ENERGY IN HISTORY

Paolo Malanima
National Research Council (Italy), Institute of Studies on Mediterranean Societies, Naples, Italy

Keywords: energy consumption, energy-environment, resources, energy systems, organic vegetable economies, organic fossil economies, energy-history.

Contents

Summary

The topic of energy is of central interest today. Debates and analyses on the future availability of energy carriers, their prices, the role of energy consumption in economic growth and its environmental impact are developing daily. In general the perspective on the past is limited, perhaps extending back to 1973 at the most. Scholarly literature provides little information on the consumption of energy sources by past societies before and sometimes after the beginning of the 20th century. However, in the case of energy, a long-term view can be useful in order to clarify contemporary trends and provide perspectives on the likely impact of policy decisions and developments.

In the following analysis the topic of energy and environment will be discussed from the viewpoint of economics, with a long-term historical perspective. After a brief introduction, Section 2 will examine some definitions and concepts, useful when dealing with energy and the role of energy within the economy. Section 3 will focus on the relationship between man and energy in early human societies. Section 4 will discuss perspectives on future options and changes in energy and the environment from the early modern age to the present day. In the Conclusion general estimates will be proposed of past energy consumption on the whole.

1. Introduction

Scholars disagree about the role of energy within the economy. An optimistic view is shared by many economists. Their opinion is that raw materials played virtually no part in the development of the economy, as growth depended and continues to depend on knowledge, technical progress and capital. The contribution of natural resources to past and present growth is almost non-existent; and energy is a natural resource. After all, energy represents today, something less than 10 percent of aggregate demand in the advanced economies.

Scholars with interest in environmental changes support the opposite view on the role of material goods and nature in the economy. Environment and natural materials have played an important function in the development of human societies and in history on the whole. Energy in particular is of central importance in economic life. Material underpinnings to economic success are not to be underrated, in their view. Energy is also a central concern since it supported human exploitation of the environment and its heavy transformation in the 19th and 20th centuries.

2. Definitions and Concepts

2.1. An Economic Definition

In daily life we have direct contact with matter, but not with energy. Matter can be touched, its form described and it is to be found underfoot as well as around us. With energy it is different. Its indirect effects are only perceived deriving from changes either in the *structure*, that is, the molecular or atomic composition of matter, or in its *location* in space, such as in the case of a stream of water or wind, whose potential energy can be exploited. In both cases effects such as movement, heat or light reveal the presence of what we call energy from about 200 years. The analysis of energy in history requires some preliminary definition in order to avoid misunderstanding.

In physics energy is defined as the ability of bodies to perform work. Since work is the product of force and distance, then energy includes any movement of some material body in space together with the potential energy deriving from its position. When referring to the interrelationship between humans and the environment, the definition is more limited. We could define energy in economic terms as *the capacity of performing work, useful for human beings, thanks to changes introduced with some cost or effort in the structure of the matter or its position in space*. Solar heat is of decisive importance for the existence of life. It is a free source of energy and thus not included in our economic definition, whereas the capture of solar rays by means of some mechanism in order to heat water or produce electric power is included. In the first case solar heat is not an economic resource, while it is in the second. The formation of biomass in a forest is a transformation of the sun's energy by the plants through photosynthesis and is not included in this definition either. On the other hand, firewood is included, which is a part of forest biomass used by human beings for warmth, cooking and melting metals. Food is a source of energy in economic terms, since its consumption enables the performance of useful work and its production implies some cost. Food for animals is only exploitable, and then it is an economic resource, when metabolized by those animals utilized by humans for agricultural work. It is not a source of mechanical power for men when consumed by wild animals in a forest. Both fossil fuels used today and uranium are also energy carriers. They were not until a quite recent epoch, since they were not utilized in order to produce economic goods and services.

Although the definition of energy in physics is much wider than in economics, the definition here proposed is much wider than the ordinary meaning of the term energy. Many people immediately think of modern sources when considering energy and do not include daily food consumption or fodder as main energy carriers. It is well known that working animals played a central role in pre-modern agricultural economies, but their feed is not considered as a main source of energy for humans such as the fuel utilized to drive cars or machines today. When looking at energy within the economy in a historical perspective, we use the word energy with a wider meaning than in everyday life. The lack of a clear definition, common to most contributions devoted to the history of energy, prevents from the possibility of calculating energy consumption in past societies.

2.2. Energy and Production

Technical progress mainly consisted in the ability to introduce changes in matter so as to exploit some indirect effects of these changes, today defined as energy. In this long history, the main developments were supported by the increasing knowledge about the possibility of "extracting" energy from the input of matter. The production process and the role of energy can be represented by the following diagram (Figure 1).

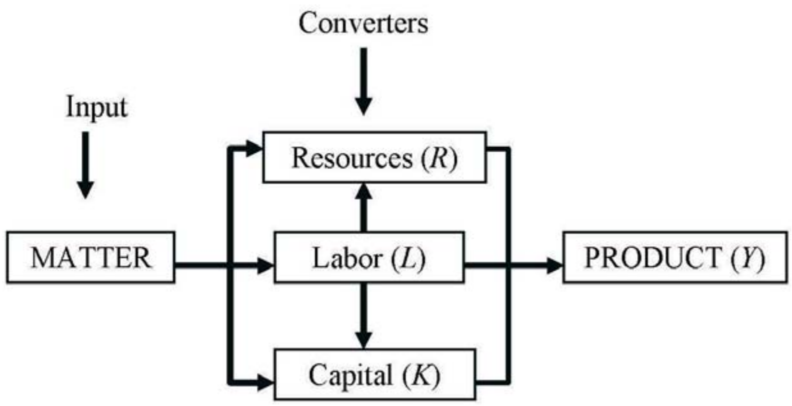

Figure 1. Matter, converters of energy, product.

The diagram can be seen as an illustration of the ordinary production function:

$$Y = AF(L, R, K)$$

Natural resources (R), labor (L) and capital (K), the inputs of any productive process of useful goods and services (Y), can be better defined, from the viewpoint of energy, as *converters* able to extract from matter the energy exploited in order to transform materials into commodities. The progress of technical knowledge embodied in A, plays a central role in the production function. In one sense, energy is the main input; that is to say, the main input is that part of matter transformed into energy by the converters, that is by workers (L), who metabolize food; natural resources (R), which convert a part of the matter used as food and firewood into biomass, through solar radiation; and capital (K), which transforms some materials such as coal, oil, gas and electricity into mechanical work, heat and light.

The increase in productivity of energy, as a consequence both of discoveries of new sources and technologies (*macro-inventions*) or improvements of those already existing (*micro-inventions*) can be represented by the following ratio:

$$\pi = \frac{Y}{E}$$

where Y is output (in value) and E is the total input of energy in physical terms (in calories or Joules or any other energy measure). The formula represents the productivity of energy, that is, the product generated by the unit of energy. In the previous diagram, it is the result of the ratio between the final product and the part of the matter transformed into energy by the converters. It is a measure of the efficiency of the energy converters from a technical viewpoint.

2.3. Energy and History

	Sources	**kcal per c. per day**	**toe per c. per year**	**%**
3.	Non organic	4.000	0.15	8
2.	Organic Fossil	40.000	1.47	80
1.	Organic Vegetable	6.000	0.22	12
		50.000		

Table 1. Daily and yearly consumption of energy per capita worldwide around 2000 (kilocalories, toe and %).

At the end of the 20th century, per capita energy consumption, on a world scale, was about 50 000 kilocalories per day; that is 76 GigaJoules per year, including traditional sources. About 80 percent of this consumption was represented by *organic fossil sources*; coal, oil and natural gas. Nuclear energy represented 6 percent and hydroelectricity 2 percent. This 8 percent was the non organic contribution to the energy balance. The remaining 12 percent consisted of biomass, i.e. *organic vegetable sources* (Table 1). If the part of waste utilized in order to produce energy is excluded, the rest of this 12 percent was composed of food for men and working animals, today a marginal source of power, and firewood, an important item of consumption only in relatively backward countries.

This composition of the energy balance reveals the strata of a long history of technical conquests. The history of energy technology is nothing else than the chronological analysis of our present energy balance, in order to single out the various ways of extracting energy from matter to produce heat, movement, light, work etc. Following Table 1, we will track the history of energy consumption from the most remote stratum (1) that is *Organic vegetable sources*, to the development of *Organic fossil sources*, the intermediate stratum (2), and subsequently to the progressing *Non organic sources* (3), which will be the basis of our future energy systems.

From the viewpoint of energy, the long history of mankind could be divided into two main epochs:

- The 5-10 million years from the birth of the human species until the early modern age, that is about 5 centuries ago, and
- The recent history of the last 500 years, which has witnessed a fast acceleration in the pace of energy consumption.

In the first long epoch, energy sources were represented by food for humans, fodder for animals and firewood, with a small addition of water and wind power. The second epoch witnesses the rapid partial replacement of the old sources by fossil carriers, which became and still are the main energy source. While in the first epoch energy was scarce, expensive and environmental changes heavily influenced its availability, during recent history energy has been plentiful, its price relatively low and the influence of the energy consumption on the environment considerable.

Although the energy system prevailing today is apparently different from the simple digestion of food, the first energy source, or from the burning of firewood by our primitive ancestors, it is based on the same principle, which is the oxidation of carbon compounds by breaking their chemical ties. Since carbon compounds are defined in chemistry as organic compounds and organic chemistry is the chemistry of organic compounds, we could define all the energy systems which have existed until today as organic and the economies based on those organic sources as *organic economies*. Coal, oil and natural gas, the basic sources oxidized today in order to bring about organized, that is, mechanical work, heat or light, are carbon compounds such as bread or firewood.

The difference between pre-modern and modern energy systems depends on the fact that, until the recent energy transition, organic vegetable sources were exploited, whilst from then on organic fossil energy sources became the basis of our economy. Since organic vegetable sources of energy were transformed into work by biological converters (animals) and fossil sources are transformed by mechanical converters (machines), we are able to distinguish past economies according to the system of energy they employed and the prevailing kind of converters in:

1. *Organic vegetable economies or biological economies;*
2. *Organic fossil economies or mechanical economies.*

Given the importance of energy in human history, changes in the use of this main input mark the evolution of humans in relation to their environment much more than changes in the use of those materials, such as stone and metals, ordinarily utilized by historians to distinguish the main epochs of human history.

3. Pre-Modern Organic Vegetable Economies

At the end of the 18th century there were three main economic sources of energy. According to the age of the discovery and exploitation of these three sources, three ages can be distinguished in the distant past. The original source was food, the second was firewood and the third was fodder for working animals. A relatively small contribution came from two other carriers: falling water, the potential energy of which was exploited by watermills; and wind, utilized both by sailboats, and mills.

3.1. The First Epoch: Food

Since the birth of the human species some 7 to 10 million years ago, and then for some 85-90 percent of human history, food was the only source of energy. In this long period, the only transformation of matter in order to engender movement and heat was the metabolism of organic material either produced spontaneously by plants and vegetation or converted into meat by some other animal consumed by humans as food. Although nothing certain can be said about energy consumption per head at that time, given the stature and physical structure of these early humans, consumption per day of 1500-2000 Calories could be plausible. Their own body was the early machine used by humans. An animal body is not very efficient in the conversion of energy. Only 20 percent of the input of energy, that is 300-400 Calories, is transformed into work, while the rest is utilized in order to support the metabolism and dispersed in the environment as heat and waste. The output of these far ancestors consisted in collecting and transporting this original input of energy.

3.2. The Second Epoch: Fire

The transition to the use of fire started the second phase of human technology and represented the main conquest in the history of energy. The first evidence of fire being used by humans refers to several different regions of the world and can be dated between one million and 500 000 years ago. Fire was a conquest of independent groups of humans in several parts of the world. Its use spread slowly. Firewood became the main source of energy for several millennia. In this case, as in the case of food, an estimate of the level of energy consumption by our distant ancestors can be only speculative. As far as is known for much more recent ages, the level of firewood consumption in different regions in pre-modern times may have varied from 1 kg per head per day to 10 in cold climates, and between 3000-4000 and 30000-40000 Calories. A daily consumption of less than 1 kg per capita could be assumed for the humans living in relatively warm climates of the African continent, where man was born. When humans spread from Africa towards the other continents, their firewood consumption rose considerably. Fire could be used for heating, cooking, producing light, and for protection against other animals. Although, with fire, Calories per head drastically increased from 2000 to 3000-4000 per day or more, that is 5-6 GigaJoules per year, the efficiency in its use was very low. An open-air fire can supply man no more than 5 percent of its Calories, that is, no more than 200-300. Useful energy exploited by the population from food and fire did not exceed 500-700 Calories.

3.3. The Third Epoch: Agriculture

During the Mesolithic, the end of glaciations and the rise in temperature enabled humans to increase the cultivation of vegetables and particularly cereals. The overall availability of energy in the form of food increased dramatically and supported the growth of population. However, observing this evolution in per capita terms, the perspective is different. While the population increased rapidly, availability of food per head did not increase. A diet based on cereals represented a deterioration, as is witnessed by the decrease in stature following the spread of agriculture. Agriculture, as the main human activity, progressed quite slowly, if we compare the diffusion of this technological conquest to the following ones. From the Near East, where primarily developed, agriculture progressed towards Europe at the speed of 1 km per year. Within 3000 years, agriculture reached Northern Europe, while, at the same time, the new economic system was spreading from Northern China and Central America, the regions of the world where agriculture independently developed at the same time or a little later than in the Near East.

New development in the agricultural transition took place during a second phase: from about 5000 years until 3000 BC. The period can be considered as a true revolution. The fundamental change was represented by the taming of animals, (oxen, donkeys, horses and camels), and their utilization in agriculture and transportation. Mans’ energy endowment was rising. If we consider a working animal as a machine and divide his daily input of energy as food – about 20 000 Calories -- among the men who employed him, human consumption may have increased by 20-50 percent or more, according to the ratio between working animals and men; which is not easy to define for these distant epochs. Only about 15 percent of this input represented, however, useful energy, that is energy converted into work. During this age, several innovations allowed a more efficient utilization of man’s power, fuels and animals; e.g. the wheel, the working of metals, pottery, the plough, and the sail. The sail was previously used, but it only spread widely during this revolutionary epoch. The use of wind was the first example of the utilization of a non-organic source of energy, not provided through the photosynthesis of vegetables. Labor productivity rose markedly. Even though some changes in the agricultural energy system also took place in the following centuries, generally technical progress was modest. Water and windmills, invented respectively 3 centuries BC and in the 7th century AD, were the main innovations in the energy basis of the agrarian civilizations. Although important from a technological viewpoint, these changes added very little in terms of energy availability: ordinarily no more than 1-2 percent.

3.4. Main Features of the Organic Vegetable Economies

Although several important differences exist among the three ages of our organic vegetable past, there are also some analogies; especially when dealing with the relationship between man and the environment. The dependence of this energy system on soil implies several constraints to the possibilities of economic development.

3.4.1. Reproducible Sources

Vegetable energy carriers are reproducible. They are based on solar radiation and since the Sun has existed for 4.5 billion years and will continue to exist for 5 billion years, vegetables can be considered as an endless source of energy. Organic vegetable economies have been sustainable since solar energy allowed a continuous flow of exploitable biomass. However, only a negligible part of solar radiation reaching the earth, less than 1 percent, is transformed into phytomass by the vegetable species. Of this 1 percent, only an insignificant part, could be utilized by men and working animals. On the other hand, increase in the exploitation of phytomass was far from easy. The availability of more vegetable sources implied extension of the arable lands and pastures and the gathering of firewood, which was difficult to transport over long distances. The ways of utilizing the phytomass were also in conflict, since more arable lands implied less pastures and woods. Thus, while the availability of these carriers was endless, their exploitation was hard and time consuming. The production of phytomass was, furthermore, subject to climatic changes both in the short and long run and heavily influenced by temperature changes and weather variations. Long-term climatic changes could also raise or diminish the extent of cultivation and wood productivity. Past organic vegetable economies, based on reproducible sources of energy, were the economies of poverty and famine.

3.4.2. Climate and Energy

Given that, in pre-modern organic vegetable energy systems, transformation of the sun's radiation into biomass by means of photosynthesis was fundamental and since the heat of the Sun is not constant on Earth, the energy basis – phytomass -- of any human activity was subject to changes. Climatic phases have thus marked the history of mankind. The availability of phytomass deeply varied and strongly influenced human economies. Glaciations caused a decline in available energy and therefore in the number of humans and the evolution of their settlements. The end of the glaciations provoked changes in the main human activities; from hunting and gathering to agriculture. Agricultural civilizations were also deeply influenced by climatic variations. While warm periods were favorable to the spread of cultivations and the multiplication of mankind, cold epochs corresponded to demographic declines. Roman civilization flourished in a warm period and was accompanied by population rise, while the early Middle Ages, which suffered a cold climate, were characterized by demographic decline. The so-called warm Medieval Climatic Optimum coincided with worldwide population increase, between 900 and about 1270, while the following Little Ice Age, from 1270 until 1840, was again a period of economic hardship and population stability or slow increase. It is common knowledge that present day energy systems heavily influence the environment and climate. Until a few centuries ago the opposite was true.

-
-
-

Bibliography

Bairoch P. (1983). Energy and Industrial Revolution: New Approaches. *Revue de l'énergie*, n. 356 [A stimulating perspective on the relationship between energy and modern growth].

Caracciolo A., Morelli R. (1996). *La cattura dell'energia. L'economia europea dalla protostoria al mondo moderno*. La Nuova Italia Scientifica, Roma [An overall reconstruction on the history of energy since the birth of the human species].

Cipolla C.M. (1962). *The Economic History of World Population*. Harmondsworth, Penguin [A path-breaking book on two revolutions in the economy due to the adoption of new energy sources: the Agricultural (Neolithic) Revolution and the Industrial Revolution].

Cook E. (1971). The Flow of Energy in an Industrial Society. *Scientific American*, 225, pp. 134-47 [The article deals above all with energy and the industrial world, in a long-term perspective].

Cook E. (1976). *Man, Energy, Society*. San Francisco, Freeman [An overall reconstruction of energy and modern economy, also dealing with the developments of energy technology in past civilizations].

Etemad B., Luciani J. (1991). *World Energy Production 1800-1985*. Droz, Genève [A useful book with a reconstruction of global energy production during the last 2 centuries].

Goudsblom J. (1992). *Fire and Civilization.* London Penguin [A stimulating analysis of the role of fire within past and present economies].

Kander A. (2002). *Economic Growth, Energy Consumption and CO_2 Emissions in Sweden 1800-2000*, Lund, Lund University [A reconstruction of consumption of modern and traditional sources of energy and their relation with modern growth in Sweden].

Lee R.B., De Vore I. (eds.) (1968). *Man the Hunter*. Chicago, Aldine [An important book dealing with a remarkable step in the evolution of the economy and society].

Lotka A. (1922). Contribution to the Energetics of Evolution. *Proceedings of the National Academy of Sciences*, VII, pp. 147-51 [A brief article on the trend of human economy and the role of energy].

Lotka A. (1956). *Elements of Mathematical Biology*. New York, Dover Publications [1924] [In the mathematical perspective of biology by Lotka energy plays a central role in this still important book].

Malanima P. (1996). *Energia e crescita nell'Europa pre-industriale*. La Nuova Italia Scientifica, Roma [A history of energy consumption in the European world before the Industrial Revolution].

Marchetti C. (1977). Primary Energy Substitution Models: On the Interaction Between Energy and Society. *Technological Forecasting and Social Change*, 10, pp. 345-56 [An important article on the substitution process in the field of energy].

Mokyr J. (1990). *The Lever of Riches. Technological Creativity and Economic Progress*. New York-Oxford, Oxford University Press [A history of technology and an analysis of the relationship technical development-economy].

Perlès C. (1977). *Préhistoire du feu*. Paris, Masson [A well-documented reconstruction of a central change in the history of technology: the discovery of fire].

Pireddu G. (1990). *L'energia nell'analisi economica*. Milano, F. Angeli [A research on the interrelationships energy-economy in the modern world].

Sieferle R.P. (1982). *The Subterranean Forest. Energy Systems and the Industrial Revolution*. Cambridge, The White Horse Press, 2001 [An important reconstruction of the passage from pre-modern to modern energy systems].

Smil V. (1994). *Energy in World history*. Westview Press, San Francisco-Oxford [One of the best histories of energy since the origin of the human species].

Warde P. (2007), *Energy Consumption in England and Wales 1560-2000.* Napoli, ISSM-CNR [Useful for the reconstruction of energy consumption in England and for the methods of calculation of energy consumption in pre-modern economies].

Wrigley E.A. (1988). *Continuity, Chance and Change. The Character of the Industrial Revolution in England*. Cambridge, Cambridge University Press [An important book on the role of energy in pre-modern English economy and an original view on energy in the pre-modern world in general].

Biographical Sketch

Paolo Malanima, Director of the Institute of Studies on Mediterranean Societies (ISSM) of the Italian National Research Council (CNR), received his education in Humanities at the Scuola Normale Superiore (Pisa) and University of Pisa; he has been Professor of Economic History and Economics at the University of Pisa and University "Magna Graecia" in Catanzaro. He is Co-President of the European School for Training in Economic and Social Historical Research (ESTER) (University of Groningen) and member of the editorial board of the journals *Società e Storia* and *Rivista di Storia Economica*, corresponding editor of the *International Review of Social History* (since 1993), member of Consejo di *Investigaciones de Historia Economica*. His research regards long-term economic history and the history of energy. His publication *Pre-Modern European Economy. One Thousand Years (10th–19th Centuries)* (Brill, Leiden-Boston, 2009), refers to both these areas of research.