The Path Towards the Modern Economy
The Role of Energy

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The transformation of the energy system during the period between the 16th and 19th centuries was the necessary, although not sufficient, condition of modern growth, first in Europe and then in the rest of the World. The transition to alternative forms of energy was prompted by the decline in per capita energy availability in early modern Europe during the phase of population rise from the late Middle Ages onwards. The transformation taking place in the energy system was composed of two significant changes, the first aimed at saving land, and the second labour. Both played a central role in the start of modern growth.

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Introduction

The strong direct link between coal, steam power and growth in the last decades of the 18th century and the first half of the 19th century might seem quite obvious to modern observers. Yet looking at coeval economists and even modern scholars, it is not so. We know that the English classical economists did not single out the importance of this linkage. "None appreciated the revolutionary possibilities for the scale and speed of expansion in industrial output (and at a later date in agricultural output) made available to an economy that switched from sole reliance upon organic raw materials to an increasing dependence upon mineral raw materials" (Wrigley, 1988b, p. 34).

John Nef (1954 and 1932) was the first modern historian who looked at energy as the main support of the industrial revolution. In his opinion, the industrial revolution was a long-term development, which started at the end of the 16th century, when a first industrial revolution occurred in Britain and strengthened during the following two centuries. His view on the energy-economy interplay did not reach the centrality it deserved.

The explanation of world economic history by Carlo M. Cipolla (1961 and 1962), based on energy changes, was appreciated, but not followed by the historians working on the beginning of modern growth. In his opinion, two economic revolutions took place in the history of mankind and both were correlated to deep changes in the energy endowment: the Agricultural Revolution in the Neolithic and the Industrial Revolution in the 18thand 19th centuries. Both marked discontinuity in demographic evolution and productive capacity.

More recently Antony E. Wrigley proposed a reconstruction of British economic history founded on the passage from an "organic" to a "mineral-based" economy supported by coal and steam power (1988a and 2004). Although the approach by Wrigley has been appreciated by the scholars, it has not been so widely followed by the historians dealing with pre-modern European economy.

Among the several constraints of past agrarian economies, the "organic" character is seldom mentioned.

Only in recent years has the emphasis on energy within the transition from the old to the modern economy received new attention (Pomeranz, 2000; Allen, 2009). Its central importance has been recognized as a main determinant of the divergence of Europe from the rest of the world in the 19th century and as the main cause of its success (Tello, Jover, forthcoming).

It is not my aim to discuss the complex interrelationships among the many variables involved in the process of transition to modern economy. Much more modestly the purpose of the following pages is to stress an immediate determinant of growth. More remote extra-economic determinants are outside the picture I will present. In the following pages the transition to modern growth will be explained as a discontinuity founded on the increase in productive capacity, due to the introduction of new energy carriers and engines able to transform energy into mechanical work. This change, on the other hand, will be correlated to the pressure of population on the agrarian system and the ensuing increase in prices both of the traditional energy sources and of labour. In the first section I will present the endowment with energy sources of pre-modern agrarian societies and the theoretical approach; in the second the stimuli to change in the energy system together with the constraints; in the third the beginning of the transition towards modern growth.

1. - The energy system of the agrarian civilisations

1.1. *Pre-modern 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, *firewood* and *fodder* for animals; with a small addition of *water* and *wind* power. The second epoch witnesses the rapid almost complete replacement of the old sources by fossil carriers, which became and still constitute the main energy source. 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 as:

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

Although the energy system prevailing today is apparently wholly different from the simple digestion of food, the original energy source, or from the burning of firewood by our primitive ancestors, it is, however, based on the same principle, that is the oxidation of Carbon compounds by breaking their chemical ties. Looking at their energy system, not only are past economies organic economies, as suggested by A. Wrigley (1988a, 2004) in important contributions to the topic of energy, but our economies too are so. Actually, 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, heating or light are carbon compounds such as bread or firewood. The difference between premodern 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.

The analysis of the passage from the first economic system to the second is the aim of the present paper.

1.2. *Phytomass and energy*

In past agricultural societies more than 95 percent of the energy input was represented by phytomass, that is, vegetable products. The problem any economy had to face was the combination of soil exploitation in order to cover the primary needs of mechanical power and heating. Food demand is the most inelastic. Food, however, is not enough. Working animals were the main capital of many past economies, essential both to work the land and transport goods…; and animals need pastures. According to the different systems of cultivation, a percentage of land varying in size had therefore to be subtracted from the arables and employed to feed the animals. However, fields and pastures were still not sufficient. Although with significant differences, depending on the location and climate, forests played an important role in the economies of past societies since they produced firewood, the main carrier of most past societies. The specific combination of these three essential needs distinguishes the several premodern agricultural systems. In any case, the availability of energy resources in pre-modern energy systems required soil and soil is not infinite (Malanima, 2006).

Low power and low energy consumption characterizes the energy systems based on phytomass. The power of a man in everyday work is the same as that of a 40 watts lamp, or 0.05-0.07 HP. The power of a horse is 15-20 times higher. The maximum power attainable on the land, in past agrarian economies, was that of a wind-mill, that is 10 HP at the best, while, on the sea, that of a sailing ship with a tonnage of 1,000, was 100-150 HP. Today a maximum power of several millions of HP is attainable by a nuclear power plant. We have here a measure of the effectiveness of work on the environment in order to transform it according to the needs and wishes of human beings.

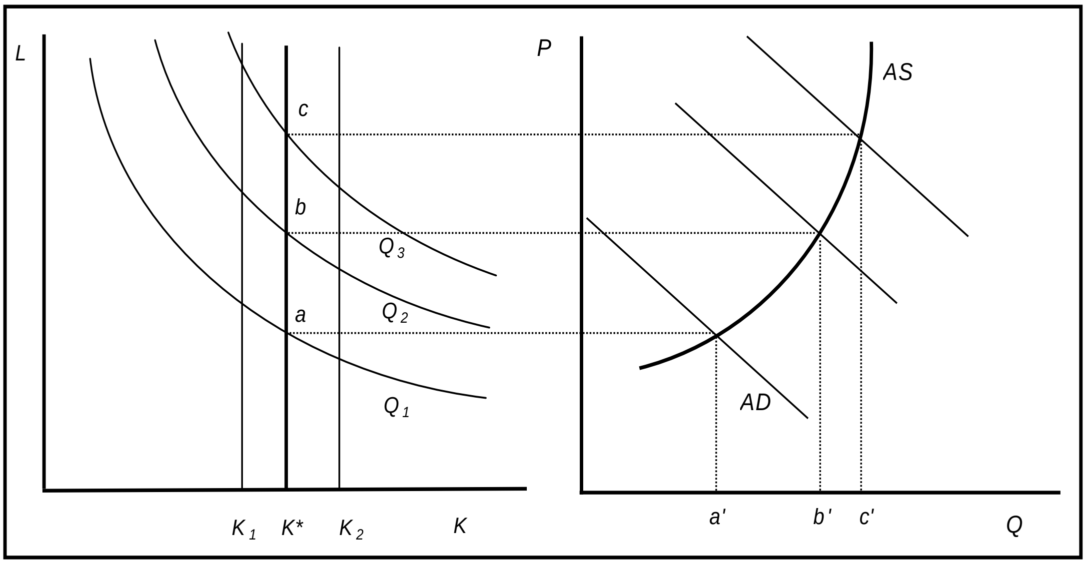
In 1750, the daily per capita energy consumption in Europe (without Russia) was about 15,000 kcal for a population of 121 million. It reached almost 40,000 kcal in 1900, when the population was 295 million. In 2000 it was 100,000, with a population of 523 million. A simple calculation shows that, if the energy system had been based for the last 250 years on the same sources exploited in 1750 -- assuming the same efficiency -- the need for fertile land would have grown to more than 3 times the entire surface of Europe –- Alps and Pyrenees included -- in 1900 and to 20 times that surface in 2000.

1.3. *The constraints of the system*

The system of energy based on land product is represented through the following Figure 1. In the left part, we see the combination of *L* and *K* to produce the output levels $Q_1<Q_2<Q_3$. *K* includes not only capital, but also natural resources, which represent the main part of *K* in pre-modern economy. A feature of these economies is, in fact, that, in order to produce the main energy carriers (food, fodder, and firewood), land is necessary and land availability can scarcely be modified. We assume then that *K* is represented in the graph by the vertical line. Some increase or decrease of *K* is in fact possible. New lands can be cultivated and their productivity increased thanks to investments of capital and labour; exogenous climatic changes can actually modify land availability. High temperatures permit the cultivation of hilly soils and lands in more northern regions. On the other hand, diminishing temperatures imply a subtraction of cultivable land. Land supply can oscillate from K^* to K_1 in this second case and from K^* to K_2 in the first.

FIG. 1

COMBINATION OF PRODUCTION FACTORS (ON THE RIGHT)
AND AGGREGATE DEMAND AND SUPPLY (ON THE LEFT).



Possibilities of producing more vegetable energy do not lack, but they require an intensification of labour (more people work and more hours are devoted to labour by any worker). We see that, as soon as the system needs a higher level of output in order to feed and heat more biological converters, more labour is employed and the intersection of *L* with the given supply of land is higher and higher (at first in *a*, then in *b* and *c*). However, decreasing returns to labour impend on the agricultural energy system of past agrarian civilisations.

This is the reason why the price of energy rises, as soon as more labour is employed in order to raise the level of agricultural product. On the right side of the graph in fact, prices of agricultural goods (in real terms, that is divided by the consumer price index) can be seen corresponding to the quantities Q_1, Q_2, Q_3.

Aggregate supply (*AS*) of energy, on the right of the previous graph, rises less and less (from *a'* to *b'* to *c'* on the horizontal axis), as soon as more labour is employed on *K* and the price of energy (*P*) rises.

On this background, the mean features of the change occurring between the late Middle Ages and the start of modern growth are represented by the following trends of the main variables:

1. L population and workers rise;

2. K resources, mainly natural resources, are stable (with the exceptions due to climatic changes);

3. p_e the real price of energy (agricultural commodities) rises;

4. MP_L marginal labour productivity diminishes and then $\frac{w}{p_e}$, the real wage, diminishes;

5. w nominal wage rises (once the level of subsistence has been reached by the real wage), and then production costs of the entrepreneurs rise;

6. p_i the real price of industrial goods diminishes;

7. $\pi = p_i - w$ profits (π), the difference between prices of manufactured goods and labour costs, shrink and represent an incentive towards innovation.

Assuming 1. and 2., the others are merely developments of these assumptions (with the exception of the decline of real industrial prices, as we will see). The start of modern growth consists in the removal of the constraints represented by the vertical line *K*, that is the limited availability of natural resources. This significant change took place in two waves. The first occurred in England, and, to a lesser extent, in The Netherlands, after the second half of the 16th century and consisted in the development of coal and peat consumption, that is of fuels that did not need soil for their production. It was a way of saving land. The second developed in England after the 18th century and consisted in the introduction of artificial resources, that is non biological energy converters. These resources were represented by steam engines, in other words by thermal machines. Fossil fuels and machines marked a sharp rise both in the sources used and in the efficiency of their exploitation; that is a true *energy transition.* Modern growth, from about 1820 until today, was the consequence of this big change.

2. -The stimuli toward a change

2.1. *Population growth (L)*

World population doubled in the 1,600 years after the birth of Christ: from 250 to 500 million. The rate of increase in this long period was, on average, 0.04 per cent per year: imperceptible, that is. The phase of population growth started at the end of the 15th century, accelerated in the 16th, slowed down in the 17th century and became ever faster from the end of this century. Over a period of 200 years, from 1650 to 1850, world population doubled: from about 600 to 1,200 million. The rate of increase was 0.4 per cent, or 10 times higher than in the previous 1600 years. These figures are, however, far from conclusive: their margins of uncertainty are wide, especially for earlier periods. No doubt, on the other hand, exists on the trend.

On the whole, the European population grew almost without interruptions from about 1450 onwards. The first wave of the *demographic transition* (Chesnais, 1986), starting from about 1670-1700, meant the acceleration of an already upward trend (Table 1).

TABLE 1

THE EUROPEAN POPULATION FROM 1400 TO 1900
(WITHIN PRESENT BORDERS) (MILLIONS).

1400	67.9
1450	71.2
1500	84.9
1550	86.6
1600	107.1
1650	105.3
1700	121.9
1750	143.2
1800	188.6
1870	310.3
1900	422.3

Source: Malanima, 2009, p. 9.

This acceleration was not a European event. The sudden demographic wave began, from the second half of the 17th century onward, to submerge the existing agrarian structures. Such a fast population growth had never occurred on a world scale. The same demographic trend was shared by other Eurasian regions such as India and China (Biraben, 1969). Although scholars do not agree on the reasons for this demographic wave, the opinion expressed by Braudel on the basis of the contemporary rise in several parts of the world would suggest a linkage with climatic changes, that is temperature increase in several regions at the same time (Braudel, 1979, I, chap. I; Galloway, 1986). Another reason (at least for Europe) is certainly the disappearance of the plague.

2.2. *Climate (K)*

When we look at energy in past agrarian civilizations, we often forget the importance of climatic changes in those traditional worlds where all forms of energy came directly from sunlight. Recent reconstructions by paleoclimatologists of temperatures over the last two millennia have shed light on the influence of variations in the sun's irradiation on energy sources. The effects of sudden climatic changes on harvests, agricultural prices and mortality have been repeatedly stressed in agrarian history. As to long-term climatic variations and their influence, historians have been much more cautious, especially because of our superficial knowledge of the subject until a few years ago and the few available series relating to climate over the very long term. However, energy availability in past agrarian civilizations not only depended on human technological ability to tap known sources, but also, and to a greater extent, on variations in the sun's irradiation reaching the Earth. To neglect this side of the problem when looking at energy in past agrarian civilizations means to neglect an important part of the whole story. A mere drop of 1 degree C° for several years can entail important effects on the energy balance of an agrarian civilization (Bozhong, 1998). The main consequences can be summarized as follows:

1. kcal from solar radiation diminish by about 10 per cent per cm^2;
2. hours of solar light decrease in the temperate zone from a yearly average of more than 2,000 to less than 1,900, with a consequent ca. three-week decrease in the growing periods of crops, pastures and forests (Marks 1998, p. 217). In cold northern European regions cereal cultivation becomes ever more difficult;
3. microbial activity in the soil declines, and with it the decomposition of organic material and the activation of latent fertility;
4. the altitude of cultivated land diminishes by 150-200 metres and the negative effects on cultivation can be serious especially in mountainous regions;
5. it is harder to feed livestock in late winter and early spring: stored grass and hay may be insufficient until pastures grow again in April or May (Pfister, 1988, pp. 38 ff).

Higher temperatures, on the other hand, mean the formation of free capital and the prospect for humans to exploit a wider range of natural energy resources. A correlation exists between long-term population movements and climatic variations. In general, warmer temperatures imply more energy from fields and woods and thus the possibility of supporting a wider population.

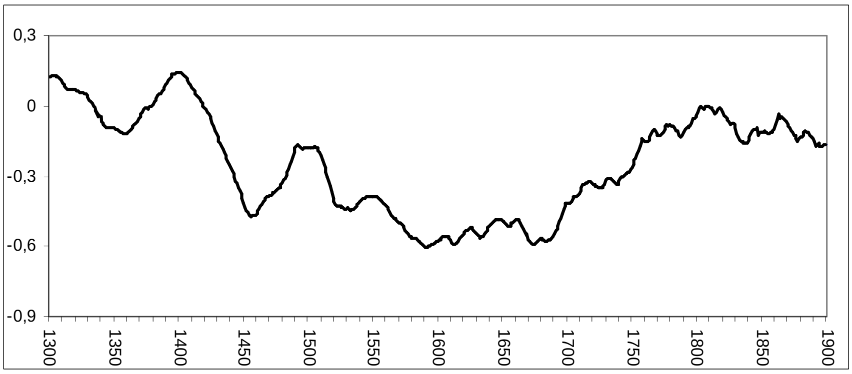
2.3. *The Little Ice Age: the last phase (K)*

It seems that in the 2000 years before 1900 annual temperatures varied within a narrow range and that long-term changes depended principally on variability of solar irradiation and volcanic eruptions (Crowley, 2000). The decline in temperatures, ordinarily defined as the Little Ice Age, occurred from the end of the 13th century, after the so-called Medieval Climatic Optimum (Figure 2). The effect on the economy is represented in the previous Figure 1 by the swing of the constraints of the natural resources from K^* towards K_1.

It seems highly probable that the negative effects of colder temperatures on vegetable energy sources were remarkable in the 17th century, when the lowest levels in the past 1,000 years were reached: 1 degree less than the average of the last millennium. “During the cooling period from around 1590 to 1670, grain yield, measures of fertility, and life expectancy were low, and the population growth rate declined” (Galloway, 1986, p. 12). The formerly mentioned rise in population occurred from the end of the so-called Maunder minimum, in the second half of the 17th century (Eddy,1977a, 1977b; Eddy, Gilman, Trotter, 1976). Demographic transition started in the last phase of the Little Ice Age, which ended during the 19th century. However, recent research has shown that temperatures rose, to some extent, from the very last years of the 17th century; although the modern rise in temperatures only took place in the second half of the 19th century. After all, even within an unfavourable climatic phase, the first wave of population growth was accompanied by milder temperatures. Only from the 1760s was a standstill reached, followed by a decrease in the first two decades of the 19th century. This decline, while population was still growing, contributed to determine a reaction to offset the worsening in the standard of living.

FIG. 2

AVERAGE TEMPERATURES IN THE NORTHERN HEMISPHERE 1300-1900



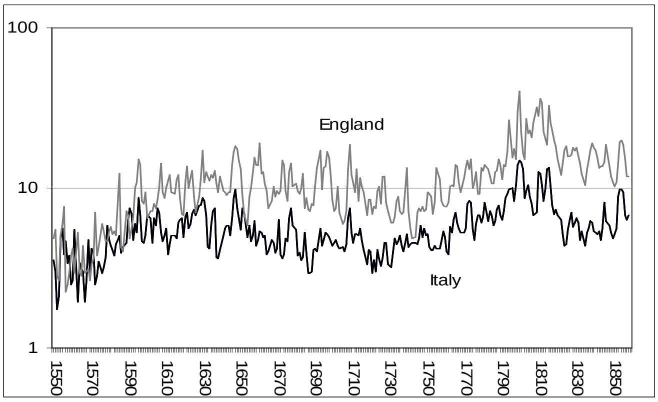
Source: Lohele, 2007; Lohele, Mc Culloch, 2008.

2.4. *Energy prices* (p_e)

Up to this point the relationship between humans and land and the relative scarcity of land following the rise in population during an unfavourable climatic age have been highlighted. The trend of energy prices contributes to specify the conjuncture of energy availability. Since we can avail of longer series of prices and wages for England and Italy, we will refer mainly to these countries.

FIG. 3

WHEAT PRICES IN ITALY AND ENGLAND 1550-1860
(FLORENTINE SOLDI PER KG –ITALY- AND PENCE PER KG –ENGLAND)



Source: for England Clark, 2004; for Italy Malanima in www.paolomalanima.it.

Evidence on the rise in prices is firstly provided by wheat (Figure 3). The correlation between the series is high (0.75), as can be seen on the graph: higher than might be expected. In the second half of the 16th century wheat prices began to increase rapidly and, after a period of stability or decline, did so again from about 1730-50. The rate of increase in the second half of the 18th century and the first two decades of the following century was more or less the same as during the Price Revolution two centuries earlier. From about 1820 wheat prices fell or stabilized. The growth in agricultural productivity allowed a larger population to be supported without any rise in prices. Previously the opposite had occurred.

Despite considerable differences amongst the various regions, price trends in the south, north and east of the continent show similar long-term trends: the 16th century rise, the 17th century decline or stability and the new 18th century increase (Figure 4).

FIG. 4

CONSUMER PRICE INDEX IN EUROPE 1500-1850 (1500-50=100)

Source: Malanima, 2009, chap. VI.

If we take fuel prices (that is firewood in most European regions, coal in England and peat in Holland from the 17th century onwards), we note the same trend of the primary energy input, food. All Carbon compounds exploited by the Europeans as sources of energy were growing in price from the 16th century onwards. Firewood prices rose about 2-3 times from 1500 until 1700. The increase was modest in the first half of the 18th century and became much stronger in the second (Table 2).

TABLE 2

INDICES OF FUEL PRICES IN SOME EUROPEAN CITIES 1500-1800 (1700=1).

	1500	**1550**	**1600**	**1650**	**1700**	**1750**	**1800**
Antwerp	0.39	0.80	0.79	0.90	1.00	0.91	0.93
Amsterdam	0.37	0.54	0.92	0.92	1.00	1.31	2.38
London	0.35	0.51	0.62	0.95	1.00	1.23	1.55
Paris	-	-	0.98	0.96	1.00	1.09	-
Strasbourg	0.36	0.70	0.87	0.88	1.00	1.60	3.31
Florence	-	0.56	0.83	1.13	1.00	0.99	1.82
Naples	-	1.42	1.68	-	1.00	1.14	1.63
Valencia	0.78	1.32	1.55	1.50	1.00	1.32	-
Madrid	-	1.43	1.89	1.57	1.00	1.34	1.88
Leipzig	-	0.83	1.16	0.72	1.00	0.88	-
Vienna	0.43	0.69	0.88	0.89	1.00	1.20	1.27
Danzig	0.56	0.97	1.00	1.06	1.00	1.68	2.73
Warsaw	-	0.59	1.25	1.05	1.00	1.71	-
Lwow	0.90	1.08	1.14	1.07	1.00	1.49	-

Source: Allen, 2003, p. 479 (fuel prices on which the Table is based are expressed in grams of silver per BTU).

R.C. Allen, noted that if we look at the real prices of fuel, that is at fuel prices divided by the consumer price indices of any country, the rise disappears completely and "what impresses is the narrowness of the range of the real price of energy across Europe" (2003, p. 474) during the early modern age. His conclusion is that "the theory that all of Europe faced an energy crisis by the 18th century is an attractive theory since it makes the Industrial Revolution the solution to a contradiction in the pre-industrial economy". This theory is, however, false in his view, since an "energy crisis" simply "did not happen. There was no general crisis, only local adjustments" (Allen, 2003, p. 477).

Allen's conclusion is only correct if we look at pre-modern energy sources in a partial way; that is if we consider firewood and fuels as the only sources of energy, excluding others. However considering energy in a wider perspective, including, that is, food for humans and animals, we can not but disagree with Allen's view. In this case, since both food and fodder were rising in the 18th as were fuels, and food is the main component of the basket used to compute consumer price indices, in real terms fuel prices were stagnant. Actually, however they rose as did the other sources of energy.

2.5. *Energy consumption per head* (*Q/L*)

Rise of population, hard climatic conditions, decline of agricultural output per head and increasing prices of energy sources resulted both in a diminishing availability of energy per capita and in reactions aimed at compensating this decline.

FIG. 5

PER CAPITA ENERGY CONSUMPTION IN EUROPE 1500-1850 (GJ PER YEAR)

Note: Before the 19th century, we lack direct estimates of energy production and consumption (with the exception of England and Wales)(in Warde, 2006). This graph is based on the series of agricultural product in Allen, 2000. We assume that, since energy consumption in pre-modern economies coincides with real agricultural product, the trend of agricultural output represents quite well the trend of energy consumption. On the basis of the relationship energy-agricultural output in the first half of the 19th century, I went back in time and reconstructed the curve presented in the Figure.

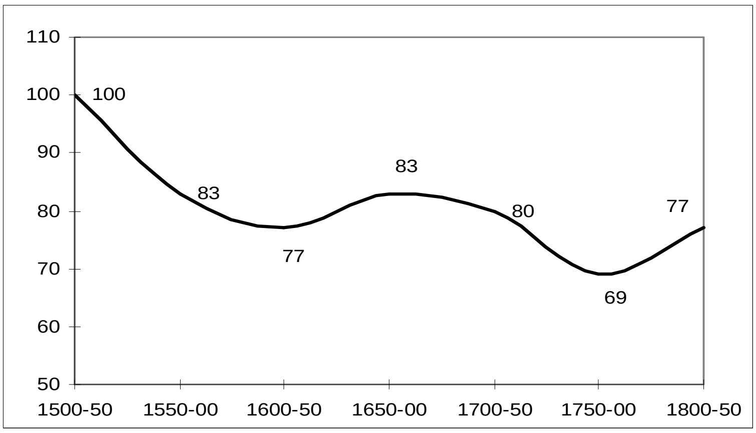
The fall in energy availability from the soil per head by about 25 per cent over the period 1500-1800, and 15 per cent over the period 1750-1820, is apparent in every European region (Figure 5). Until a few years ago, one could still entertain doubts on agricultural product in England. Today it may be seen that a remarkable growth in labour and land productivity had also occurred in England in the 17th century, however the second half of the 18th century was not a prosperous period, at least from the point of view of agricultural output in per capita terms. During this half century "food consumption per person fell, reaching its nadir during the Napoleonic wars. In terms of food consumption, the idea of absolute immiseration during the early industrial revolution was no myth" (Allen, 1992, p. 217). It appears that per capita agricultural product probably dropped less in England than elsewhere in Europe, including Italy, Belgium and the Netherlands.

2.6. *Real wages and living conditions* (*MP_L and w/p_e*)

Series of real wages witness a declining trend from the 15th century onwards. Rising population and declining per-worker resources within a relatively stationary technical framework implied a fall in labour productivity and subsequently in wage rates. Data referring to wages in different European cities reveals a 16th century slump which continued into the first half of the 17th century. Losses even reached 50 per cent. Stability followed for about a century, but subsequently, during the second half of the 18th century, a uniform decline, although of different intensity, brought real wages to a level between 20-60 per cent lower than that of the beginning of the 16th century.

FIG. 6

TREND OF THE EUROPEAN REAL WAGE-RATES 1500-1850 (1500-50=100)



Source: Malanima, 2009, chap. VI.

Expressed in terms of wheat, in Western Europe the wage in building industry "fell from about 12 to 15 litres of grain in 1500-20, to 6 to 10 litres in 1780-1800" (Van Zanden, 1999, p. 188). This trend is not very different from that of agricultural real wages.

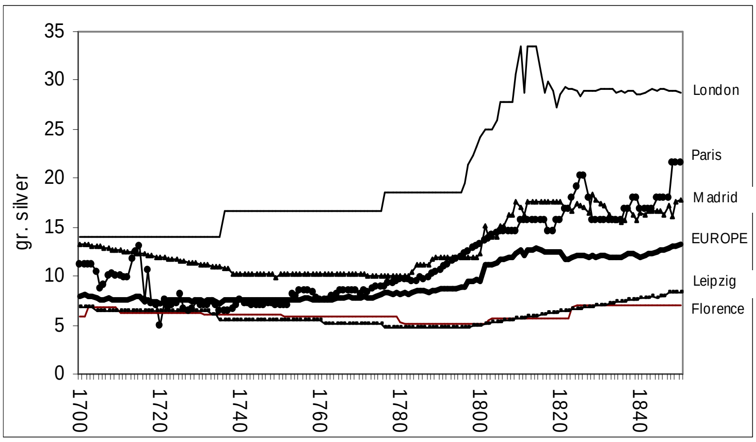
The average European trend can summarise more clearly the phases of decline and growth in urban real wages (Figure 6). In the first half of the 17th century, European real wage-rates were 23 percent lower than during the period between 1500-50. They recovered between 1650 and 1750. Subsequently they fell again between 1700-50 and 1800, reaching their lowest level since the late Middle Ages in 1780-1818. After 1818 prices began to diminish and wages to rise. From the perspective of the wage trend, the decades around 1800 can be considered a period of crisis.

2.7. *Nominal wages and labour costs* (*w*)

Whenever real wage is near the subsistence level, rising prices of agricultural goods can not but be followed by some rise in nominal wage. Increases in nominal wages occurred all over Europe during the second half of the 18th century. Since any input of energy was rising in price, there was no alternative for the entrepreneurs, either in the cities or the countryside, than to grant their workers a rise in their nominal wages; in reality the rise was not sufficient to keep their standard of living stable. The consequence was the rise in cost paid by the entrepreneurs in order to carry out their activity. Prices of the commodities produced, on the one hand, and wages in money paid out, on the other, are the basic elements of their economic calculation.

FIG. 7

NOMINAL WAGE RATES IN EUROPE AND IN SOME EUROPEAN CITIES 1700-1850 (GR. OF SILVER)



Source: based on data in Allen, www.iisg.nl/hpw.

Nominal wages, that is wages expressed in the silver content of the currency of any country, show that, in silver, British wages were already sensibly higher during the second half of the 18th century than before and than those of other regions (Figure 7). When the value of something expressed in precious metal rises, it means that the commodity or service purchased is more expensive, or that precious metals are cheaper, in that country; and probably, in the case of England during the so-called commercial revolution, both things were true. On the other hand, we know that the purchasing power of English wages was higher than that of other European workers. It can also be seen that everywhere in the continent nominal wages were increasing, during the second half of the 18th century.

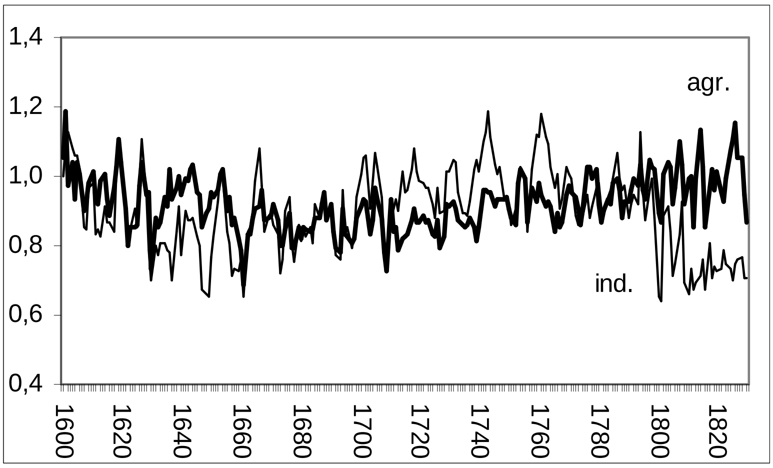
2.8. *The price of manufactured goods (p_i) and profits (π)*

In every branch of activity, the difference between prices and costs and then the margins of profit were diverse. It seems reasonable to suppose that agricultural entrepreneurs were favoured by an upward trend of agricultural prices, followed, but only with some delay, by nominal wages. However, in the case of industrial entrepreneurs it was different. Prices of secondary commodities were in fact, growing much less than agricultural prices. In the case of industry, margins of profit could be endangered by the rising trend of nominal wages, primarily determined by the rising prices of food.

If industrial real prices in England and agricultural real prices (deflated by means of the consumer price index) are observed, it can be discerned that although the 18th century trends were fairly similar, at the end of the century industrial prices relatively fell, as a consequence of the ongoing increase of productivity in textile production (Figure 8). In other European countries, the divergent trend was similar to that of England (Malanima, 2009, chap. VI).

FIG. 8

REAL PRICES OF AGRICULTURAL AND INDUSTRIAL GOODS IN ENGLAND
1600-1830 (1600-10=1)



Source: based on data in Allen, www.iisg.nl/hpw.

As David Ricardo showed, this different behaviour of agricultural and industrial prices can be explained as the consequence of the influx of innovations in industry and trade. “The natural price of all commodities…”, Ricardo wrote, “has a tendency to fall, in the progress of wealth and population”, thanks to “improvements in machinery”, “better division and distribution of labour”, and “increasing skill both in science and art of the producers”. On the other hand, the diminishing returns in agriculture tend to enhance “the natural price of the raw material of which they are made” (Ricardo, 1821, chap. 5).

3. - The start of the energy transition

3.1. *Saving land*

Under the pressure of population and in the face of declining per capita availability of natural resources and rising prices, any traditional agricultural society reacts by trying to intensify the use of land, and especially the arables, in order to meet the most inelastic need: food. Intensification means a higher ratio between harvest (in quantity or value) and cultivated soil (Boserup, 1965). It is a way of increasing the productive value of the soil, since less soil is needed to meet the same volume of the harvested calories. It represents a land-augmenting innovation.

The developments allowing land intensification in Europe began in the 16th century. These were as follows:

a. colonisation of new lands;
b. introduction into European agriculture of new, more productive, crops;
c. new forms of rotation.

The other more important development, which will require particular attention, is the resort to coal.

a. *Colonisation*. Colonisation of new lands accompanied the rise in population and often meant deforestation. On the one hand new arables supported the growing demand for food, but, on the other, they implied a reduction in the availability of the main fuel: firewood. On the basis of contemporary literature on forest degradation and the frequent attempts to control and limit wood destruction, K. Pomeranz (2000) wrote of a European ecological crisis during the 18th and 19th centuries. Throughout the 19th century, not only did this process of conquering new space for agriculture continue, but it also spread outside Europe, opening up new lands on other continents, especially the Americas. These vast areas of natural resources were for the most part entirely unexploited.

b. *Maize and potato*. Although already known in some European regions in the 16th century, it was not until the end of the 17th century that maize spread across a part of Europe extending from the North of Spain and Provence, through the whole of the North of Italy (especially the Po Plain) to Slovenia and Hungary and subsequently to the Balkans. Another vegetable which originated in America was the potato. One hectare cultivated with potatoes could supply a caloric value two to three-fold that of a hectare cultivated with grain; sometimes even higher (Grigg, 1982, p. 84). It spread particularly in northern Europe where in many cases it became the first agricultural product.

c. *Convertible husbandry*. The spread of convertible husbandry in England represented an important change, not only increasing land productivity, but labour productivity as well. According to Wrigley, this progress in labour productivity which occurred in England was still within the “organic” economy and was connected, in the 17th century, to the exploitation of more mechanical energy from animals than before (Wrigley, 2006). This progress in agricultural productivity was an aspect of the first stage of the energy transition in England.

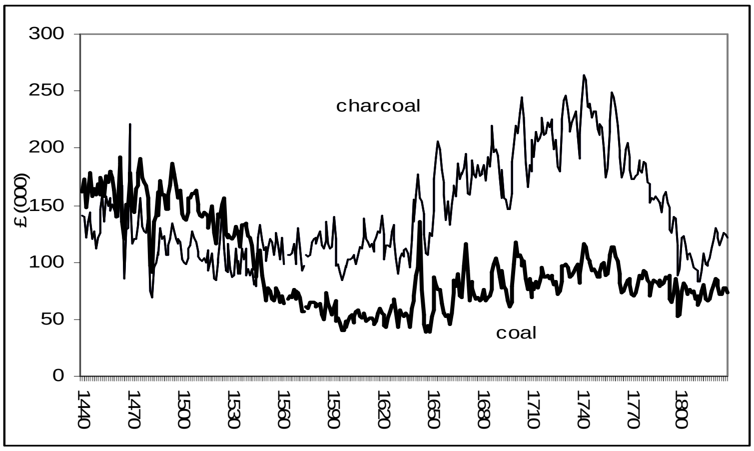
These three reactions to the decline in per capita energy were able to partially compensate the decline in per capita terms. Only after 1820 did productivity of land rise faster than population. Agricultural prices, as we have seen, clearly witness this change.

3.2. *Coal*

Another way of saving land was through the greater use of coal. England was the first country in Europe to resort to coal on a wide scale. Looking at the dynamics of firewood and coal prices, we notice a scissor movement between the price of charcoal and that of coal after about 1530, when a true transition to coal started. Between 1500 and 1700, the rate of increase of charcoal prices was twice that of the consumer price index and the differential among these series became wider and wider in the 18th century (Wilkinson, 1973, p. 114). Only at the beginning of the 19th century, when charcoal consumption had almost disappeared, did the prices of these fuels begin to draw closer to each other (Figure 9).

FIG. 9

PRICES OF CHARCOAL AND COAL IN THE SOUTH-EAST OF ENGLAND 1440-1830 (000 POUNDS PER TOE).



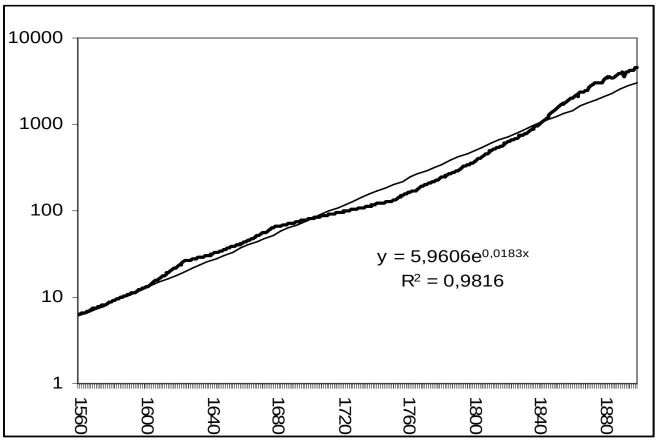
Source: Fouquet, 2008.
Note: a Toe (ton of oil equivalent) = 10 million kcal.

Coal resources are distributed among 2,000 areas throughout the world. Within Europe, coalfields are virtually inexistent in the Mediterranean countries. They are almost completely localized in the centre, north and east, and especially England, where the main deposits were and are located. In many places these coal deposits were easy to exploit. There is little wonder that they have been exploited since remote times

The existence of fossil fuels had been known in Europe since the times of ancient Rome. During the late Middle Ages, in those northern European regions where coal was easily available, its consumption spread, as its price was far lower than that of firewood. In China coal was also widely used in metallurgy during the late Middle Ages (Hartwell, 1966, 1967). From the second half of the 16th century, the use of coal increased above all in England. The rising population and particularly that of London represented a strong stimulus towards the consumption of a much cheaper fuel than firewood. In the whole of England the production of coal increased 7-8 times between 1530 and 1630, thanks to the greater depth of the shafts and better drainage of the mines and by the 1620s it had become more important than wood as a provider of thermal energy. For a long period, England was by far the main producer of coal. Only at the end of the 19th century, was the rest of Europe able to compete with England. The proportion of coal consumed in England was 12 per cent of the total energy consumption in 1560, 20 per cent in 1600, and 50 per cent in 1700. Its consumption from 1560 until 1900 reveals an almost stable rate of growth, as a graph in log scale shows (Figure 10).

FIG. 10

COAL CONSUMPTION IN ENGLAND & WALES 1560-1900 (IN PETAJOULES; LOG SCALE)



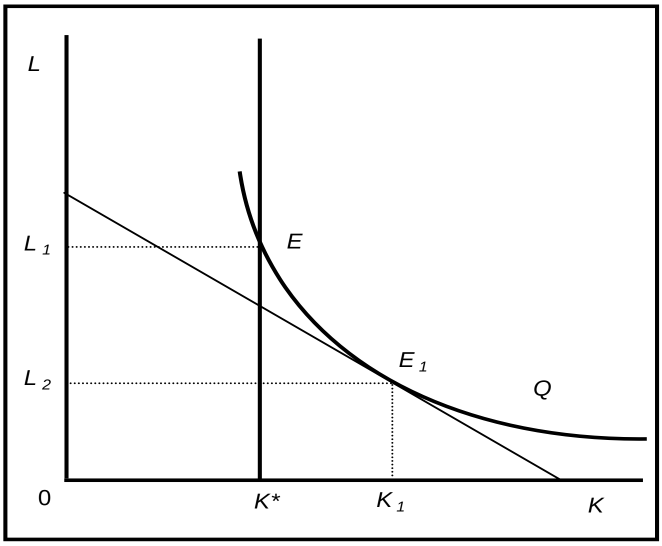
Source: Warde, 2007.

In The Netherlands another fossil fuel, peat, began to be used on a wide scale from the 17th century onwards (De Vries, Van Der Woude, 1995). It was an important support of the Dutch Golden Age. England and The Netherlands were the countries in Europe endowed with fewer woods in relation to their extent. At the end of the 19th century these were 4.1 per cent of the total surface in England and 7.5 per cent in The Netherlands, while the European average was 25-30 per cent (excluding or including Russia) (Lunardoni, 1904, p. 81; Chierici, 1911, pp. 258-59). The per capita area of woodland was 0.03 hectares in England and 0.05 in The Netherlands, while the European average was 0.75 including Russia, and 0.39 excluding Russia. By means of the use of peat, "the Dutch lived as if their country was twice its actual size" (De Zeeuw, 1978, p. 24). It was really a land-augmenting innovation.

Wrigley calculated that 1 ton of coal could replace the calories of 1 acre of forest (Wrigley, 1988a, pp. 54-5). If we follow this calculation, coal extraction in Britain was replacing in 1700 12,000 square kilometres, which we could call "ghost square kilometres", that is 5 percent of the extent of Great Britain, and in 1800, with 15 million tons of coal annually extracted, 60,000 square kilometres, that is one-fourth the extent of the island. Thanks to these innovations, natural resources (included in *K* in our previous Figure 1) were no longer fixed. On the other hand, convertible husbandry, with the elimination of fallow land allowed the widening of the arables and contributed to the increase both of food and fodder production. These changes were taking away the constraint of the fixed resources, that is the main obstacle of any agrarian civilisation on the path towards growth. As represented in Figure 11, a lower investment ($L_2E_1K_10<L_1EK0$) made possible to reach the same level of product (*Q*), thanks to the rise in capital (*K*) from K^* to K_1 and the decline in labour (from L_1 to L_2).

FIG. 11

COMBINATION OF LABOUR AND CAPITAL (LAND INCLUDED) TO PRODUCE Q



3.3. *Saving labour*

It has recently been sustained that the British Industrial Revolution was the consequence of the level of British wages, which were higher than those of continental workers (Allen, 2009). Since wages represent marginal labour productivity and since productivity was higher in 18th and 19th century England than in other European countries, the obvious consequence is that growth had already taken place in the country. We can also hypothesize that the British growth, although slow, derived from ongoing energy transformation, both in food production and industry. The Industrial Revolution only accelerated this change in progress.

The shift to new fuels represented one aspect of the energy transition then in act. However, it was not the most important. The main technological change was the new utilisation of fuels, that is, the techniques designed to employ the heat of these organic sources to different ends. For about one million years, fuels were utilized for heating, lighting and melting metals, while work, in economic terms, that is organized movement in order to produce commodities and services, was only provided by men and animals; apart from wind and water (whose mechanical work, in any case, was not a conversion of fuel power). The only engines capable to provide work were biological machines. The introduction of machines able to convert heat into mechanical power was the main change in the energy system, comparable in importance to the discovery of fire. It was only during the 18th century, with the invention of the steam engine by Thomas Newcomen and James Watt that the *Age of the Machines* really began. The fundamental technological obstacle that had for millennia limited the capacity of the economic systems to perform work was only then overcome. In 1824, the French physicist Sadi Carnot clearly pointed out the great novelty represented by what he called the “machines à feu”, the thermal machines. In his opinion they would replace both the force of animals and that of water and wind. This is precisely what has happened over the last two centuries (Carnot, 1978). The age of machinery began with the steam engine and such energy transition resulted in great changes in the volume of energy consumption, the process of substitution of energy carriers, the geography of energy production, the price of energy, and the energy-economy relationship.

Technical change is always the answer of a producer to a specific problem, and it aimed at saving labour, raw materials or energy sources. Chance plays an important role in finding this solution. Sometimes economic changes generalize the utility or need of the new discovery and the discovery spreads. More often the novelty or mutation is relegated to a specific niche and cancelled by the following development; such as a new tool set in a toolbox and then forgotten being of modest utility or even completely useless. Population growth, decline of soil per capita, unfavourable climatic conditions, price increase, diminishing real wages but rising nominal wages all pushed entrepreneurs and workers towards the replacement of traditional biological converters of energy with machines. We could also say that a “latent demand” existed for the replacement of labour with capital. To this purpose, the economic necessity had to meet exogenous developments taking place in technical knowledge.

The invention of thermal machines was a slow development which depended on the increasing know-how in metallurgy and the construction of mechanical instruments. The strong interdependence between energy, on the one hand, and science, on the other, took place during the so-called Second Industrial Revolution in the last decades of the 19th century, but did not exist during the First Industrial Revolution. Protagonists of this first phase of development in energy and technique were able craftsmen (Ruttan, 2001, pp. 70-4). “In the Industrial Revolution the knowledge that lay behind the economic success appears to have been largely craft skills and Britain was spectacularly successful in exploiting them. In the 20th century, formal qualifications and formal education increasingly became the source of success” (Harley, 2009, p. 334).

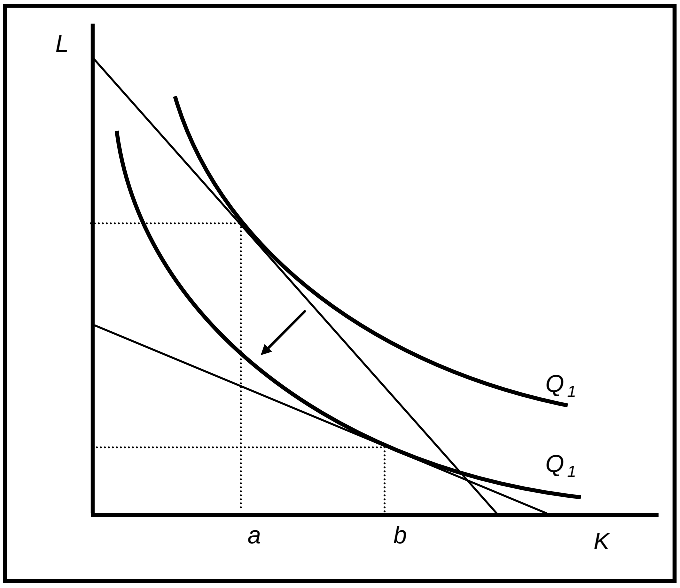
3.4. *Main changes*

The main changes from the 19th century onwards can be represented by the following graph (Figure 12).

With the introduction of mechanical converters of energy, in the 18th and 19th centuries, the novelty was the availability of a technical solution: the replacement, that is, of biological converters fed by means of food, with mechanical converters fed with coal. Technical evolution and capital accumulation implied the possibility of reaching the same value of product Q_1 with lower costs (the line of the isocosts was nearer the intersection of the vertical and horizontal axis) and a different combination of production factors: relatively much more capital (K) and less labour (L). This shift allowed the same volume of product to be obtained but with reduced investment (the rectangle of the first combination of production factors was bigger than that of the second combination). Since labour was endowed with more capital than before (incorporating a more advanced technique) labour became more productive. All this meant an increase in wages and then labour costs and a tendency to replace labour with capital. Technical progress in the production of capital goods implies a decreasing price of capital as regards labour (Salter, 1966). The replacement of labourers by machines became a strong tendency of the economy and was the basis of the continuous replacement of biological converters (workers) with mechanical converters (machines) fed by means of new energy sources. The energy transition has been and still is a process of substitution of capital, both fixed and circulating, for labour. On the lower part of the graph it can be seen that the new combination of production factors was able to provide the same supply as before (*Q_1*) at a lower price.

FIG. 12

COMBINATION OF PRODUCTION FACTORS
AND AGGREGATE DEMAND AND SUPPLY



3.5. *The rise in the consumption of energy*

Energy consumption per head diminished in Europe during the 18th century, whilst, from 1800 until 2005, it rose considerably more than population: 9-fold from 1800 until 2000: from 23 Gigajoules to 156. Since at the same time population increase was 3.8 fold, total energy consumption registered a 36-37-fold rise (Table 3).

TABLE 3

ENERGY CONSUMPTION IN EUROPE FROM 1800 UNTIL 2000 (IN KCAL PER CAPITA PER DAY, IN TOE PER YEAR, EUROPEAN POPULATION AND TOTAL ENERGY CONSUMPTION IN MTOE)

	kcal. per c. per day	Toe per c. per year	Traditional sources %	Rate of growth (%)	European population	Total Mtoe
1800	15,000	0.6	87		189	104
1830	15,150	0.6	80	0.09	234	129
1900	37,590	1.4	25	1.31	422	578
1950	47,430	1.7	15	0.47	548	948
1970	89,560	3.3	5	3.23	656	2,145
1989	101,057	3.7	5	0.63	720	2,680
2000	101,882	3.7	5	0.07	728	2,707

Source: Martin, 1990 ; Malanima, 1996.

Until about 1840, energy consumption per head did not increase in Europe, since the input of fossil fuels rose at the same rate as the population. However, from 1840 until the First World War, growth was remarkable. After a period of stability between the two World Wars, a significant increase took place from the 1950s onwards, with a slower increase occurring from the 1970s onwards. (Figure 13).

On the World scale, the rise of per capita consumption was even higher than in Europe. It increased 10 times. Since population growth was 6.3-fold, the aggregate rise was 63 times (Table 4). It can be seen that modern or commercial sources overcame traditional sources, or the phytomass, in the last decades of the 19th century or the epoch of the second industrial revolution.

FIG. 13

PER CAPITA ENERGY CONSUMPTION IN EUROPE 1800-2005 (GJ).

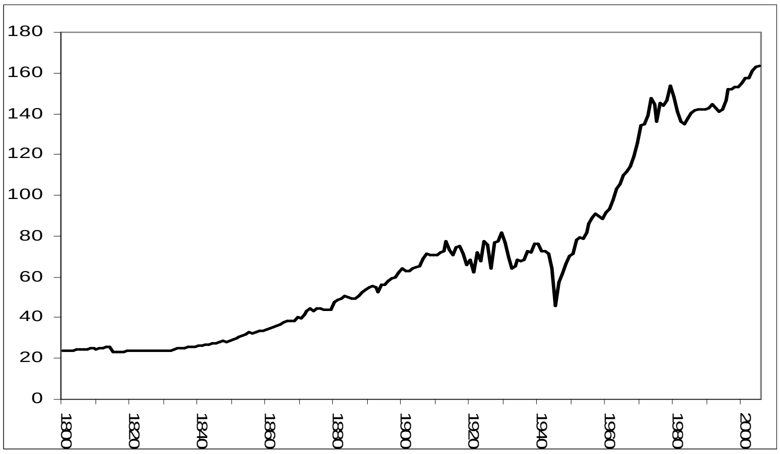


TABLE 4

WORLD ENERGY CONSUMPTION FROM 1800 UNTIL 2000 IN KCAL PER CAPITA PER DAY, IN TOE PER YEAR, WORLD POPULATION AND TOTAL IN MTOE

	kcal. per c. per day	Toe per c. per year	Traditional sources %	Rate of growth (%)	World Population	Total Mtoe
1850	9.500	0.3	80		1,241	430
1880	12.300	0.4	50	1.35	1,330	597
1900	17.500	0.6	45	2.26	1,634	1,044
1950	25.600	0.9	30	1.42	2,530	2,364
1970	41.380	1.5	20	2.57	3,637	5,493
1985	41.100	1.5	20	0.12	4,815	7,223
2000	50.400	1.8	15	0.81	6,000	11,038

Source: Martin, 1990 ; Malanima, 1996 ; IEA data from 1990.

4. - Conclusion

The escape from the economy of poverty: so could be summarized the change taking place in early modern Europe. Increase of population in front of given resources implies a decline of labour productivity and wages. Low wages do not drive the economy towards the replacement of labour with mechanical engines. We followed, in the previous pages, some main reasons that pushed towards the increase of mechanical converters per worker, which represented the main support of the modernisation of the European economy from the beginning of the 19th century onwards.

The marked increase of mechanisation and the wide use of coal, at first in England and then in Western Europe, contributed to expand the productive capacity. The effect of this expansion was the rise in output per capita rather than population. We have seen, however, that the main changes setting the background for this great transformation were: increase in population, increase in energy prices, decrease in marginal productivity and real wages, but rise in nominal wages and diminishing profits. The background was set for a new combination of production factors, with a reduction of natural resources and the rise of produced resources, that is capital. In England the environment was more favourable to this development than elsewhere. However, this great transformation was a European phenomenon and spread fast on the continent. Everywhere the rate of growth began to rise wherever new energy carriers began to be exploited by means of machines.

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