energy. This is the basic reason why energy is always scarce in agricultural economies, and why there are ever-recurring complaints about imminent energy (mainly fuel) shortages.

There has been a long debate in the history of forestry, whether or not the European societies in the wake of industrialization have been facing a severe shortage of wood (cf. Radkau 1986). Wood, of course, has been a central resource in these economies, not only as a fuel, but as a material for a whole variety of purposes. Structurally, the problem of preindustrial fuel shortage has the following scope: when an agricultural society expands, when its population and its industrial output grow, more agricultural area is needed, while at the same time more forest products, mainly wood, are required. As the amount of available land is given, a problem of alternative land use arises. Shall the surface of a country be used for forests or coppice woods for timber or fuel, or for fields for grain, or for grassland, to win meat or wool?

Of course, there was always the opportunity of technological change. When new methods of husbandry are developed, it becomes possible to raise more food from a given area. The same is the case with forestry. But the basic problem remains unchanged: a solar energy system depends on the surface of land on which energy can be collected and stored. From this basic characteristic, the following tendencies of agricultural civilizations can be deduced:

1. A consumer who wants to use fuelwood must collect this fuel from an area, before he can burn it. The relation between his expenditures and the returns remains in all cases linear. Economies of scale are not possible, on the contrary: the farther the distance between the woodland and the consumer, the more difficult it becomes to transport this bulky commodity. This means that the size of a productive unit is energetically restricted. As for the smelting of iron, an ironwork in the 18th century could not produce more than about 2000 t a year. Similar restrictions are to be found in water mills, whose maximum amount of available mechanical energy are limited by the capacity of the river and by the problems of transporting mechanical energy (cf. Hills 1970; von Tunzelmann 1978). A preindustrial solar energy system thus had to remain decentralized.

2. As the energy income of the biosphere is the only energy source of a solar energy system, a certain country cannot in the long run use more energy than is flowing onto its surface. Of course, there are potentials for technological innovation, so that the ultimate limit may be rather flexible. Finally, however, there must be limits to growth in such an economy. Moreover, economic growth can not accelerate very much in a system which is always on the brink of energy shortage. An agricultural economy, therefore, is always confronted with the dismal perspective of a stationary state of production, consumption and population. If there is a tendency toward social change and economic/demographic growth, arising from the dynamics of the social and economic system itself, as was the case in 18th-century Europe, this growth would have been throttled, had there not been a fundamental change of the energy system.

These general considerations make clear that something of the kind of an "industrial revolution" could not have been possible on the basis of a solar energy system. The process of industrialization seen by Europe during the last 200 years was necessarily linked with the change of the energy system. Or, to put it the other way round, an energy system had to be developed which bore physical properties, giving room for the unfolding industrial dynamics. The historical switch from the moulded solar energy system to the fossil energy system was thus functionally connected with industrialization. Different uses of energy form different system requirements of social and economic formations. Energetically, the transition from agricultural to industrial economy is *identical* with the transition from solar to fossil energy system. The relative abundance of energy generated by the use of fossilized biomass was the driving force in the new industrial economy developing since the late 18th century. The basis of the new processes of chemistry, metallurgy, transportation, agriculture etc. is the breaking of the bounds set by the traditional solar energy system.

This is not the place to retell the story of the historical change from the solar to the fossil energy system (cf. Siefert 1982). In short, it originated out of certain local energy shortages, which were always inherent in the agricultural economy, but which could be overcome in England, where exceptional environmental conditions allowed the use of coal. This opened a self-increasing and self-intensifying process, beginning with local and sporadic uses of fossil fuel, in the course of which a new energy system was formed, showing unprecedented priorities and qualities which fitted into the requirements of the industrial economy. In the course of this process, many technological problems had to be solved; some solutions were extremely difficult to find. At the end of the 18th century, however, the key innovations in mining, metallurgy, and transport had been achieved, so that the fundamental characteristics of the new energy system became totally visible and, for the non-English world, the development of a fossil energy system became a matter of necessity. The fossil energy system formed a new evolutionary stage of human ecology; it was no longer possible to remain within the bounds of the traditional solar energy system, unless a country was

content to be marginalized or, in the long run, to be taken over by a more advanced world economy based on fossil fuel.

In the case of England, it can be easily demonstrated what the change of energy systems meant ecologically. When wood was substituted by coal as a fuel, the whole pattern of land use could be changed. In an agrarian economy there must always exist a certain proportion between fields, pasture, and forests/coppice woods. When this economy succeeded in substituting coal for wood, it could use the woodland area for other purposes, e.g., to raise sheep or grain. Land for energy plantations — and coppices are such from an energy point of view — is not needed any longer, when there is an alternative energy resource. Thus it becomes possible to compare a certain amount of coal with an amount of fuel wood, which was not needed any more, this fuel wood being the yield of a certain woodland area.

I would like to illustrate this with some rough data. A coppice of 1 ha yields annually about 5 m³ wood. As 1 t of coal has an energy content equivalent to about 5 m³ wood, by the use of 1 t coal an area of 1 ha woodland is set free for other purposes. On the basis of this data it is possible to assess the amount of space England won by using coal as a fuel. For this purpose, I would like to compare the historical development of British coal production with substituted wood and space equivalents (Table 1).

The whole area of England and Wales being about 150 000 km², we get an impression what the change of the energy system meant in terms of land use. The 210 000 t coal which were annually produced in the years between 1551 and 1560 replace a coppice area of about 2000 km²; that is just 1.4% of the whole area of England and Wales. These data illustrate that the early modern coal use had nothing to do with a severe wood shortage, but that it was only a sporadic and local matter of substitution. Coal was still used within the general framework of the solar energy system, having some slight advantages in some professions. By 1681–90 about 30 000 km², about one-fifth of the whole area of England and Wales, should have been used as coppices had there been no coal. Here we are at the point of transition to the new energy system. In the early 19th century, however, the whole area of England should have been planted with wood for

energy purposes, had there been no coal. In other words, England of the early industrial revolution could use a land equivalent twice as large as its own surface, thanks to fossil fuel.

The same can be shown for single industrial branches, e.g., iron smelting, since this was a key industry for modern development. Traditionally, iron was smelted and refined in charcoal furnaces. To produce 1 t pig iron, 800 ft³ of charcoal were needed (Hammersley 1973), for refining another 1000 ft³ of charcoal were necessary. The whole amount of charcoal to win 1 t wrought iron had to be produced from 50 m³ wood. This was the perpetual annual yield of a coppice of 10 ha extension. Thus we get a rough equation of 1 t wrought iron = 10 ha land. From these data we can extrapolate the area equivalents of British steel production (Table 2).

From these data we can see that the development of British steel production is closely connected with the development of coal production. It has been a long-discussed matter that British steel production stagnated from the 17th century to the middle of the 18th because of charcoal shortage (Hammersley 1973; Hyde 1977; Flinn 1978). I cannot go into the details of this debate here, but one point seems to be clear: about 1820, already one-third of the whole area of England and Wales would have to have been turned into coppice woods, had the British steel production of this time been obliged to use charcoal as its only fuel. In the middle of the 19th century, the area of woods necessary for fuel would have been more than equal to the whole surface of the country. This makes clear, again, what the change to the fossil fuel system meant in terms of land use: it was as if Britain had won another British island.

The use of coal has thus been a fundamental requisite for industrialization; on the other hand, the formal condition for this use did not lie in the hands of human societies. The mere existence of coal-beds arises out of an geological accident. There are parts of the earth where there is no coal at all; there are other

Table 2. Conjectural area equivalents of British steel production (calculated after Hammersley 1973; Mitchell 1973)

Year average ^a	Steel production (1000 t)	Area equivalent (1000 km ²)
1620	19	1.9
1690	23	2.3
1720	25	2.5
1781/90	69	6.9
1800/14	127	12.7
1820/24	669	66.9
1850/54	2716	271.6
1900/04	8778	877.8

^a The early and later data are not exactly compatible, since they may not contain the difference between pig iron, wrought iron, and steel, and since there may be severe regional differences. These data only give rough orientation marks, showing the tendency and the order of magnitude.

Table 1. British coal production and its conjectural wood and area equivalents (cf. Sieferle 1982 for further details)

Year average	Coal in Mio t	Wood in Mio m ³	Forest area in 1000 km ²
1551/60	0.2	1.0	2.0
1681/90	2.9	14.5	29.0
1751/60	4.3	21.5	43.0
1781/90	8.0	40.0	80.0
1801/10	13.9	69.5	139.0
1821/25	22.6	113.0	226.0
1841/45	46.3	231.0	463.0
1913	287.4	1437.0	2874.0

parts, where the first mining of coal, or the first extraction of other fossil fuels such as petroleum are so difficult, that even great energy shortages cannot induce a change of energy systems. There are two basic geographical conditions for a coal economy: (1) the existence and accessibility of coal and (2) suitable transport facilities for this bulky commodity. From this it becomes clear that only in England could the transition to a fossil energy system begin, apart from its indigenous social and economic dynamics of capitalist production.

In the case of Italy and Greece, both countries are easily accessible by water, so that there was never a problem of transport. Unfortunately, there was no coal, so that it was impossible to overcome the permanent fuel shortage. This may have been a severe obstacle for an industrial development in this region, although they did not lack a commercial or technological spirit. On the other hand, in the Ruhr valley or in Silesia there were huge coal deposits, reaching partly to the surface, already accessible in the Middle Ages, or even back in Roman times. But since they could not be transported over land, the great centres of population and industry could not easily be supplied with them.

Only in Britain did both conditions come together: coal, lying at the surface of the Tyne valley, and cities, which could easily be reached by water transport. If anywhere in the world, or at least in Europe, it was in Britain where the new energy system could come into existence. Once the fundamental threshold was overcome, this development could be copied in other countries, at least when overland transport by rail and steam became available.

One could speculate what would have happened if there had been no coal in England. Obviously, the industrial revolution would have had severe shortages not only of fuel, but also of iron and steel. It has been estimated that in the middle of the 18th century about 30–50% of the iron used in England was absorbed by agriculture (Bairoch 1978, p. 491). The great breakthrough in agrarian technology in the 18th century meant that increasing amounts of iron went into agriculture. Supposing that the European iron production would have become stationary at the turn of the 19th century, most of the iron would have gone into food production to rear a growing population. There would not have been much left for steam engines or railroads.

Of course, one could argue that wood could have been imported to England, since there were still huge forest areas in the Baltic or in Scandinavia. As a matter of fact, there were high imports of forest products to England, mainly of materials for ship building such as timber, masts, planks, tar, and pitch, not to mention iron or potash. In the 18th century, annual British timber imports lay between 0.04 M m³ and 0.2 M m³ (Aström 1970, p. 20). This was a huge amount, but it was nothing compared with the wood equivalents of coal used at the same period. Since the shipping of a bulky commodity like timber was rather expensive (cf. Albion 1926; Davis 1962), it was limited for building materials, especially for ship-building. Imported wood was far too expensive to be used merely as a fuelstuff.

What can be said for wood goes for energy-intensive commodities in a similar way. To illustrate this point, we can compare the weight of certain products with the weight of fuelwood necessary to produce them (Table 3).

Table 3. Weight proportions between products and fuelwood used (Gleitsmann 1981)

Salt	1:7
Pig iron	1:15
Wrought iron	1:30
Silver	1:200
Glass	1:2400

Similar proportions are found in other materials or chemical products. In this respect it seems quite improbable that fuelwood would have been transported to England just to burn it with the intention to smelt or process a stuff which could itself more easily be transported. There is one striking example: wrought iron could be economically produced with coke only since the last third of the 18th century, because there were severe technological problems. The British iron industry almost stagnated after the late 17th century, as it was cheaper to import iron from Scandinavia. A similar thing would have happened with other branches of industry where large amounts of fuel were needed. So it may be no exaggeration to hold the view that the European industrial evolution would have been much more decentralized (and slower), had there been no coal in England. The country would not have become the workshop of the world, except, perhaps, for the textile manufacture, which before the comparatively late introduction of steam power was based completely on solar energy: biomass, water, wind (sails).

The data presented above show the sheer amount of energy which became available through fossil fuel. Of course, coal, too, contains chemically fixed solar energy, but there are critical differences between a solar energy system and a fossil energy system. In the latter, energy is used which has been stored over periods of time which are orders of magnitude larger than the time of consumption. We may compare this with the first use of a primeval forest. It may contain an amount of energy fixed by photosynthesis over 300 years. When such a virgin forest is first used, we get a large amount of stored energy within a short time. From a forest managed by forestry, however, we can only harvest the annual yield, being the same amount as is fixed within the same period of time. To use fossil energy means in this perspective that we can use something like a very large, albeit not inexhaustible forest. A society changing to a fossil energy system thus moves into a state of energy abundance; this is historically a pioneer situation. Large, almost infinite energy resources allow the transformation of a whole set of ecologically relevant parameters. This pioneer situation, however, is not perpetual. One day the "subterranean forest" must be exhausted, and contrary to a real forest, it is not possible to switch to a "husbanding", i.e., continual harvest of perpetual yields.

From the basic characteristics of the fossil energy system, some of the physical features of industrial economy can be explained. First, the number of human beings could multiply almost tenfold. Then, the flow of materials running through the social and economic system could multiply in even larger proportions. The natural cycle of materials could be broken up. Material resources began an

accelerated move, from concentrated ores through higher concentrations in industrial processes to finite dispersion over the whole surface of the earth and the oceans. In this perspective, the transition of the energy system is the formal precondition of industrial pollution, since mobilizing such gigantic amounts of materials, effectively disturbing large natural systems such as the global atmosphere, requires quantities of energy, so large that they could never be available within the bounds of a traditional solar energy system.

In this perspective it is interesting to see what happened in agriculture itself. Within the framework of the solar energy system, agriculture was a central part of the energy system itself. It could be defined as a means to collect energy for human consumption. This meant that preindustrial agriculture had to have a positive energy yield. It was impossible that the energy input for food production was (on the average and overall) greater than its energy output. But this is what has happened in modern agriculture: the aggregated energy inputs in tilling, fertilizing, plant protection, harvesting, processing, and conservation are far greater than the energy content of food. Agriculture thus changed from an energy-yielding to a material-transforming system, with positive inputs of fossil energy (cf. Leach 1976).

Some additional features of industrial economy can be explained by basic characteristics of the fossil energy system. While solar energy radiates over large areas and has first to be collected and concentrated before it can be used, coal and petrol are found in high concentrations and locally fixed. Thus the labour needed to make energy available is comparatively low. When coal is mined, it appears in great quantities on the pit mouth, so that it is sensible to build canals or railroads to transport it (which would have been prohibitively inefficient for a woodland). These new transport systems allow the concentration of industries as well as a swelling of sheer size. Economies of scale get into operation, especially in rolling mills, in furnaces, and in chemical manufactures. Concentration and centralization of industrial activities become possible and, soon after become almost essential for works who want to survive industrial competition.

Another important effect of the fossil energy system is the technological acceleration of many productive processes. When pig iron was fired into wrought iron in a preindustrial charcoal furnace, the whole process took about 2 weeks. The puddle process of the late 18th century, based on coked coal, was finished after 2.5 days. The Bessemer or Thomas process of the 19th century was only a matter of 20 min. This shows that even if it had been possible to considerably increase the number of charcoal furnaces, the industrial development would have slowed down when such a key process could not be speeded up.

Taking all these points together, it can hardly be imagined that industrialization with its characteristic acceleration of cultural, technological, and economic evolution could have been possible without the use of fossil energy resources. The huge reservoir of energy, becoming available through the utilization of coal, petrol, and natural gas, catalyzed the emergence of totally new patterns of behaviour shown by socio-economic systems. This means, too, that these patterns can only be conserved as long as this period of energy abundance lasts.

It is the intention of this argumentation to show to what extent the characteristics of energy systems define the scope of ecologically relevant behaviour in human societies. This remains, of course, a rather global and abstract argument. What ecological anthropologists have tried to demonstrate for "primitive" societies should vice versa be possible for more differentiated civilized societies in the past. The patterns of energy use have here been shown on a very aggregated level, e.g., energy potentials in Britain. Historical reality, however, is far more complex, and what may be true for the whole, may be quite different in some local parts. So I see in these systematic remarks more a matter of question than a set of answers.

In conclusion, I would like to put the energy system analysis into the framework of the more general problems of environmental history in an age of ecological crisis. Environmental history can try to give an answer to the question, as to the fundamental features of this crisis. It can do so, when it takes the perspective of universal history seriously, asking what are the peculiarities of man-environmental relations, taking into account that it is the social system with its own logic of differentiation and evolution that brings "the human race" into specific contact with "nature".

In this perspective, the present ecological crisis results from a radicalization of the primitive human potential for ecological disturbance. Environmental problems have a long tradition, but they have won a new quality through the novel dimensions of industrial economy and modern society. The following factors can be mentioned: growth of human populations; synthesis of new materials; development of huge areas; omnipresence of human artefacts; emissions of materials in unprecedented concentration or amount (pollution problem); destruction of various ecosystems and species; change of elementary parameters of the biosphere, such as the gas composition of the atmosphere, the acidity of precipitations, of the radiant milieu and even — prospectively — of the climate.

The core of the present and future environmental problems can thus be defined in the following way: it is improbable that the multiple and rapidly expanding ecologically relevant human activities are neutralizing each other in such a way, that exactly those environmental conditions are preserved which existed previously and whose further existence is desirable or necessary for human survival. It is more likely that unwanted, unforeseen, uncontrolled, and uncontrollable effects are produced. On the other hand, modern technology is far from being sophisticated enough to repair damages and to restore mechanisms of natural self-regulation which produce favoured conditions. Technology may be competent enough to transcend the self-regulating capacities of natural systems, but may fail to restrain itself on a level below self-destruction.

Therefore, the critical question of environmental history is, how and when has the threshold been passed, beyond which this dynamic of self-destruction has been set free. When exactly has the point-of-no-return been reached, beyond which the present tendency toward an ecological crisis has become possible or even probable? It has been suggested that the transformation of energy systems played a major role in this process; this of course will not be the whole story.

Below this level of universal ecological history there is, I think, a whole set of further questions. Is it possible to distinguish different phases of ecologically relevant activities, correlated to different types and evolutionary stages of society? Which are the structural determinants other than energy systems which define evolutionary conditions of the man-nature-relationship? Are there key activities, key industries, key technological tendencies? What is the role of social values, preferences, cognitions, types of social organization and stratifications, or political grievances? An environmental history which will not just add some interesting remarks within the traditional framework of social and economic history needs to address these questions.

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From Ecological History to World Ecology

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"From space, we see a small and fragile ball dominated not by human activity or edifice, but by a pattern of clouds, oceans, greenery and soils. Humanity's inability to fit its doings into that pattern is changing planetary systems, fundamentally. Many such changes are accompanied by life-threatening hazards. This new reality, from which there is no escape must be recognized — and managed" (World Commission of Environment and Development).

It is no longer possible to close one's eyes to the obvious; man does not use the planet with impunity; he does not dominate it; he is a part of it. It is no longer possible to grasp and understand the ecological determinations of society's evolution without an in-depth examination of the influence of natural determinants on very-long-term history. This sort of historical thinking, however, is barely emerging from its childhood, and ecological thought often ignores the scant, but available, information on the environmental past of great civilizations. Yet the value of ecological thinking based on a systematic body of duly analyzed historical data need no longer be demonstrated; it is today one of the key conditions for mastering our own history (Debeir et al. 1986; Ruffolo 1988).

1 The Temporalities of History and the Temporalities of Nature

Societies and their ecosystems, all the biotopes and physical environments in which they are inserted and from which they draw their resources, form living, interactive wholes in motion. An ecological time therefore exists in history, side by side with the economic, cultural, political, and other times. Any attempt at historical ecology must therefore interpret the relations between human populations and their environment in an evolutionist perspective, and apply different time scales in considering social ecosystems, and the mechanisms which guarantee the latter's stability as well as the processes which, to the contrary, undermine their properly ecological foundations (Febvre 1922; Crosby 1986; Ruffolo 1988).

Duration is therefore a decisive modality in the various ecological regulations of human demography. Alter their duration and you interrupt these processes of limitation or regulation. The global stability of human ecosystems is only ap-

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