

ENERGY AND POPULATION IN EUROPE
The Medieval Growth
(10th-14th Centuries)

Paolo Malanima

Institute of Studies on Mediterranean Societies (ISSM)
National Research Council (CNR)

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www.paolomalanima.it
malanima@issm.cnr.it

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Historians agree that the long period between the 9th and the 14th century could actually be defined as a period of growth in Europe. Population rose, urbanisation spread both thanks to the formation of new centres and increase in numbers of inhabitants in the old ones, technical abilities developed and institutional changes supported this material progress of the European world. These four centuries set the bases of European identity from institutional, political, social and cultural viewpoints. Since information on demography and the economy during this long period of the European history is scanty, many doubts still remain regarding the character of this growth and its specific features. Although we know the order of magnitude of population and urbanisation around the year 1300, for the beginning of this phase of growth we have only rough information on the demography and urban inhabitants. The precise epoch when this new phase started is far from clear. Ordinarily the 9th and 10th centuries are considered probable.

A yet more complex task is to specify the character of this phase of growth. Was it an epoch of mere rise in population, but without any improvement in the standard of living of the individuals, or did it witness a true economic rise even in per capita terms? Economic historians label the first form of growth as *extensive* growth, and the second as *intensive* growth. Since any growth in population, must be supported by a rise in the endowment with energy and this endowment with energy is likely to increase even more whenever the multiplication of population is accompanied by improvements in the standard of living, it is reasonable to ask whether new energy sources began to be exploited or if exploitation of the old ones improved. The relationship between population and energy will therefore be the focus of our analysis.

It would be certainly too ambitious to aim at establishing certain figures regarding the medieval phase of growth. What we can more modestly do is to recall figures already proposed by past historians and demographers on population rise, evaluate their plausibility and speculate on the energy basis of medieval populations. While in the first two sections, I will examine the demographic trend and level attained by the population between 1000 and 1300, in the subsequent three sections some likely changes in the energy basis of the European civilisation will be suggested.

1. The European population

There is much indirect evidence on population growth during the high Middle Ages which is often recalled by the historians. While in the 7th–8th centuries density of population in the continent was low indeed and perhaps reached its nadir since late antiquity, in the following three-four centuries the number and size of inhabited areas increased, new centres of population multiplied, cities became more populous, deserted regions, especially in the east and north of the continent, began to be inhabited. Yet quantitative figures on population for this far age are almost entirely lacking; with the exception of scattered information in medieval censuses of land-ownerships (the so-called polyptics). Any quantitative attempt at estimating European population at the beginning of the phase of growth can proceed either from the information on the inhabited centres and population density in some areas then extended to wider regions, or from the population rate around 1300, going back to previous epochs through plausible rates of increase. If, for example, population in 1300 is estimated to be about 100 million inhabitants and we assume a rate of rise of something more than 2 per thousand, then the population around the year 1000 could be estimated about 50 million. With a rate of 3 per thousand, it would be 40 million. The starting point is simply reached through the following formula:

$$P_i = \frac{P_e}{(1+r)^n} \quad [1]$$

where P_i is the population at the beginning of the period (the unknown); P_e is the population at the end (100 million), r is the assumed rate of rise (something more than 2 per thousand – or 3 -- and therefore 0.002 per year – or 0.003 --) and n is the number of years between P_e and P_i (300 years in our example).

This is the method followed in the column 7 of Table 1¹, while in the other columns we find data proposed by historians and demographers on the European population between 1000² and 1500, with figures for the years 1000, 1300, 1400, 1500.

Table 1. Data on the European population between 1000 and 1500 (000).

	1 Uralanis	2 Mc Evedy- Jones	3 Biraben*	4 Russell	5 Le Bras	6 Maddison	7 Malanima
1000	56.400	36.000	43.000	38.500	43.000	39.200	47.000
1300	78.700	79.000	86.000	73.500	87.000		93.600
1400	78.100	60.000	65.000	50.000			67.800
1500	100.400	81.000	84.000	81.800	84.000	87.700	84.800

Sources:

1. B.T. Uralanis, *Rost Naselenie v Europe*, Moscow, Ogiz, 1941.

¹ Assuming the yearly per cent rise of 2.3 per thousand, plausible in the case of pre-modern economies.

² The information collected in the following Table 1 starts from 1000. This is, however, only a chronological simplification deriving from our ignorance about the starting period of the medieval demographic growth.

2. C. Mc Evedy, R. Jones, *Atlas of World Population History*, New York, Viking Penguin, 1978.
3. J.-N. Biraben, "Essai sur l'évolution du nombre des hommes", in *Population*, 34 (1969), pp. 13-25.
4. J.C. Russell, *European Population 500-1500*, in C.M. Cipolla (ed.), *The Fontana Economic History of Europe*, Glasgow-London, Collins, 1973, I, pp. 25-70.
5. H. Le Bras, *La popolazione*, in P. Anderson, M. Aymard, P. Bairoch, W. Barberis, C. Ginzburg (eds.), *Storia d'Europa*, I, Torino, Einaudi, 1993, pp. 71-130.
6. A. Maddison, *Contours of the World Economy, 1-2030 AD. Essays in Macro-Economic History*, Oxford, Oxford University Press, 2007.
7. P. Malanima, *Pre-modern European Economy. One Thousand Years (10th-19th Centuries)*, Leiden-Boston, Brill, 2009; and text.

* All Russia is included and not only the European part.

We see that the estimates for the beginning of the series range between 36 and 56 million. Between the lowest and the highest value, the range is wider than 50 per cent. If we exclude, however, the outlying figure proposed by Uralnis³, the range shrinks to 30 per cent. For 1300 a remarkable difference still exists between the highest (94 million) and the lowest figures (73 million): 20 per cent. For the year 1500 the difference between the extreme values is still about 20 percent. Yet excluding again the figure by Uralnis, the range diminishes drastically to 5 per cent.

Historical demographers suggest that the number of inhabitants in the 10th century was not so different from that of 5 centuries before and that between the 10th century and 1300, European population doubled.

Figure 1 shows both the demographic rise and the range of our uncertainty about the level (shrinking from the beginning to the end of our series). This does not mean that the real data are necessarily comprised in this range, but only that scholars place their uncertain figures within this range. The intermediary data of 1100 and 1200 have been adjusted assuming a trend described by a logistic curve according to the following equation:

$$P = \frac{P_{1300}}{1 + P_{1000} \cdot e^{-rt}} \quad [2]$$

where: P is the unknown, that is population in a given year (in our case in 1100 and 1200), P_{1300} is population around 1300, P_{1000} is population at the start of our period (that is in the year 1000), e stands for the Euler number 2.7182, r is the rate of demographic growth and t the years elapsed from the year 1000, the first year of our series.

In our series population diminished by about 25-30 percent with the Black Death. Recovery started from the middle of the 15th century. In 1500, however, population was still 10 per cent lower than in 1300, while in 1600 it was a little higher (10-15 per cent). Because of the uncertainty of our figures, however, we can wonder if the level reached by the population was actually higher in 1600 than in 1300 (a date for which the range of uncertainty is wider than for 1600). The demographic peak of 1300 was eventually exceeded only during the start of the demographic transition from the second half of the 17th century. During me-

³ Let's consider that the estimate by Uralnis is the earliest among those quoted on European population among those quoted.

dieval growth, Europe reached the demographic level it was later to maintain for several centuries.

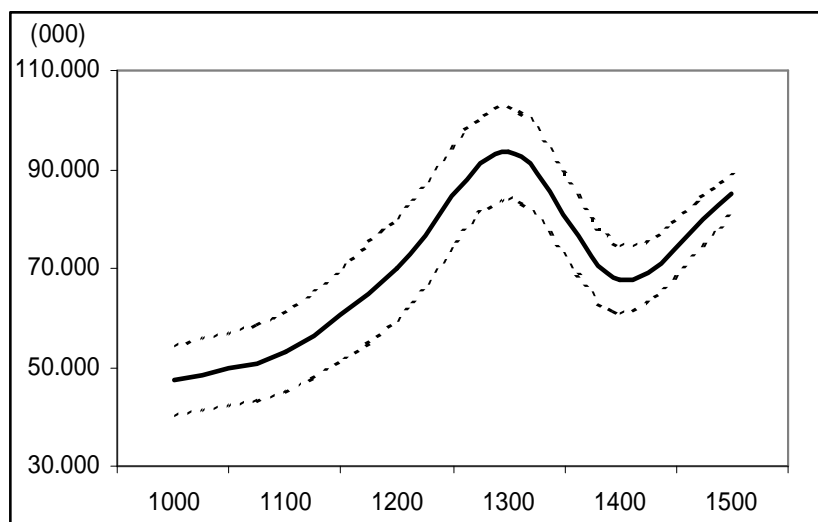


Figure 1. European population and range of uncertainty of our estimates from 1000 until 1300 (000).

Sources: the same of Table 1, col. 7. The dashed curves draw the range of uncertainty of our figures, diminishing from the beginning to the end of our series. The interpolation of the figures for 1100 and 1200 is adjusted in order to describe a logistic curve.

2. European population per area

Much less is known about the population per country or area. Our data for the start of demographic growth are simply calculated going back from the figures for 1300 and assuming the same rate of growth by any region during the late 15th and 16th centuries (Table 2)⁴.

Table 2. European population per area 1000-1500 (000).

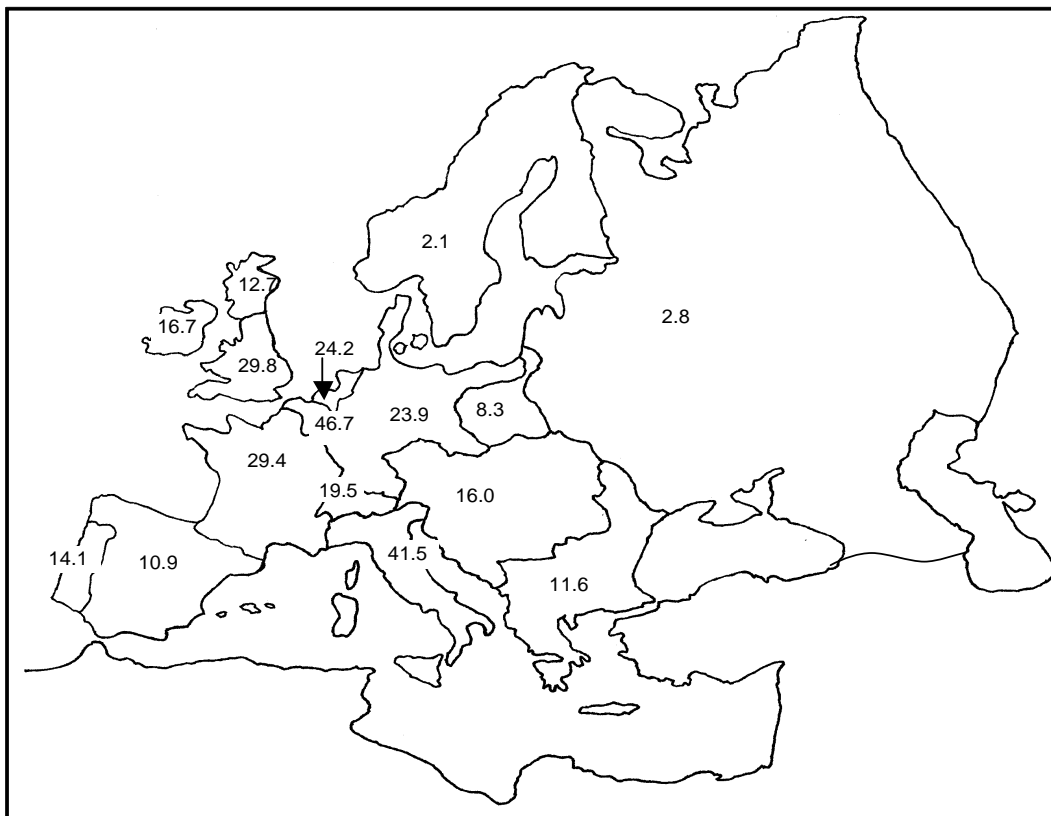
	1000	1100	1200	1300	1400	1500
Scandinavia	1,100	1,300	1,900	2,500	1,400	1,500
England (Wales)	2,100	2,500	3,600	4,500	2,700	3,500
Scotland	580	700	900	1,000	700	800
Ireland	750	800	1,100	1,300	700	800
Netherlands	200	250	400	800	600	950
Belgium	600	700	1,000	1,400	1,200	1,300
France	8,400	10,000	14,000	16,000	12,000	15,000
Italy	5,800	7,000	9,900	12,500	8,000	9,000
Spain	2,900	3,500	4,900	5,500	4,500	5,000
Portugal	950	1,000	1,200	1,300	1,050	1,200
Switzerland	280	350	500	800	500	800
Austria (Czech., Hung.)	5,900	7,000	9,000	10,000	9,000	11,500
Germany	4,500	5,000	7,800	13,000	8,000	11,000

⁴ With the exception of Belgium. In this case I assumed the estimate proposed by Uralnis for 1000.

Poland	900	1,200	1,500	2,000	1,500	2,000
Balkans	3,600	4,300	5,000	6,000	5,000	5,500
Russia (European)	8,500	10,000	14,000	15,000	11,000	15,000
EUROPE	47,060	55,600	76,700	93,600	67,850	84,850
EUROPE (without Russia)	38,560	45,600	62,700	78,600	56,850	69,850

Sources: P. Malanima, *Pre-modern European Economy*, chap. I, and text, for the borders of any region and the sources of the data for 1300, 1400 and 1500. Data for the year 1000 have been computed according to equation (1); for the years 1100 and 1200 they have been calculated adjusting equation (2) that refers to the whole continent (the rate of growth is low in the 11th century, increases in the 12th, and diminishes in the 13th).

In 1300 the density of population was already high in the central belt of Europe running from Italy through France, until Flanders, Holland and England. Both going west, toward Spain and Portugal, and east, toward Poland, Hungary, the Balkans and Russia, population density declined fast (see Map).



Map. Population density in 1300 Europe (inhabitants per km²).

Source: Table 3.

A comparison of urbanisation in 1300 with urbanisation before this data is not easy at the moment, given the scarcity or lack of information on urban population before the 14th century (Table 3). Historians have stressed, however, the increase in the number and population of the urban centres as a landmark of the

medieval European civilisation and it is ordinarily assumed that urbanisation was rising during the high Middle Ages. The results of a recent estimate of the western European centres with more than 10,000 inhabitants indicate that there were 74 of these around 1000 and 156 around 1300. In the same period, the urbanisation ratio would have risen from 5.8 per cent to 6.5: a modest increase indeed. The rise is higher if the value for 1300 is compared to that of 900 when urbanisation in western Europe has been estimated 3.5 per cent.⁵ If we consider as cities the centres with more than 10,000 inhabitants, in the Europe of 1300 (as a whole and not only western Europe, as in the previous estimate) 210 cities could be counted and the urbanisation rate was about 5 per cent⁶. The most urbanised regions were Italy and Flanders, with 18 per cent of the population living in towns of more than 10,000 inhabitants. Spain as well boasted a high level of urbanisation (12 per cent). In some regions, such as Scandinavia, Scotland and The Netherlands no city reached the threshold of 10,000 inhabitants. As we see, only in part did urbanisation coincide with high population density. Densely populated countries such as England and France did not exceed the European average rate of urbanisation, while, by contrast, Spain was highly urbanised, although scarcely populated.

Table 3. Extent of the European regions (000), density of population and urbanisation rate in 1300 (towns with over 10,000 inhabitants).

	Km² (000)	1300 density	1300 urbanisation
Scandinavia	1,198	2.1	0.0
England (Wales)	151	29.8	4.0
Scotland	79	12.7	0.0
Ireland	84	15.5	0.8
Netherlands	33	24.2	0.0
Belgium	30	46.7	18.8
France	544	29.4	5.2
Italy	301	41.5	18.0
Spain	505	10.9	12.1
Portugal	92	14.1	3.6
Switzerland	41	19.5	3.0
Austria (Czech., Hung.)	626	16.0	0.6
Germany	543	23.9	3.4
Poland	240	8.3	1.0
Balkans	516	11.6	5.2
Russia (European)	5,400	2.8	2.1
EUROPE	10,383	9.0	5.3
EUROPE (without Russia)	4,983	15.8	5.4

⁵ M. Bosker, E. Buringh, J.L. Van Zanden, "From Baghdad to London. The Dynamics of Urban Growth in Europe and the Arab World, 800-1800" (forthcoming; provisional draft).

⁶ P. Malanima, *Pre-modern European Economy*; P. Malanima, "Decline or Growth? European Cities and Rural Economies, 1300-1600" (forthcoming).

Source: Table 2, P. Malanima, *Pre-modern European Economy* and Malanima, "Decline or Growth? European Cities and Rural Economies, 1300-1600" (forthcoming). The urbanisation rate of Italy actually refers only to the centre and north.

Whenever population grows in number, energy sources have to grow at the same rate in order to support the same standard of living. Whenever an intensive form of growth occurs, per capita energy must grow or the existing energy carriers must be more efficiently exploited. Now, we have just seen that during the 3-4 centuries of medieval growth, population doubled, that is it increased by about 50 million. If we optimistically assume that for survival an inhabitant needed 2 hectares of arable (fallow land included), forest and meadows (to feed working animals), then the exploitable surface in order to meet the needs of 50 million inhabitants was 1 million km², that is 10 per cent of the whole extent of Europe if we comprise European Russia (which represents half the extent of Europe within present borders), and 20 per cent excluding it.⁷

Any calculation of this kind is only a rough approximation. Naturally the need of forest was much higher in cold, northern Europe than the south. Also whenever we refer to arable soil, the required amount of land to support a person differed as land productivity was diverse. Because the dry European agriculture needed working animals, the demand for land was inevitably greater. In any case a massive effort was required in order to support the doubling of the population. Excluding Russia, we can estimate that medieval demographic growth had to be supported by the colonisation of one third of the total extent of the continent, if we exclude lands where survival was impossible as in the case of high mountains.

The question is: what changes did occur in the energy basis during medieval growth?

3. *Energy sources of the agricultural civilisations*

Today the daily consumption of energy on the world scale is 50,000 kilocalories per capita. In Europe it is notably higher: 150,000 kilocalories. At the beginning of modern growth in the first decades of the 19th century, however, about 10 times less energy was consumed: 5,000 kilocalories on the daily world scale and 15,000 in Europe⁸. Despite the growing exploitation of coal, energy consumption in Europe was still based on the traditional carriers of any agricultural society: food first of all, and then firewood and fodder for working animals. A relatively small contribution came from two other carriers: falling water, whose potential energy was exploited by watermills, and wind, utilized both by sailships, boats and mills. Water and wind were the only non organic sources of energy. If we exclude these carriers, the original source of energy since the beginning of the human species had been, obviously, food. The second source was firewood, discovered between one million and half million years ago. The third source, fodder for working animals, began to be exploited on a wide scale by agricultural civilisations between 5,000 and 4,000 years B.C., that is when the taming of animals

⁷ I presented an estimate of the extent of land necessary to provide the energy in pre-modern Europe in P. Malanima, "The Energy Basis for Early Modern Growth 1650-1820", in M. Prak (ed.) *Early Modern Capitalism. Economic and Social Change in Europe, 1400-1800*, London and New York, Routledge, 2000, pp. 51-68.

⁸ I examined the topic of energy consumption in pre-modern Europe in P. Malanima, *Energia e crescita nell'Europa preindustriale*, Roma, La Nuova Italia Scientifica, 1996.

and their exploitation in agricultural labour and transport began. Food and fodder were, so to speak, the fuels of animate, biological converters and their shares were similar in the overall energy balance. Their joint contribution was equal to that of wood: about 50 per cent in southern Europe and less in the north, where firewood constituted a higher share. They were also the main sources of mechanical energy, since, through their metabolism, they provided almost the totality of work power.

At the beginning of the 19th century, the contribution of water and wind to the overall energy consumption was modest indeed. Even though we assume that watermills, windmills and sails, whose number and power are known for several European countries, functioned all day long and their contribution to consumed energy is divided among the population, the result seldom exceeds 1-3 per cent of the total energy consumption⁹.

All these forms of energy are reproducible and will in all likelihood remain so for some 5 billion years, that is for as long as the sun's rays will continue to reach the Earth. These are organic vegetable sources, while fossil sources are organic mineral¹⁰. They may effectively be considered as inexhaustible sources. In the long run their availability is without limits. Yet in the short run it is hard to increase their exploitation. Sunlight can be employed more advantageously by increasing the number of cultivated areas, managing woodland with greater efficiency and harnessing more effectively the power of the wind and water. These are, however, slow processes which increase human strength only in the long term. It is easy, by contrast, to extract ever larger quantities of crude oil or coal. Although growth existed before modern times, the increase of production in those pre-modern epochs met with difficulties in energy availability that were virtually impossible to overcome on a short-term basis.

4. *Energy in the high Middle Ages*

We can only speculate about energy consumption during the high Middle Ages. Deviations in food consumption from the average of 2-3,000 kilocalories per day can not be too great. Information relating to the early modern centuries suggests, furthermore, that a technical ratio existed in Europe between working animals and population: an ox or horse every 4-7 people¹¹. Since, taking into account their size, any medieval draft animal needed about 20,000 kilocalories in fodder per day, then a European inhabitant had to avail himself of a further 2,800-5,000 kilocalories in order to feed the animal. Considering a draft or transport animal as a machine, we merely divide daily fodder consumption by the population. Variations in firewood consumption were sharp in different European regions. While in the south 1 kg, or 3,500 kilocalories, could be enough per head, in the extreme north any inhabitant had to consume 5 kg or more, including the industrial uses of fuel.

⁹ Malanima, *Pre-modern European Economy*, chap. II.

¹⁰ As defined by E.A. Wrigley, *Continuity, Chance and Change. The Character of the Industrial Revolution in England*, Cambridge, Cambridge University Press, 1988.

¹¹ A. Kander, P. Warde, "Energy Availability from Livestock and Agricultural Productivity in Europe, c. 1800-1913: a New Comparison" (forthcoming). See also the figures proposed in P. Malanima, *Energia e crescita*.

Thus the energy balance of medieval Europeans can be synthesized by the following equation:

$$c = \frac{F_h}{N} + \frac{F_a}{N} + \frac{F_i}{N} + \frac{W}{N} \quad [3]$$

where c is per capita consumption of energy, F_h , F_a , F_i and W , respectively the total consumption of food for humans, fodder for working animals, firewood and both water and wind-power, and N population. Only a small part of the whole energy input was converted into useful energy, that is mechanical work or heat that people could actually exploit. If we divide useful energy (E_u) by the total energy input (E_t), and multiply by 100, the result, that is the efficiency in the exploitation of energy, is about 15-20 per cent in pre-modern agrarian societies, while today, in our modern economies, it is about 30 per cent¹²:

$$\eta = \frac{E_u}{E_t} \cdot 100 \quad [4]$$

Arables. Medieval colonisation came about over a period of time from the 10th century to the 14th century. The boundaries of farming shifted and woodland regions were cultivated for the first time. From the 10th century onwards settlements multiplied, along with the conquest of new agricultural lands. Furthermore, through the initiative of the lords, castles were built and scattered inhabitants of the region concentrated around these built up areas protected by fortifications¹³. This is another aspect of demographic expansion and human conquest of space. Among the settlement processes, which took place on the continent, one of considerable importance was that which occurred from the 12th century onwards, beyond the river Elba¹⁴. A veritable migration took place. Thousands and thousands of German settlers flooded into Eastern Europe. The European border was pushed further east and thousands of farming villages were created. In East Prussia alone there were as many as 1,400, with a population of about 150,000 people.

On the basis of European and non-European examples, an elasticity of woodland to population rise of -0.6 has been recently estimated, which means that an increase of 10 per cent in population implies a reduction of woodland by 6 per cent¹⁵. This means that during the centuries of the medieval European demographic rise, forests diminished by 30 per cent and their area was replaced by arable lands.

Firewood. During the later centuries of Roman civilisation, forests had been cut down in many densely inhabited areas of the Mediterranean. Dense woods

¹² P. Malanima, *Pre-modern European Economy*, chap. II.

¹³ See the important work by P. Toubert, *Les structures du Latium médiéval*, Roma, Ecole Française de Rome, 1977, which refers to Italy.

¹⁴ H. Aubin, "Medieval Agrarian Society in Its Prime: The Lands East of the Elbe", in M.M. Postan (ed.), *Cambridge Economic History of Europe*, I, Cambridge, Cambridge University Press, 1966, pp. 449-506.

¹⁵ O. Saito, 'Forest History and the Great Divergence: China, Japan and the West Compared', in *Journal of Global History*, 4 (2009), pp. 379-404.

still existed in numerous uninhabited or scarcely populated zones of northern and eastern Europe. Following the fall of the Roman Empire in the west, population declined in the Mediterranean regions and consequently forests grew up again. There were less than 30 million people living in Europe in the 8th century, with demographic density at below 3 inhabitants per kmq¹⁶.

From the 10th century onwards demographic growth began to intensify in Europe thus forcing forests to be cut back. As the demand for food gradually increased, farming families, monasteries, and landowners cleared gaps in the thick forests in order to gain land for agriculture. Cultivated lands extended north, south and to the east, where German settlers searched for land to cultivate.

The attack on the forests concerned not only Europe, but also China, where in the high Middle Ages there was a sharp rise in population. Many forests were cut down to meet heating requirements as well as for building and industrial use, especially for the casting of metals. One consequence was the increase of the use of coal in metal working during the high Middle Ages¹⁷.

In Europe, from the 13th century onwards, the increasingly widespread destruction of woodlands by the population began to be seen as dangerous, and, by the end of the century, the first laws appeared, attempting to limit the felling of forests. According to the Domesday Book of 1086, 15 per cent of the land surface of England was woodland. Over the next two centuries between one third and one half of this area had been cleared¹⁸.

Wood was not only necessary for building and heating, but also for use in many industries. Wood and charcoal were used in breweries, potteries, salt refineries, dye-works, bakeries, and distilleries, but above all for working metals. The ratio between charcoal used and iron obtained was 16 to 1. According to another calculation it was necessary to process 200 kg of minerals and burn 25 square metres of wood to obtain 50 kg of iron¹⁹.

It has been previously seen that rising population implied a reduction of forests of about 30 per cent. We know that, at the end of the 19th century, woodlands represented 30 per cent of the whole surface of the continent and that the strong demographic rise from the end of the 17th century meant a remarkable decline in the extent of woodland areas. If, as already recalled, the high medieval decline of woods was about 30 per cent and at the beginning of demographic growth forests presumably covered 70-80 per cent²⁰, then in the 14th century they covered 40-50 per cent of the entire surface of the continent.

¹⁶ Ch. Higounet, "Les forêts de l'Europe occidentale du V^e siècle à l'an mil", in *XIII settimana di studi del Centro italiano di studi sull'alto Medioevo (Spoleto 1965)*, Spoleto, CISAM, 1966, pp. 343-99.

¹⁷ M. Elvin, *The Pattern of the Chinese Past*, Stanford, Stanford University Press, 1973, p. 85; and above all R. M. Hartwell, "A Cycle of Economic Change in Imperial China: Coal and Iron in North-East China, 750-1350", in *Journal of the Economic and Social History of the Orient*, X (1967), pp. 478-92.

¹⁸ E.A. Wrigley, "The Transition to an Advanced Organic Economy: Half a Millennium of English Agriculture", in *Economic History Review*, II s., LIX, 2006, 3, pp. 435-80. p. 439, n. 18 (on the basis of O. Rackam).

¹⁹ R.F. Tylecote, *Metallurgy in Archaeology*, London, Arnold, 1962, pp. 190-1; R.F. Tylecote, "Furnaces, Crucibles, and Slags", in T.A. Wertime e J.D. Muhly (eds.), *The Coming of the Age of Iron*, New Haven and London, Yale University Press, 1980, p. 183; J. Schneider, "Fer et sidérurgie dans l'économie européenne du XI^e au XVII^e siècle", in *Actes du colloque international "Le fer à travers les âges"*, Nancy, Annales de l'Est, 1956, p. 125.

²⁰ C.H. Higounet, "Les forêts de l'Europe occidentale du V^e siècle à l'an mil".

Other fuels: Coal was almost unknown in the ancient world. Already widely utilised in medieval China, it only started to be used in Europe to a limited degree at the end of the 12th century. We know that it was extracted in 1200 in England, Scotland and in the Netherlands, around Aachen, in Franche-Comté, near Lyon, in Forez and in Anjou²¹. Limited quantities were transported by sea and therefore consumed in places some distance from the mine. In the 13th century coal from Northumberland was transported not only to London, but also to the Netherlands²². Peat, another fossil fuel, which had formed over the centuries in areas of marshland, was already employed when the Romans reached the Dutch plains. During the 11th–12th century its use spread with the population.

In the 15th century coal and peat were widely used around Liège and near Newcastle. In urbanised, therefore deforested, areas such as Flanders, such quantities of peat were used as to exhaust the peat fields. Further supplies were sought elsewhere, to the north of Antwerp and near Utrecht²³.

Draft animals. From the 8th century onwards, animal power began to be employed to a much greater extent on the European continent. It has been calculated that, as a result of this progress, 70 percent of the available mechanical energy in 11th-century England was provided by working animals (still mostly oxen in that period) and only the remaining 30 per cent by human muscle power or by water mills²⁴. Although we assume a more modest increase in the use of horses outside England, we can, nonetheless, suppose a rise in the availability of energy per capita in the high medieval centuries.

In the early Middle Ages horse power was little used and, as in ancient times, the horse was still considered a war machine. Horses were not exploited in agriculture and were expensive, owned only by rich people. In Anglo-Saxon documents of 7th century England, for example, the horse is never mentioned as a working animal²⁵. In early 9th-century France only the ox appears as a working animal in the fields, whereas the horse is employed exclusively for the transportation of people and goods.²⁶

Technical and organisational innovations, even when not developed to harness a new source of energy, favoured a more productive use of the energy and materials already employed. Innovations of this type were not uncommon in western European agriculture. It is difficult to say exactly how far these innova-

²¹ J. Nef, "Mining and Metallurgy in Medieval Civilization", in M.M. Postan, P. Mathias (eds.), *Cambridge Economic History of Europe*, II, Cambridge, Cambridge University Press, 1952, pp. 691-761.

²² M. Postan, "The Trade of Medieval Europe: the North", in M.M. Postan, P. Mathias (eds.), *Cambridge Economic History of Europe*, II, Cambridge, Cambridge University Press, 1952, pp. 240-304.

²³ J.W. De Zeeuw, "Peat and the Dutch Golden Age. The Historical Meaning of Energy-Attainability", in "A.A.G. Bijdragen", 21, 1978, pp. 3-32.

²⁴ J. Langdon, *Horses, Oxen and Technological Innovation. The Use of Draught Animals in English Farming from 1066-1500*, Cambridge, Cambridge University Press, 1986, p. 20. In this estimate only mechanical energy is included. See also Langdon, "The Use of Animal Power from 1200 to 1800", in S. Cavaciocchi (ed.), *Economia e energia Secc. XIII-XVIII*, Firenze, Le Monnier, 2003, pp. 213-21. See also P. Vigneron, *Le cheval dans l'antiquité gréco-romaine*, Nancy, Annales de l'Est, 1968, R. Lefebvre De Noëttes, *L'attelage. Le cheval de selle à travers les âges. Contribution à l'histoire de l'esclavage*, Paris, I, 1931 ; A.G. Haudricourt, M. J-B. Delamarre, *L'homme et la charue à travers le monde*, Paris, Gallimard, 1955.

²⁵ Langdon, *Horses, Oxen and Technological Innovation*, p. 26.

²⁶ C. Parain, "The Evolution of Agricultural Techniques", in M.M. Postan (ed.), *Cambridge Economic History of Europe*, I, Cambridge, Cambridge University Press, 1966.

tions increased man's capacity to exploit the environment to his advantage. The first appearance in Europe of a new type of harness dates back to the 6th century²⁷. The most important new tool for agriculture in medieval Europe was the *heavy, asymmetric plough*, which became a well-known piece of equipment in the central-northern areas of the continent²⁸.

The exploitation of horse power was most intense in northern Europe and particularly in England and the Netherlands. Certainly the wider exploitation of animal power was an important support to the colonisation of northern Europe during the high Middle Ages and was, as suggested, the cause of the changing demographic balance between the south and the north. Europe was becoming more and more continental and ever less Mediterranean²⁹.

Water and wind. Until a few decades ago, the opinion prevailed that the water mill, although an ancient invention, was definitely a medieval "innovation"; it spread that is during the high Middle Ages. It was commonly believed that water mills, after enjoying a short-lived period of technological development in the late Roman Empire, rapidly declined and almost disappeared in the early Middle Ages. Only from the 9th-10th centuries onward did mills spread again thanks to the initiative of monasteries and feudal lords. The span of time between the 9th century and the 12th century is usually regarded as a period of rapid progress in water technology. Mills began to be used not only to grind cereals, but also for many different kinds of industrial work. Around the time of the Domesday Book, in the late 11th century, the population-waterwheels ratio had already reached the level it was to maintain for the following centuries until the beginning of economic modernization³⁰. In their important studies, both M. Bloch³¹ and L. White³² support this notion of technological progress in the Middle Ages. Several scholars argued that an industrial revolution had taken place in the central centuries of the Middle Ages³³ and that this revolution had been supported by the rise in energy availability.

As landmarks of this revolution the following novelties have often been quoted. The spread and eventually the prevailing of the overshot vertical mill, much more efficient than the old horizontal water mill, is often credited as having opened a new phase in the history of water technology. Because of its higher power yield, the vertical wheel found application in many different industrial sectors³⁴. The cam was until a few years ago believed to have been a 10th-century

²⁷ Langdon, *Horses, Oxen and Technological Innovation*, pp. 9 ff. C. Parain, "The Evolution of Agricultural Techniques", anticipates it during the 5th-7th centuries.

²⁸ On the topic, see particularly Haudricourt, Delamarre, *L'homme et la charrue*.

²⁹ Russell, "European Population 500-1500".

³⁰ M.T. Hogden, "Domesday Water Mills", in *Antiquity*, XIII (1939), pp. 261-79.

³¹ M. Bloch, "Avènement et conquête du moulin à eau", in *Annales d'histoire économique et sociale*, VII, 1935, pp. 538-63.

³² L. White Jr., *Medieval Technology and Social Change*, Oxford, Oxford University Press, 1962.

³³ B. Gille, "Le moulin à eau, une révolution technique médiévale", in *Techniques et civilisations*, III (1954), pp. 1-15.; E. Carus-Wilson, *Medieval Merchant Venturers*, London, Methuen, 1954.

³⁴ See especially J.H. Munro, "Industrial Energy from Water-Mills in the European Economy, 5th to 18th Centuries: the Limitations of Power", in S. Cavaciocchi (ed.), *Economia e energia Secc. XIII-XVIII*, Istituto Internazionale di Storia economica "F. Datini", Firenze, Le Monnier, 2003, pp. 223-69, who summarizes many previous works on this subject.

invention³⁵ that allowed rotary motion to be converted into alternate motion, and thus set the basis for all further progress in the use of hydropower. Amongst the new industrial applications of water as energy carrier were the fulling mill, water-powered suction pumps in the mines, hydro-powered bellows and the blast-smelter in metallurgy, paper mills, and silk-throwing mills. As we go back in time, however, we find out that these innovations are only apparently such. In many cases, recent archaeological investigations indicate that they were already employed in ancient times. We have furthermore to stress that the addition of new power from the water-mill was relatively limited.

From our late medieval-early modern documentary sources, we know that the power of an ordinary water-mill seldom exceeded 3 HP, and was often lower -- around 2 HP or less --. By way of a comparison, ordinary Watt steam engines in 1800 had 10 times this power. Let us make some calculations assuming a power of 2 HP. If a grain-grinding water mill with a power of 2 HP worked 12 hours a day, its daily energy consumption would have been 24 HPh (HPh being a measure of the energy consumed, while HP is a measure of power). The mechanical work it performed in 12 hours hence amounted to 24 HPh. One HPh being equal to 736 Watthours, 24 HPh are equal to 17,986 Watthours or 15,475 kcal. This was therefore the energy output of a water mill working half a day. If we assume a ratio watermill-population of 1 every 300, we conclude that inhabitants could each enjoy 50 kilocalories more with the instalment of a watermill. If we also assume that per day consumption by any inhabitant was 10,000 kcal, then a watermill contributed by 0.5 per cent to the energy balance.

Something similar can be said about windpower, although, in this case we have to distinguish between the wind used for mills from the wind used for sails. The wind-mill supposedly originates from Asia. The first evidence we possess refers to the 7th century AD³⁶. Whatever the origins really were, windmills were long known in Europe as Persian mills. Thus were they mentioned in one of the first, if not the first, account of windmills in Europe: the *Book of King Ruggero*, written in 1154 by the Arabian geographer al-Idrisi. In Sicily, al-Idrisi wrote, in Calatubo, near Erice, on the extreme southwest point of the island, "exists a quarry where they cut stone for the use of mills driven by water and for those called <<Persan>>"³⁷.

The regions in which wind power played a more important role were the great plains of northern and western Europe, where the winds are constant and there are no mountains; from northern France, to Holland, Denmark and then inland as far as Poland and Russia. In any case windmills only became important

³⁵ The issue is discussed in P. Malanima, "The First European Textile Machine", in *Textile History*, XVII (1986), pp. 115-27, and P. Malanima, *I piedi di legno. Una macchina alle origini dell'industria medievale*, Milano, Franco Angeli, 1988 and K.H. Ludwig, "Die Innovation der Nockenwelle im Übergang vom Früh- zum Hochmittelalter. Eine Skizze Quellenprobleme unter besonderer Berücksichtigung der Walkmülen", in *Technikgeschichte*, 61 (1994), pp. 227-38.

³⁶ R.J. Forbes, "Power", in Ch. Singer, E. J. Holmyard, A. R. Hall, T. I. Williams (ed.), *A History of Technology*, New York-London, Oxford University Press, 1956, II, pp. 589-628.

³⁷ Idrisi, *Il libro di Re Ruggero*, in M.G. Stasolla (ed.), *Italia euro-mediterranea nel Medioevo: testimonianze di scrittori arabi*, Bologna, Patron, 1983, p. 118. For the origins of the windmill see E.J. Kealey (1987), *Harvesting the Air. Windmill Pioneers in Twelfth-Century England*, Woolbridge, Boydell Press, p. 69 and J. Langdon, "Water-mills and Windmills in the West Midlands, 1086-1500", in *Economic History Review*, II s., XLIV (1991), p. 433 (n. 21) who criticises Kealey for his dates.

engines after the medieval growth and did not contribute at all to the energy balance during the high and late Middle Ages.

Whilst the use of wind power for milling was an innovation of considerable economic influence, the modifications in the use of the wind for navigation were less important and only marginally concerned the use of energy³⁸. Although the harnessing of wind power in navigation was not a real innovation, uninterrupted progress occurred in quantity: increase in the number of sails on the seas implied a growth in the magnitude of energy exploited³⁹. For the second half of the 15th century the carrying capacity of the European fleet has been estimated between 200,000 and 350,000 tons.

5. *Climate and energy*

Could the above mentioned energy sources have represented the only support of medieval demographic growth? Some doubts remain. We saw that engines such as water-mills, often mentioned as the vital components of the medieval energy revolution, actually played a quite marginal role. Colonisation contributed to the increase of energy availability in the form of food and fodder. On the other hand the extension of the arables increased at the expense of the forests.

When speaking of energy in pre-modern times, however, we often neglect the role played by climate and climatic changes. 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. While warm periods were favourable to the spread of cultivations and the multiplication of mankind, cold epochs were correlated with demographic declines. Roman civilisation 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. During the following period, long phases of temperature variations were detected, though within a relatively warm post-glacial era⁴⁰. There were warm millennia from 8500 to 1500 BC, after which a long cold period ensued. We know, how-

³⁸ See R.W. Unger, *The Ship in the Medieval Economy*, London-Montreal, Croom Helm, McGill-Queen's University Press, 1980, pp. 29 ff.

³⁹ R.W. Unger (1980) *The Ship in the Medieval Economy* is an important work on the topic.

⁴⁰ Two introductions to the topic of climate over very long periods are those of E. Le Roy Ladurie, *Histoire du climat depuis l'an mil*, Paris, Flammarion, 1967, and M. Pinna, *La storia del clima. Variazioni climatiche e rapporto uomo-clima in età post-glaciale*, Roma, Società Geografica Italiana, 1984.

ever, that temperatures slowly increased in the 3rd century B.C. reaching a peak towards the beginning of our era and then declined in the 2nd century A.D.⁴¹

The recently obtained series of annual temperatures in the northern hemisphere clearly show a declining trend in the early Middle Ages⁴². Temperatures remained low until the beginning of the so-called Medieval Climatic Optimum, which lasted from the 9th century until 1250-1300⁴³. It became possible to cultivate land located in cold regions and therefore feed an increasingly larger population⁴⁴ (Figure 2). Moreover, the higher temperature resulted in the formation of greater biomass for both men and working animals. The growth in population during the medieval period, and indeed of production in general, depended not only on the conscious efforts of men to harness new energy sources by means of new converters, but also on the variation in the availability of energy due to climatic phenomena.

Decadal data contribute to clarify the overall trend in the northern hemisphere (Figure 3).

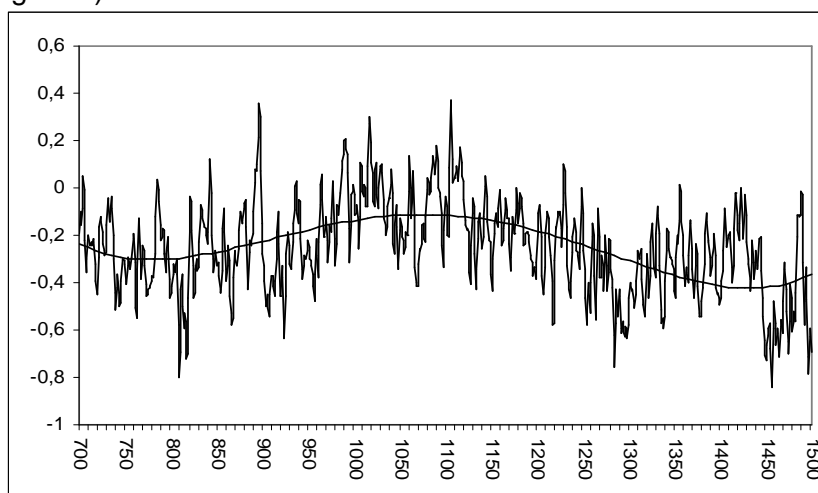


Figure 2. Temperature in the northern hemisphere from 700 until 1500.

⁴¹ An overview is proposed by M. Pinna, *Le variazioni del clima. Dall'ultima grande glaciazione alle prospettive per il XXI secolo*, Milano, F. Angeli, 1996, pp. 118 ff. For a recent long-term reconstruction, see B.E. Berglund, "Human Impact and Climate Changes -Synchronous Events and a Causal Link? ", in *Quaternary International*, 105, 2003, pp. 7-12.

⁴² On the temperature-economy relationship in the late Middle Ages, see B. Campbell, "Cause and Effect? Physical Shocks and Biological Hazard. The Crisis of the XIVth Century Revisited", in S. Cavaciocchi (ed.), *Le interazioni fra economia e ambiente biologico nell'Europa preindustriale*, Istituto Internazionale di Storia Economica (2009), Firenze, Firenze University Press, 2010; B. Campbell, "Nature as Historical Protagonist. Environment and Society in Pre-industrial England", in *Economic History Review*, 63, 2 (2010), pp. 281-314.

⁴³ A general approach to climate in the past millennium is provided by R.S. Bradley, K.R. Briffa, J.E.Cole, M.K. Hughes, T.J. Osborn, "The Climate of the Last Millennium", in K. Alverston, R.S. Bradley, T. Pedersen (eds.), *Paleoclimate, Global Change and the Future*, Berlin, Springer, 2003, pp. 105-44, and by C. Pfister (), "I cambiamenti climatici nella storia dell'Europa. Sviluppi e potenzialità della climatologia storica", in L. Bonardi (ed.), *Che tempo faceva? Variazioni del clima e conseguenze sul popolamento umano. Fonti, metodologie e prospettive*, Milano, F. Angeli, 2003, pp. 15-59.

⁴⁴ M.E. Mann, "Medieval Climatic Optimum", in *The Earth System: Physical and Chemical Dimensions of Global Environmental Change*, 1, in T. Munn (ed.), *Encyclopedia of Global Environmental Change*, Chichester, Wiley, 2002, pp. 514-16.

Source: A. Moberg, D.M. Sonechkin, K. Holmgren, N.M. Datsenko, W. Karlén, "Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data", in *Nature*, 433 (2005), No. 7026, pp. 613-17.

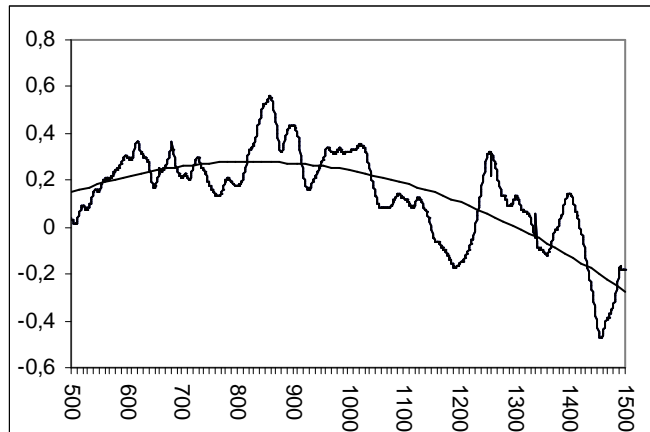


Figure 3. Temperature in the northern hemisphere from 500 until 1500.

Source: C. Lohéle, "A 2000-Year Global Temperature Reconstruction Based on Non-Treering Proxies", in *Energy and Environment*, 18 (7-8) (2007), pp. 1049-58.

With the increasing density of population in northern Europe, the possibility of cultivating lands located at higher latitudes and on the hills enabled to increase both the production of the arables and forests. It may be noted that temperatures in the Alps increased from the 8th century until the second half of the 13th century (Figure 4).

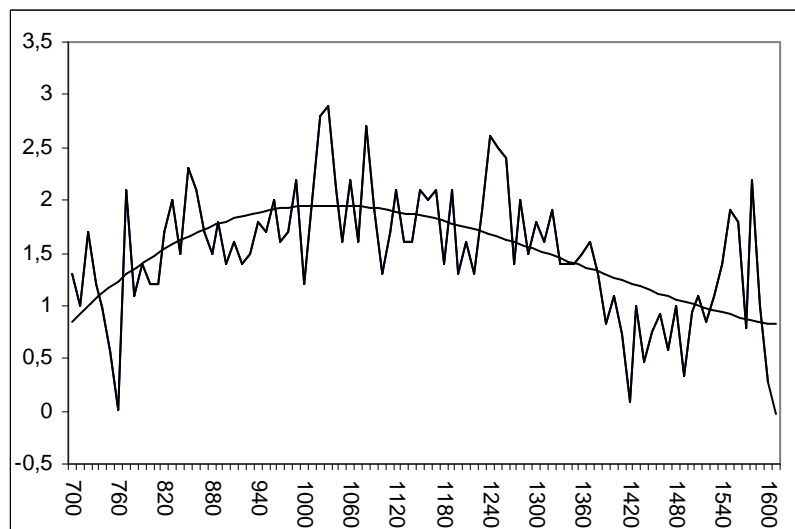


Figure 4. Temperature in the Alps from 700 until 1600.

Source: A. Mangin, C. Spötl, P. Verdes, "Reconstruction of Temperature in the Central Alps During the Past 2000 years", in *Earth and Planetary Science Letters*, 235 (2005), 3-4, pp. 741-51.

Many historians have suggested an interruption in the rise of population as from the beginning of the 14th century and again only a few decades after the end of the favourable climatic phase. At this moment in time we lack evidence about

a relationship between climatic evolution and the Black Death. Recently, however, B. Campbell stressed that the outburst of the plague, not long after the climatic change, might not be merely circumstantial

As far as we know, the demographic rise experienced by Europe was shared by other civilisations at the same time. Information on China and India confirms that growth in population was a worldwide phenomenon during the high Middle Ages⁴⁵. If it is so, then similar causes were at work in different parts of the world despite the specific characters and historical developments of diverse civilisations. In this case, the only possible cause both in Europe and elsewhere in the northern hemisphere was climate.

Conclusion

The doubling of the population in Europe, from about 50 to 100 million between the 10th and the 14th centuries, implied a relatively low average rate of growth per year: around 2 per thousand and then some 5 times less than in the 19th century. However, this represented a relatively high increase when compared to the demographic rise characteristic of the agricultural economies. It was not until after a long period of approximately three centuries that the level of the European population around 1300 was exceeded. Only from then onwards, with the start of the energy transition, did the European population begin to rise rapidly for about three centuries.

Medieval demographic rise implied a strong effort by the European populations in order to develop energy availability. The main feature of the pre-modern energy systems, that is the vegetable organic base, did not favour the easy rise in energy availability. Colonisation of new lands in the north and east increased the arables and allowed for the support of more inhabitants and draft animals. This increase of the energy basis occurred at the expense of the forests and implied the resorting to mineral energy carriers such as coal and peat. Even allowing for the progress of cultivation and the exploitation of new sources, it seems that the mere extension of the arables would not explain periods of intensive growth that the rising urbanisation seems to suggest. If we accept a demographic rise of 0.2 per cent per year and some increase in output per head then output could have grown a little more than population. Would an increase of 0.5 per year be plausible? In any case, growth in output per capita would hardly have been perceptible by the people of that time. Climatic changes played a decisive role in the energy availability and resulted in periods of rise both in population and even more so in output. Their role was much more important than the often recalled institutional and social changes taking place over the same long period. The end of the Medieval Climatic Optimum, in the last decades of the 13th century contributed to favour (or even determined) the interruption of medieval growth in the central centuries of the Middle Ages. The European populations had to wait at least three centuries for a new epoch of growth, this time much faster than ever before.

⁴⁵ Biraben, "Essai".