

# Patterns of Energy Transitions

## The Long-Term Role of Energy in the Economic Growth of Europe

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Debates and analyses on the role of energy consumption in economic growth and its environmental impact are of central interest today. Most studies, however, rely on post-1960 data and they usually focus on a single country or region, with a limited perspective on the past. In this article, the topic of energy will be analyzed from the viewpoint of economics, with a long-term historical perspective, over a period of almost 150 years. Several Western European countries will be considered (England, Italy, the Netherlands, Spain and Sweden).

In the transition from the old to a modern economy, energy is of central importance. In recent studies, energy has been recognized as a main determinant of the divergence of Europe from the rest of the world in the 19<sup>th</sup> century and as the main cause of its success.<sup>1</sup> Despite the central importance of energy, historians dealt for a long time only sporadically with energy problems. John Nef was the first historian who analyzed energy as the main pillar of the industrial revolution.<sup>2</sup> After the energy crisis of the 1970s, much empirical research took place on energy, within the context of

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**1** | Kenneth Pomeranz: *The Great Divergence. China, Europe and the Making of the Modern World Economy*. Princeton, NJ: Princeton University Press, 2010, 37-47; Paolo Malanima: *Pre-Modern European Economy. One Thousand Years (10<sup>th</sup>-19<sup>th</sup> Centuries)*. Leiden: Brill, 2009, 49-94.

**2** | John Nef: *The Rise of the British Coal Industry*. London: Routledge & Sons, 1932 and John Nef: *La Naissance de la Civilisation Industrielle et le Monde Contemporain*. Paris: Colin, 1954.

both economic and environmental history. In 1988, Tony Wrigley analyzed the historical transition from organic to mineral resources in the course of industrialization of the British economy, stressing the importance of energy in the industrial revolution.<sup>3</sup> Vaclav Smil dealt with energy transitions in a long historical perspective.<sup>4</sup> Joachim Radkau analyzed the connections between forest history and technological developments from the 16<sup>th</sup> to the 19<sup>th</sup> century and the energy transition in the wider context of environmental history.<sup>5</sup>

The aim of this article is to examine the role of energy in long-term economic growth. The analysis relies on new data that so far have been mostly used in analyses of long-term trends in energy consumption.<sup>6</sup> In the first part, I will explain the main changes which have taken place in the energy system over the past two centuries, and in particular the energy transition from traditional to modern energy sources. In the second

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**3** | Edward Anthony Wrigley: *Continuity, Chance and Change: The Character of the Industrial Revolution in England*. Cambridge: Cambridge University Press, 1988.

**4** | Vaclav Smil: *Energy in World History*. Boulder, CO: Westview Press, 1994.

**5** | Joachim Radkau: *Nature and Power. A Global History of the Environment*. Cambridge: Cambridge University Press, 2008. On these aspects see also Rolf P. Sieferle: *The Subterranean Forest. Energy Systems and the Industrial Revolution*. Cambridge: White Horse Press, 2001; Clive Ponting: *Storia Verde del Mondo*. Torino: Società Editrice Internazionale, 1991.

**6** | Long-term trends in energy consumption have been quantified by the *Energy, Growth and Pollution Network* which was set up in 2003 to link together historians working on the history of energy use and its consequences for the economy and environment in Europe from ca. 1500 to the present. The first stage of the group's work has consisted of developing a common methodology for quantifying energy inputs into the economy and publishing sets of data as the basis for further research, including the first detailed and reliable quantification of consumption of 'traditional' energy carriers in the pre-industrial and modern era for a wide range of countries. This provides a reliable quantitative basis for investigation of the role of energy in economic growth, especially the impact and cause of transition between 'energy carriers'. Other areas of study include the relationship between energy consumption and income levels (energy intensity) in the long-term, CO<sub>2</sub> emissions and energy use. For further details see [www.histecon.magd.cam.ac.uk/ees/energy\\_and\\_growth.html](http://www.histecon.magd.cam.ac.uk/ees/energy_and_growth.html).

part, I will reconstruct the current structure of energy consumption. The next section will explore the relation between energy, economy and technological change. Energy intensity, i.e. the ratio of energy to output, and its reciprocal, i.e. energy productivity, will be reconstructed and I will try to show the relative importance both of rising consumption and of changes in the productivity of energy in growth of per capita output. In the final part, I will discuss the constraints of the current energy system. The paper's long-term outlook may serve to clarify contemporary trends and provide perspectives on the impact of policy decisions on the energy problem.

## THE ENERGY TRANSITION

Over the past two centuries there has been a massive and continuing increase in the consumption of fossil fuels: first coal and then oil and natural gas. Large-scale use of fossil fuels has led to greatly increased energy consumption. Since 1800, energy consumption in Western Europe has grown about six fold, in per capita terms (Fig. 1) and 26 fold in total terms.

At the end of the 18<sup>th</sup> century, the main sources of energy were food, firewood and fodder for working animals. A relatively small contribution came from two other carriers: falling water, utilized by watermills, and wind, exploited by sailboats and mills. Modern growth, from about 1820 to the present, has marked a sharp rise both in the energy sources and in the efficiency of their utilization. This change can be defined as an 'energy transition'. The transition to modern growth is explained as a discontinuity founded on the increase in productive capacity, due to the introduction of new energy carriers (fossil fuels) and engines able to transform energy into mechanical work. Although other deep changes occurred in the use of energy before the modern era<sup>7</sup>, this transition is considered a watershed between past and present.

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7 | For instance the use of fire, which represented the most fundamental conquest in the history of energy.

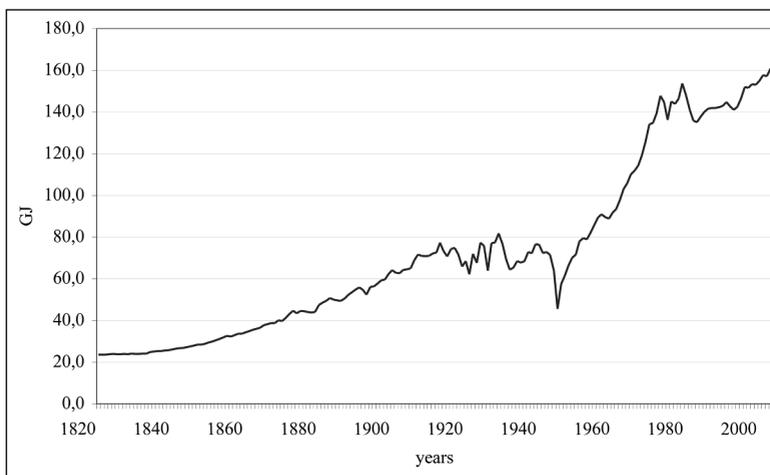


Figure 1: Per Capita Energy Consumption in Europe, 1820-2003 (Gigajoules)

The profound and rapid changes, which took place especially in the second half of the 19<sup>th</sup> century and the early 20<sup>th</sup> century, accelerated the process of transition to the new energy system. The strong population growth, worsening climate conditions and the decline of per capita amount of traditional energy sources are the main causes. Especially in the first half of the 19<sup>th</sup> century, there was a marked acceleration in the rate of population growth. In just 50 years, from 1800 to 1850, Europe's population expanded from 189 to 288 million.<sup>8</sup> The balance between the established renewable energy sources on the one hand and the growing population on the other was becoming increasingly difficult to maintain within the prevailing energy system. Wood, the main energy source until the eve of the Industrial Revolution, became increasingly scarce. The energy crisis played an important role for the urbanization process. To feed the growing urban population, the surrounding countryside needed to produce an adequate exchange and agricultural surplus.<sup>9</sup> However, the

**8** | Malanima: *Pre-Modern European Economy*, 49-94.

**9** | With the widespread use of coal instead of wood, cities began to change and grow rapidly, especially since the beginning of the 19<sup>th</sup> century. For the case of London see Robert C. Allen: *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge University Press, 2009; for the case of Naples and other Italian cities see Silvana Bartoletto: "Dalla Legna al Carbon Fossile. I Consumi di

whole system reached a critical point when population growth exceeded that of agricultural production.

Deforestation for claiming more arable land had already sharply reduced the availability of wood, but it was the acceleration of a series of industrial and commercial activities which brought about a real energy crisis. The food, glass and soap industries consumed enormous quantities of wood, but the highest demand came from shipbuilding and iron production. To understand the magnitude of the energy crisis, it must be kept in mind that wood was the dominant industrial resource as it was used as a fuel and as raw material for instruments, machines, tools and equipment, but also for many end products. It had the same importance as fossil fuels today.<sup>10</sup> Jeremy Rifkin introduced the concept of ‘watershed entropy’ to explain the transition from one energy system to another: It was the scarcity of wood that determined its replacement by coal. However, it was not simply the substitution of one energy source with another, but it resulted in a radical change in the way of life.<sup>11</sup>

There are, however, quite a few dissenting opinions on the subject of ‘energy crises’. Joachim Radkau for instance, has criticized the thesis that the Industrial Revolution should be seen as a consequence of the catastrophic shortage of wood resources that necessitated the transition to coal, first in England and then in other parts of Europe.<sup>12</sup> Robert Allen has recently maintained that there was no energy crisis in the 18<sup>th</sup> century.<sup>13</sup> Instead, coal was abundant and cheap in Britain and wages were high in

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Combustibile a Napoli nel Corso dell'Ottocento”, in: *Mélanges de l'Ecole Française de Rome* 116 (2004), 705-21; Silvana Bartoletto: “L'Energia delle Città. Percorsi di Ricerca, Muovendo dal Caso di Napoli”, in: Gabriella Corona/Simone Neri Serneri, eds. *Storia e Ambiente. Città, Risorse e Territori nell'Italia Contemporanea*. Roma: Carocci, 2007, 218-33; Silvana Bartoletto: “Energy Consumption in Naples between the 19<sup>th</sup> and the 20<sup>th</sup> Centuries”, in: *Working Papers Department of Economic Studies*, University of Naples Parthenope 3, 2009.

**10** | Lewis Mumford: *Tecnica e Cultura*. Milano: il Saggiatore, 1961. Original: *Technics and Civilization*. New York: Brace & Company, 1934.

**11** | Jeremy Rifkin: *Entropia*. Milano: Baldini & Castoldi, 2000.

**12** | Radkau: *Nature and Power*, 195.

**13** | Robert C. Allen: “Was There a Timber Crisis in Early Modern Europe?”, in: Simonetta Cavaciocchi, ed. *Economia e Energia secc. XIII-XVIII*, Istituto Internazionale di Storia Economica. Firenze: Le Monnier, 2003, 469-82.

comparison to other countries in Europe and Asia. Thus, it was profitable for Britain to replace workers by machines, and that is why the use of coal and steam engines increased rapidly.<sup>14</sup> Paolo Malanima, by contrast, emphasized the role of energy crises in the energy transition.<sup>15</sup> He argued that “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.”<sup>16</sup>

The analysis of the times and ways of the passage from an energy system based on traditional energy sources to another based on fossil fuels reveals considerable differences between countries. The energy transition occurred very rapidly in northern Europe, particularly in England and Wales, where in the mid-19<sup>th</sup> century fossil fuels represented about 91 percent of total consumption while the percentage of traditional energy sources dropped to only 9 percent (Tab. 1). In the Netherlands in 1850, traditional energy sources represented the largest part of total consumption, but fossil fuels had already gained an important position with 41 percent of the total. The profile of energy balance that emerges from comparative data for Sweden, Italy and Spain is very different. In these three countries in 1850, the role of fossil fuels was very marginal. In Southern Europe at the beginning of the 20<sup>th</sup> century, the traditional sources of energy accounted for 70-80 percent of the energy consumed.<sup>17</sup>

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**14** | Allen: *The British Industrial Revolution*; Joseph Zeira: “Workers, Machines and Economic Growth”, in: *The Quarterly Journal of Economics* 113:4 (1998), 1091-117.

**15** | Paolo Malanima: “Energy Crisis and Growth 1650-1850: The European Deviation in a Comparative Perspective,” in: *Journal of Global History* 1 (2006), 101-21.

**16** | Paolo Malanima: “The Path Towards the Modern Economy. The Role of Energy”, in: Bruno Chiarini, Paolo Malanima, eds. *From Malthus’ Stagnation to Sustained Growth, Rivista di Politica economica* (aprile-giugno 2010/2011), 89.

**17** | Silvana Bartoletto/Mar M. Rubio: “Energy Transition and CO<sub>2</sub> Emissions in Southern Europe: Italy and Spain (1861-2000)”, in: *Global Environment* 2 (2008), 46-81.

Table 1: Composition of Energy Consumption in 1850 (%)

	England & Wales	Sweden	Netherlands	Italy	Spain
Muscle	7	25	38	41	50
Firewood	0	73	11	51	46
Wind, water	2	<1	10	1	2
Fossil fuels	91	2	41	7	2

In Italy and Spain in particular, only on the eve of World War II was the contribution of traditional energy sources reduced to less than half of total consumption. In Italy, the scarcity of fossil fuels resulted in fuel costs 3 to 5 times higher than in competing Western European economies. In order to get a clearer view of these differences we can also consider production quantities. In 1910, the United Kingdom produced about 270,000 tons of coal per year, Germany 150,000, and Italy only 3,000.<sup>18</sup> The scarcity of energy resources has seriously affected the process of industrialization in Italy, which has followed a different path compared to countries like England where the industrial revolution came about much earlier. In fact, Italy has been specializing in industries with a high intensity of labor, which has been abundantly available, and a low intensity of energy, which has been scarce. This confirms the thesis that the adoption of energy intensive technologies (e.g. the steam engine) was not beneficial everywhere, but depended crucially on the price of production factors.<sup>19</sup>

## ENERGY CONSUMPTION

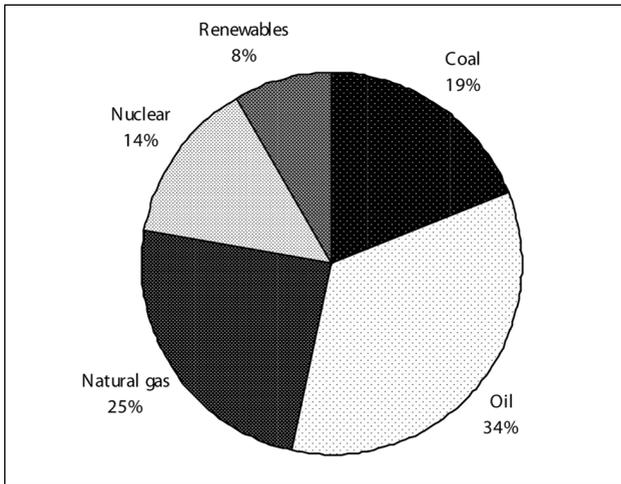
Currently, energy consumption in Europe is about 1,759 Million Tons of Oil Equivalent (Mtoe) and fossil fuels represent 80 percent of total consumption. Oil is the main energy source, with a percentage of about 33 percent, followed by natural gas (24.6 percent) and coal (18.8 percent). In comparison, the role of renewable energy remains very marginal,

**18** | Carlo Bardini: *Senza Carbone nell'Età del Vapore. Gli Inizi dell'Industrializzazione Italiana*. Milano: B. Mondadori, 1998.

**19** | Zeira: "Workers, Machines and Economic Growth", 1091-117.

representing only 8 percent of total consumption (Fig. 2). If we examine the evolution of the structure of fossil fuel consumption in a long-term perspective, it is possible to identify three main phases: the first, culminating in the early 1950s, which saw coal in first place in order of importance of fossil fuels; a second phase, during which the consumption of oil exceeds that of coal; a third phase, following the energy crises of the 1970s, which saw the emergence of natural gas as an energy source and the growth of nuclear power, while the use of oil remains predominant, not only in Europe but also worldwide.

*Figure 2: Energy Consumption in Europe in 2007 by Energy Sources (percentages)*

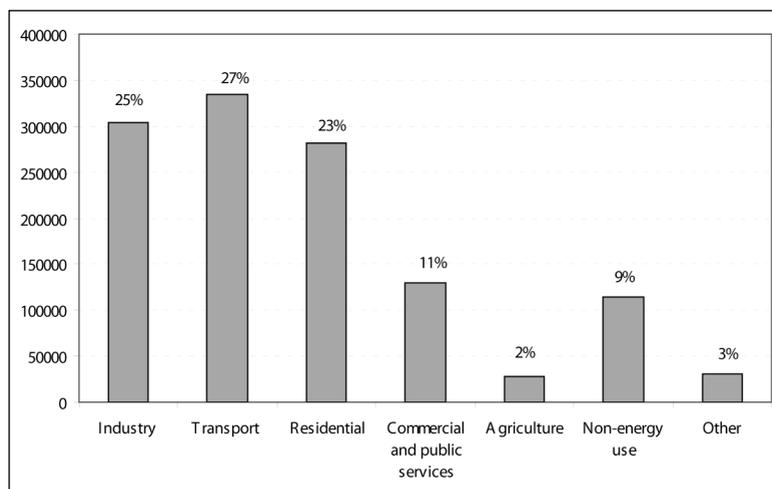


*Note: Renewables include hydro (1.51 percent), geothermal (0.32), solar/wind/other (0.61), renewable and waste (5.7).*

In the years following the oil crises, one of the main objectives of European energy policy and more generally of industrialized countries has been to shift the supply and demand of energy to the non-oil sources, since they were considered politically more secure. Achieving this goal would entail, on the industrial level, the expansion of nuclear power and increased use of coal in thermoelectric generation besides the intensification of the uses of natural gas not only in industry but especially in residential heating and cooking.

Final energy consumption in Europe is about 1,224 Mtoe, corresponding to 15 percent of the world's final energy consumption.<sup>20</sup> Over time, energy consumption in various sectors has changed (Fig. 3).

Figure 3: Final Energy Consumption in Europe in 2007, by Sectors (percentages)



Note: Data refers to EU 27.

The agricultural sector has lost ground to the industry, transport and service sectors, the latter being more intensive in energy use and making almost exclusive use of modern energy sources. The transport sector represents about 27 percent of total final consumption, while industry's share amounts to 25 percent. The tertiary sector, which includes the residential, commercial and public sectors, represents 34 percent of the total. Energy consumption in the industrial sector has decreased since 1973, not only percentage-wise, but also in absolute terms.

**20** | Total final energy consumption is the sum of consumption by the different end-use sectors: industry, transport, residential, commercial and public services, agriculture, forestry, fishing. Non energy-use covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel.

Typically, over the course of economic development, the output mix changes. In the earlier phases of development, there is a shift away from agriculture towards heavy industry, and in the later stages there is a shift from the more resource-intensive extractive and heavy industrial sectors toward services and lighter manufacturing. Different industries have different energy intensities. This typically results in an increase in energy used per unit of output in the earlier stages of economic development and a reduction in energy used per unit output in later stages.

## **ENERGY INTENSITY**

To analyze the relation between energy and economic growth it is important to consider two indicators, energy intensity and its reciprocal, energy productivity.

Energy intensity is the ratio of consumed energy to the gross domestic product (GDP) and expresses the energy required to produce one monetary unit of income. In particular, primary energy intensity is calculated as the ratio of gross domestic energy consumption to GDP, while final energy intensity is obtained by dividing the final consumption of energy by GDP.

As a first approximation, a decline over time in energy intensity beyond a certain level of income could be interpreted in terms of increased efficiency of economic systems. What does increase or decrease the ratio of energy intensity is the change in energy consumption (numerator) compared to GDP denominator. If the numerator (energy) increases less than the denominator (GDP), then the energy intensity decreases. The indicator shows to what extent there is a decoupling between gross energy consumption and economic growth, but not the reasons for the trend. It is, in fact, an indicator that enables us to grasp the complexity of the energy-economy link. To consider it as a measure of the efficiency of an economic system may lead to erroneous conclusions. The change in energy intensity of a given country over time reflects the different nature of the relationship between the growth of energy consumption and the underlying level of economic development. The energy intensity curve shows a trend that varies depending on the state of economic growth. In particular, if the calculation of energy consumption only includes modern energy, the curve grows rapidly during the industrialization phase and reaches its peak at the stage of industrial maturity; afterwards, the energy intensity tends to

decrease with increasing income, therefore the corresponding curve also decreases thanks to the growth of the services with high added value.

According to an interpretation widespread among economists, energy consumption does not increase in proportion to GDP. The relationship between energy and GDP (energy intensity) shows a pattern which resembles an inverted U-shaped curve or a curve that grows in the early stages of industrialization and subsequently declines during the post-industrial period. This theory was supported in an influential article of Jose Goldenberg and Amulya Reddy, published in the *Scientific American* in 1990.<sup>21</sup> This study, however, did not take into account traditional energy sources that were consumed before the introduction of fossil fuels. More recent studies, conducted with reference to countries such as Italy, Spain, Sweden and the Netherlands, have shown that in the longer term, energy intensity tends to decrease and the respective curve does not show an inverted U-shape if the calculation also includes traditional energies (Fig. 4).<sup>22</sup>

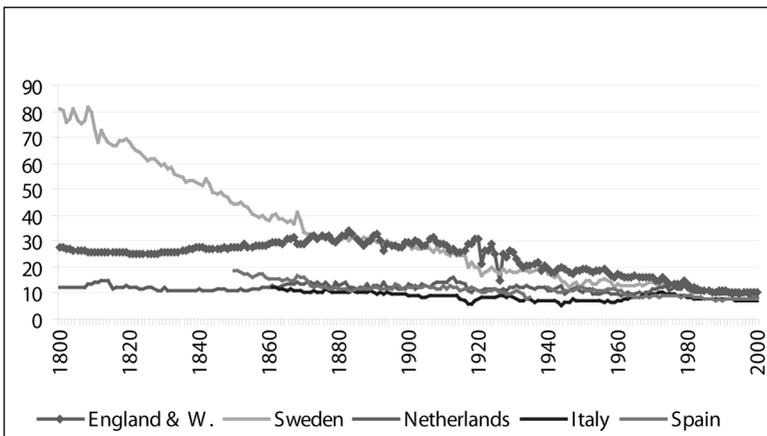


Figure 4: Energy Intensity in Europe, 1800-2000 (Megajoules/1990 \$ PPP)

**21** | Jose Goldenberg/Amulya Reddy: “Energy for the Developing World”, in: *Scientific American* 263:3 (1990), 111-18.

**22** | Ben Gales/Astrid Kander/Paolo Malanima/Mar M. Rubio: “North versus South. Energy Transition and Energy Intensity in Europe over 200 Years”, in: *European Review of Economic History* 11 (2007), 219-51.

For England and Wales, the estimated trends diverge widely prior to 1850, depending on which estimates for GDP have been chosen. Energy intensity rose steadily peaking in 1883. After 1883, with a few exceptions, energy intensity showed a steadily declining level until the 1990s, with particularly rapid drops in periods when the traditional manufacturing industry was struggling: the early 1930s and 1973-88.<sup>23</sup>

There is no consensus on the causes of the downward trend in energy intensity. For Italy, Spain, Sweden and the Netherlands, more recent studies have shown that the growth of services in economic structure determines only about 15 percent of the total reduction in energy intensity. Technological change has played a more important role in this decline than services' growth. Thanks to mainly technological progress, further economic growth with decreasing energy intensity becomes possible. Not only technical changes but also many other variables have affected progress in energy intensity trends, e.g. structural changes, energy prices and the quality of energy. Since technical and structural changes occur simultaneously in the economy, it is hard to determine which of the two variables is responsible for changes in energy intensity. The use of new energy sources stimulated and, at the same time, came about as a result of the exploitation of new technologies which in turn, had an impact on productivity, the prices of commodities and their consumption.

Production can be boosted either by means of a quantitative increase of production factors or by increasing overall productivity. Investment and capital increases are one of the most important growth factors in industrialized countries. However, as far as energy intensity is concerned, the quality of production factors is far more important than their quantity. In the industrial sector, for example, microelectronics has facilitated automation and coordination of production systems, and this has affected both labor demand and energy consumption. Microelectronics has also had a decisive impact on other sectors of the economy.<sup>24</sup> Automobiles, TV-sets,

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**23** | Paul Warde: *Energy Consumption in England and Wales*. Naples: Consiglio Nazionale delle Ricerche, Istituto di Studi sulle Società del Mediterraneo, 2007.

**24** | I refer especially to the semiconductor, which is considered the most spectacular macroinvention of the 20<sup>th</sup> century (Joel Mokyr: *The Gifts of Athena*. Princeton, NJ: Princeton University Press, 2002, 112). For a deeper analysis of the role of technological and scientific knowledge in the economic development during the past two centuries, see also Mokyr's *The Lever of Riches: Technological*

radios, and household appliances all rely on electronic circuitry, and this affects energy consumption. Going back in time, in the industrial sector, assembly-line production was important for specialization and economies of scale, and electricity played a decisive role in raising productivity in assembly lines since they employed electric motors.

Energy prices have a crucial impact on the development of energy intensity. When prices rise, energy intensity tends to decrease for a more efficient use of energy thanks either to increasingly efficient energy utilization or to a structural shift. In fact, the reduction in energy intensity means energy savings per unit of output and it is caused, first of all, by the desire to save money in the production process in order to maintain or increase profits, as demonstrated by past experiences. During the 1950s and 60s, when energy was plentiful and cheap, energy intensity was high.

Following the oil crises of the 1970s and the large increase in oil prices, total world energy intensity has decreased. From 0.32 (toe/thousand 2000 U.S. \$ ppp) in 1971<sup>25</sup>, the intensity dropped to 0.20 in 2007 (Fig. 5).

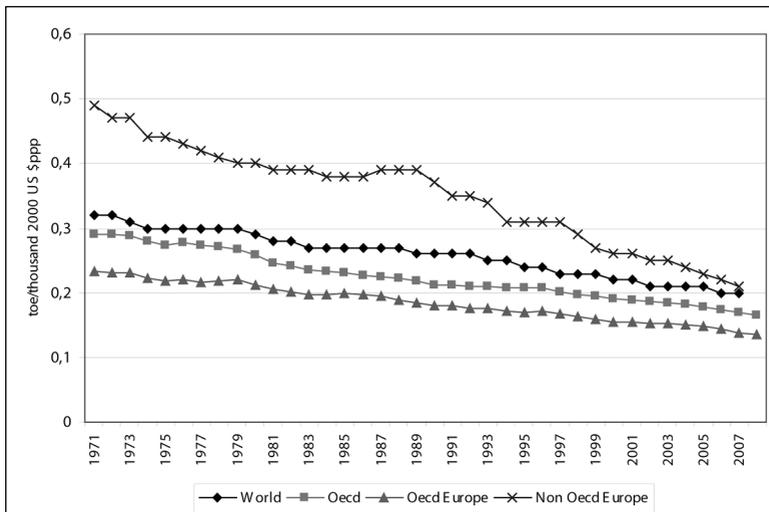


Figure 5: Energy Intensity Trends in Europe (1971-2008)

*Creativity and Economic Progress*. New York: Oxford University Press, 1990 and *Leggere la Rivoluzione Industriale*. Bologna: il Mulino, 1997.

**25** | Energy consumption is expressed in tons oil equivalent (toe), while GDP is expressed in 2000 \$ at purchasing power parity (ppp).

As for European countries, there are very stark differences between those that are members of OECD and those that are not. Non-OECD countries have much higher energy intensity, although over the last forty years, the decline was much sharper than that of other European countries.

However, the energy intensity indicator alone is not sufficient to understand the complexity of the link between energy, economy and environment. In particular, from an environmental point of view, everything depends on the amount of energy consumed and the mix of fuels used. Even if two countries have the same energy intensity or show the same trends during a certain time period, there may be significant environmental differences between them. In other words, even without a significant reduction in energy intensity, the environmental impact of energy consumption can be reduced, for example as a result of a change in fuel mix. Emblematic are the cases of China and the United States which, despite the reduction in their energy intensities, remain the two biggest polluters of the earth.

## ENERGY PRODUCTIVITY

There is no direct link between the energy converted in the production of goods and their economic value. Very small amounts of energy conversion can create large value and vice versa. The size of energy flow is not necessarily correlated with the value we give to a particular economic output. At the same time, there is a difference between the thermodynamic efficiency of the physical conversion of energy from one form to another and the economic efficiency in turning energy into value. Energy carriers, whether primary or secondary, are converted into energy services, which are heat, motion and light. In line with the second law of thermodynamics, all these conversions of energy from one form to another entail losses. Thermodynamic efficiency ( $\eta$ ) can be expressed through the ratio (and then multiplied by 100)

$$\eta = \frac{E_u}{E_i}$$

where  $E_u$  is useful energy (or energy services) and  $E_i$  is the input of energy in the form of a primary or secondary source.

The measure of economic and not only thermodynamic efficiency is called energy productivity

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

where Y is output in monetary terms and  $E_i$  is the raw input of energy (and not energy services) into the economic flow. As far as we know, increases in thermodynamic efficiency imply increases in energy productivity. For example, the transition from biological engines to mechanical engines, which is the main recent change in the energy system, implied both a rise in energy yield or efficiency and energy productivity. However, while the first formula deals with the mere technical structure of an engine or a series of engines, the second is more comprehensive and includes, at the same time, both technical and organizational and institutional changes. Productivity of energy is not only influenced by the technical capacity of conversion, but also by other variables, such as the specialization of economy in particular sectors and sub-sectors. If parts of the economy that are more energy-efficient than others grow faster and provide a greater share of national income, the energy productivity of the economy will increase even though technical knowledge has not changed. Many variables can influence energy productivity such as climate and the structure of the economy. In a northern country, specialized in heavy industry, energy productivity can be much lower than in a southern region specialized in light industry.

Also, the level of gross output and changes in the institutions that rule the economy, society and the performance of economic variables all influence energy productivity.

Table 2: *Energy Productivity, Energy Consumption and Population in 12 Western European Countries (1820-2001)*

	Energy productivity (GDP/GJ)	Energy consumption (PJ)	Population (million)
1820	52.71	2,707	115
1850	56.48	4,222	144
1870	52.57	6,450	162
1890	48.24	10,259	187
1913	47.72	17,617	228
1921	53.27	13,832	222
1931	58.27	16,467	237
1941	69.80	17,941	248
1951	67.67	20,107	258
1961	84.75	25,794	276
1971	83.29	40,107	298
1981	99.60	43,133	306
1991	117.76	45,503	314
2001	127.04	51,242	325

Note: This table includes 12 Western European countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland and United Kingdom.

From the analysis of energy productivity in Europe (Tab. 2), it may be noted that the introduction of modern energy carriers and machines implied a rise in energy productivity only from the end of the 19<sup>th</sup> century onwards.<sup>26</sup> Replacing the work of humans (or draught animals) by that of machines can bring about either an increase or a reduction in energy productivity,

**26** | For data on energy productivity in Western European countries see Silvana Bartoletto: "Energy and Economic Growth in Europe. The Last Two Centuries", in: Bruno Chiarini/Paolo Malanima, eds.: *From Malthus' Stagnation to Sustained Growth, Rivista di Politica economica* (aprile-giugno 2010/2011), 57-75; Angus Maddison: *The World Economy. Historical Statistics*. Paris: OECD, 2002.

depending on the efficiency of machines versus muscle power. In the early 19<sup>th</sup> century, machines were less energy-efficient than human beings and animals; only gradually did the machines' energy-efficiency surpass that of living beings. As long as machines remained less efficient, the increase of the machine-work ratio resulted in a reduction in energy productivity. And conversely, ever since machines became more efficient than living beings, every increase in the ratio of machine work to human or animal muscle power has determined an increase in overall energy productivity.

In the case of Western Europe, energy productivity fell from 52.71 (GDP/GJ) in 1820 to 47.72 (GDP/GJ) in 1913 (Tab. 2). During this period, the GDP increase depended totally on the growth of energy consumption. From the First World War to the Second World War, there was an important increase in energy productivity. Improvements in the efficiency of the techniques of energy exploitation played a very important role. Otherwise, in the 1950s and 60s, economic growth was sustained not only by an increase in energy productivity, but also by a strong increase of energy consumption. Oil was the main energy source and since it was abundant and cheap, no particular attention was paid to energy saving methods. After the 1970s oil crises, the productivity of energy played a more important role than energy consumption.

In order to better understand the relative importance of the input of energy and the efficiency of its exploitation, we can carry out a decomposition analysis of per capita GDP. Per capita GDP ( $Y/P$ ) is, in fact, the product of energy consumption per capita ( $E/P$ ) multiplied by the productivity of energy ( $Y/E$ ):

$$\frac{Y}{P} = \frac{E}{P} \cdot \frac{Y}{E}$$

If we assume:

$y$  as the rate of growth of  $Y/P$ ;

$e$  as the rate of growth of  $E/P$ ; and

$\pi$  as the rate of growth of  $Y/E$ ;

we can specify the relative importance of  $e$  and  $\pi$  in the growth of  $y$ , during the period concerned; that is the years from 1820-30 until 2000. Thus:

$$y = e + \pi$$

*Table 3: Rates of Growth of Per Capita GDP ( $\gamma$ ), Per Capita Energy Consumption ( $\epsilon$ ) and Productivity of Energy ( $\pi$ ) 1820-2000 in Western Europe*

	$\gamma$	$\epsilon$	$\pi$
1820-1850	0.42	0.32	0.10
1850-1870	0.50	0.65	-0.16
1870-1890	0.51	0.70	-0.19
1890-1913	0.63	0.65	-0.02
1913-1921	-0.58	-1.18	0.60
1921-1931	0.86	0.47	0.39
1931-1941	0.96	0.18	0.78
1941-1951	0.19	0.32	-0.13
1951-1961	1.76	0.78	0.98
1961-1971	1.51	1.59	-0.08
1971-1981	0.98	0.20	0.78
1981-1991	0.84	0.11	0.73
1991-2001	0.70	0.37	0.33

From 1820 until the First World War, a remarkable decline took place in energy productivity, especially during the period 1850-1890 (Tab. 3). The input of energy contributed more than the productivity of energy to the growth of GDP. From 1913, both the contribution of rising consumption and its more efficient use determined a growth in GDP, with some differences. The rate of growth of energy productivity was much higher than the rate of growth of per capita energy consumption during the periods 1913-1921, 1931-1941 and 1971-1991, reaching a maximum during the decade 1951-1961. During the 1960s, energy productivity slowly diminished because energy, especially oil, was both abundant and cheap and energy use was less efficient. After the severe oil crises of the 1970s, the higher price of energy encouraged more efficient exploitation and a decline of energy consumption in the industrial sector. Compared to other continents, Europe today has the highest energy productivity and the lowest energy intensity. Because of the high dependence on fossil fuels, the reserves of which are finite, and the high price of energy, Europe's energy policies are

aimed at increasing the ratio of renewable energy and improving energy efficiency.

## THE CONSTRAINTS OF THE CURRENT ENERGY SYSTEM

Currently, world total primary energy consumption is 12,267 Mtoe and it has doubled since the beginning of the 1970s.<sup>27</sup> The increase has been determined by several causes. Not only population growth, but also the increase of final energy consumption played a very important role. In 1973, about 60 percent of total final energy consumption was concentrated in OECD countries. During the following years, this percentage declined and in 2008 final energy consumption in OECD countries was 43.8 percent. In contrast, in China and Asia, total final energy consumption has doubled. It also increased significantly in the former Soviet Union and in the Middle East. From 1973 to 2008, the percentage of oil consumption on total final energy consumption in the world declined from 48.1 to 41.6 percent. Coal is employed mainly in industry (78.5 percent), oil is consumed mostly for transport (61.4), while gas is used mainly in the tertiary sectors but also plays an important role in industry (35.1).

The world energy balance is changing due to the enormous growth in the energy consumption of China and India, whose role in international trade of fossil fuels continues to increase. The strong economic growth of these two countries in recent years has resulted in a significant increase in their demand for energy, which is increasingly met through imports. The energy resources of China, especially coal, are substantial, but not enough to completely satisfy its growing needs. In the first half of 2007, China became a net importer of coal.<sup>28</sup> In India, coal remains the main fuel. It is expected that over the next 20 years India will even triple its coal consumption.<sup>29</sup> The growing worldwide demand for energy has led

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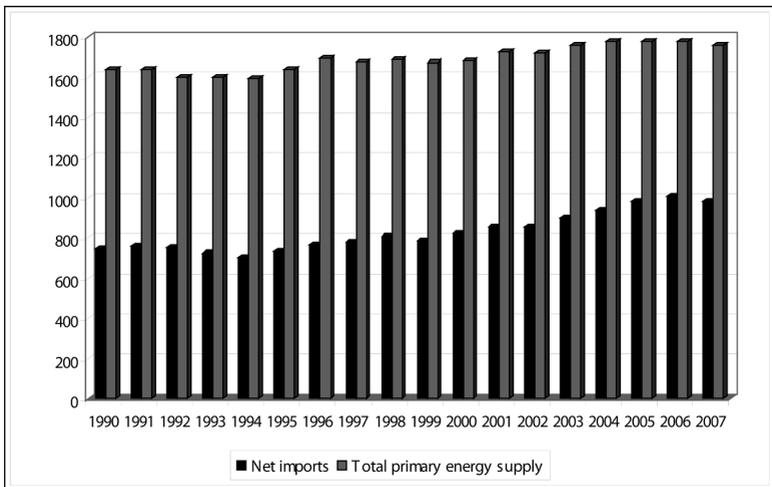
**27** | International Energy Agency (IEA): *Key World Energy Statistics 2010*. Paris: OECD/IEA, 2010. Data on total world energy consumption refers to 2008.

**28** | On the Chinese energy transition pattern see also Vaclav Smil: *Energy Transitions – History, Requirements, Prospects*. Santa Barbara, CA: Praeger, 2010, 95-99.

**29** | International Energy Agency (IEA): *World Energy Outlook 2007*. Paris: OECD/IEA, 2007, 3.

to considerable concern about the security of energy supplies because of growing competition between countries for supplies and the increasing dependence of the consuming countries on few producing countries, which are often politically unstable. The concentration of oil and gas reserves in a small group of countries, particularly in Russia and the countries of the Middle East members of OPEC, determines their market dominance. The greater the increase in the demand for oil and gas in these regions, the greater the likelihood of rising prices. In Europe, the problem of secure energy supplies has become an issue as a result of increasing energy dependence.<sup>30</sup> Since 1990, the energy dependence of Europe has grown from 45 to 55 percent (Fig. 7).

Figure 6: Energy Dependency in Europe, 1990-2007 (Mtoe)



From the mid 18<sup>th</sup> century until the first half of the 20<sup>th</sup> century, coal was the main energy source on which Europe built its industrial power, largely under conditions of energy autonomy. With the outset of the age of oil and later of natural gas, imports of energy sources have become inevitable and are steadily growing. Only after the energy crises of the 1970s did the

**30** | Energy dependency is calculated as net imports (imports-exports) divided by total energy consumption.

problem of energy dependence and security of energy supply in Europe capture the attention of the economic policy debate.

Italy is certainly one of the countries with the highest levels of energy dependency, as about 90 percent of its energy demand is met by fossil fuel imports, notably through oil and natural gas. Following the oil crises of the 1970s, natural gas consumption has greatly increased in Italy, currently representing 39 percent of total demand. However, oil remains the main source of energy, because it represents 42 percent of total demand.<sup>31</sup> In Italy, energy policies have failed to reduce the degree of dependence. The diversification of the energy sources supply has been only marginal, replacing imported oil with imported natural gas. Not only Italy, but also other European countries have invested in natural gas. In fact, the greater part of new thermoelectric capacity installed in Europe over the past ten years is fuelled by gas, which currently provides about a quarter of Europe's electricity production, compared to 7 percent in the early 1980s.<sup>32</sup> However, having focused so strongly on natural gas, for the European Union this has meant a greater dependence on imports.

After the oil crises, several European countries have invested heavily in nuclear power. In France, for example, nuclear power is the main energy source, with a share of 43 percent of total demand. In Sweden, nuclear power represents 33 percent of total consumption.

The recent disaster at the Fukushima nuclear plant has reignited the debate on the use of nuclear power, leading some countries to abandon it permanently. In Germany, where nuclear power currently accounts for 22 percent of the electricity needs of the country, the government has decided to shut down all reactors by 2020, following strong protests against the use of atomic energy. In Italy in 2008, the Berlusconi government had announced it would resume its nuclear program through the construction of four third-generation nuclear power plants, with the aim of covering at least 10 percent of Italy's energy demand. But, after the Fukushima disaster, following the referendum in June of 2011, Italy has once again abandoned the project to produce electricity by splitting the atom. Risks associated with the process of nuclear power generation are very serious, as amply demonstrated by the disasters of Fukushima (2011) and Chernobyl in the

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**31** | International Energy Agency (IEA): *Energy Balances of OECD Countries*, 2009 edition. Paris: OECD/IEA, 2009.

**32** | Alberto Clò: *Il Rebus Energetico*. Bologna: il Mulino, 2008, 45-82.

Ukraine (1986). Another serious problem is how to deal with radioactive waste from nuclear power plants. The approximately 440 existing nuclear reactors in 31 countries produce thousands of tons of waste annually.<sup>33</sup> In addition, there is the risk that certain countries that have nuclear technology may use it to develop nuclear weapons.

Thus, in seeking a more secure and reliable energy system, increased deployment of renewable energy sources is essential. The heated political and economic debate on unsustainable present-day energy consumption encourages the development of a more secure and sustainable energy consumption model. Great hopes are placed especially on wind, hydroelectric, and solar energy. The capital intensity of renewable energy is greater than that of fossil fuels and therefore the investment required to create additional generating capacity from renewable sources is very high. Thus, energy policies should focus on the goal of increasing the importance of the combination of different renewable energy sources, as approved in the package “Climate Action and Renewable Energy”, adopted by the European Council on April 6, 2009. Here, member states have agreed to reduce emissions of greenhouse gases by 20 percent below 1990 levels by 2020 and to increase energy efficiency by 20 percent, reaching a quota of 20 percent renewable energy for end use by 2020. Of course, the answers to the problem vary from country to country. Oil is the main source of energy in the world and will remain so for a long time, even under the most optimistic assumptions about growth rates and diffusion of alternative technologies. A quantitatively significant transition from fossil fuels to new renewable sources cannot be seen only in the long term perspective. A market penetration of renewables will require strong public support for a rapid development of technologies to reduce costs of producing and using renewable energy.

## CONCLUDING REMARKS

In recent years, the emphasis on energy within the transition from the old to the modern economy has received new attention. During the last two centuries, the energy system has changed, shifting from renewables to non-renewable energy sources. Currently, fossil fuels represent 80 percent

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**33** | Clô: *Il Rebus Energetico*, 97-109.

of total consumption in Europe and in the world. Following large-scale use of fossil fuels, energy consumption grew exceptionally strongly, especially after the Second World War.

The transition from traditional renewable energy sources to fossil fuels was a slow process because the two sources have coexisted for a long time. We could say that the present energy balance represents the result of a long and slow evolution of the energy system and of technologies used to transform energy into work. In Europe, the use of coal during the 17<sup>th</sup> century and much of the 18<sup>th</sup> century remained modest and devoid of real importance in the economy. An exception is northern England and the Netherlands, whose economic success, especially since the 17<sup>th</sup> century, was largely dependent on the exploitation of new energy sources. Until the early decades of the 20<sup>th</sup> century, much of Western Europe still depended significantly on traditional energy sources. Working animals continued to play an important role in agriculture and transport. Wood was still widely used for heating and cooking. Not only that, but in vast regions, wood, water and wind represented the major sources of energy in industry even in the late 19<sup>th</sup> century. The advantages of energy-intensive manufacturing and transport technologies are immediately visible in the trend of energy productivity ( $Y/E$ ), which is the reciprocal of energy intensity formula ( $E/Y$ ). Analyzing the trend of energy productivity in Europe, we can identify four periods during which the energy-growth relationship has presented different characteristics. A first phase, which covered the time span from 1820 to the end of the 19<sup>th</sup> century, is characterized by a reduction of energy productivity. A second phase lasted from the beginning of the 20<sup>th</sup> century until the Second World War. In this period, the improvements in the efficiency of techniques of energy utilization played a more important role for economic growth than the amount of energy used. In a third phase, from post-World War II until the energy crises of the 1970s, the output growth was sustained mainly by the increase in the availability of energy sources and not by increases in the thermodynamic efficiency of techniques used. During the fourth phase following the oil crises, improvements in the efficiency of energy exploitation played and continue to play an important role in economic growth. Despite growing awareness of European dependency on finite fossil energy sources and the growth of CO<sub>2</sub> emissions, the consumption of renewable energy sources remains marginal. If in the past century, the transition to fossil fuels was an important condition to overcome the limits to growth, today we risk

a new 'trap' without a new transition path towards a new energy system where renewable energy will play an important role.

## UNITS OF MEASURE

Kilocalorie (Kcal): 4,1868 Joule

Joule (J) or kilojoule: 0,239 kcal

Gigajoule (Gj): 1 million of kilojoule

Petajoule (Pj): 1 million of gigajoule

Tons oil equivalent (toe): 10 million of kcal

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\* Data used in the figures and tables have been taken from these titles.