## Natural Resources, Electrification and Economic Growth

## From the end of the XIXth century until WW II.

Introduction

The intensity in the use of energy, the possibility of obtaining greater quantities and its transformation into movement to mechanise work have been important successes of the Industrial Revolution[1]. As we know coal as a mineral was able to increase the quantity and the intensity of the energy consumed as compared to the energy obtained from organic sources, either wood, human strength or of animal origin and even water. Coal reduced the dependence on the organic form, and therefore also the limits to economic growth[2]. The invention of the Watt steam engine allowed the application of new ways to mechanise work which meant an increase in the use of power by man. Having abundant stocks of coal was an important factor of economic growth together with other natural resources endowments[3].

Not all countries had good endowments of the new energy-producing mineral, and for that reason not all of them had the same opportunities to use it given that the transport cost was very expensive due to its weight in relation to its calorific power. The possibilities of mechanisation and the location of economic activities changed during the First Industrial Revolution. The most important manufacturing sectors where the new energy could be applied were the textile and the iron and steel industries as well as transport: railways and shipping. These were activities where continuous movement could be applied. Their location changed from the countryside near rivers and waterfalls to cities and towns where coal could be transported to and the machines powered by the steam it produced in the big chimneys. The location was restricted to places with minimum transport costs between the location of the supply of the coal mineral and other raw materials and the location of the demand[4]. This fact increased the location of activities to where the demand was important as opposed to

[1] Landes, (1969).
[2] Wrigley, E.A. (1988).
[3] In the case of the US, Wright, G. (1990) and Nelson & Wright, G. (1992) have studied this success.
[4] Lösch, A. (1924), Isard (1956), Hoover (1948).

where the water was[5]. This situation was further helped by the improvement in transport propelled by steam.

The appearance of new energies, electricity and oil, at the end of the XIXth century, again changed the possibilities of mechanization and the location of economic activities. In this case the electric engine and the internal combustion engine were the ways in which the new energies were driven. Electricity had enormous applications: lighting, transport (railways, underground, tramways) and power. It facilitated the mechanisation of the majority of manufacturing processes because of the possibility of fractioning the use of energy and thus movements and the use of more precise machines. Another important thing from the point of view of the location of manufacturing was that this energy could be consumed far away from the electricity production centre. The advantages were its ability to be transmitted, its capacity to be transported without losses, its flexibility, that is, its easy and efficient conversion into other energy sources: heat, light and movement, and its cleanness. Electricity meant greater freedom in the organization of work in the factory and greater flexibility in the use of energy because the engine connected to the machine could work independently. The free connection to the supply of electricity meant a reduction in both the space and the work dedicated to energy production as compared to the production of steam by the combustion of coal or the movement of the water turbine. The elimination of the shifts and belts to transmit energy allowed the production organisation, or the division of labour, to change[6]. In this period, oil was used in transport with the internal combustion engine where it had many advantages when applied to the driving of transport vehicles. Electricity was produced as a secondary source from the primary ones or raw energy forms: hydraulic (from water) and thermal (steam from coal). The increased efficiency in thermal electricity reduced the unit of coal per unit of driving. The distinguishing factors of the twentieth century were more productive efficiency, an increase in the production of all kinds of goods because of the improvement in factory organisation and mechanisation and the production of more and new goods with respect to the old energies, coal and water power.

In this way electricity forms part of what are called General Purpose Technologies (GPTs) because it has a great scope for improvement, opens up new opportunities with a wide variety of uses, produces more than one distinct output, and also has a wide range of uses in

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[5] Hoover, (1948), Krugman, P. (1991).

[6] Above all the implication of these changes sees Devine, W.D. (1983).

the sense of the activities in the economy using the technology[7]. Recently, David and Wright (1999) have applied this concept to show the importance in the U.S. economy of electrification and its similitude with computer technology. Electricity caused the total factor productivity growth with a significant investment in new plants and equipments and at the same time a capital saving and an important increase in labour productivity. However, the improvement and the application of this kind of technological change with a general impact in all the economy involves a slow process of diffusion, in terms of technical requirements, financing the investment, scale economies, structural change, institutions etc., until an important increase in productivity is achieved. Computer technology as a general purpose technology displays a similar pattern.

The objective of this paper is to analyze the importance of one of the new energy sources, electricity, from the end of the XIXth century until 1945, from the point of view of natural resource endowments. The advent of electricity, as we have said, not only meant the substitution of one energy source for another but also the introduction of new ways of organising production, the possibility of mechanising new activities in the economy, as well as the advantages of its flexibility, easy transmission and cleanness. Electricity indeed reduced the dependence on coal resources as it can be produced not only from coal, thermoelectricity, but also from water, hydroelectricity and other primary energy sources. Yet another advantage was in relation to the lack of restriction it placed on the location of industry: the transport cost of energy is saved because the place where electricity is consumed does not necessarily have to be the place where it is produced. Furthermore, its transport is cheap and clean once the initial investment in the network has been made.

We want to analyze the importance of this new energy source by means of an international comparison between economies with and without coal resources these being the main energy source of "the first industrial revolution". Consequently, our first step is to obtain a database about these economies. We have found data of the study period 1890-1945 for the USA, the United Kingdom and France which had abundant coal resources, and for Italy, Spain and Canada which had better water resources. For the latter, we only have data for the majority of the variables from 1930 onwards.

The principal database consists of the prices of the two important alternative energy sources, coal and electricity, their production, their consumption, the capacity utilisation

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[7] About the concept and definition of General Purpose Technologies (GPT), see Bresnahan, T and M.

index, the proportion of hydroelectricity and thermoelectricity for the countries mentioned. There are different prices of electricity for each consumer: industrial, domestic, services and transport, called respectively: power, lighting, commercial and traction. We have not found electricity prices for all of these categories, and for that reason we present the price series available for the different countries in order to study the differences. Because there is a similar tendency or behaviour between them, we use the lighting price series to compare with the alternative energy, steam, by way of coal prices.

The second step is to describe the performance of these variables during the period under study. We want to highlight the relation between natural resource stocks and energy uses. Then, we will look at the relative prices between the two energies, electricity and coal, in the countries both with and without coal resources.

The third step is to assess the importance of this technological change in each country. We calculate for electricity demand, price elasticity, income elasticity and substitution elasticity for the countries under consideration. We also look at the influence of economies of scale on the electricity price determination by the proxy of the degree of the installed power utilisation or capacity utilisation index (production over installed power or worked hours by the production plants).

The fourth step is to analyse the effects of the new energy on industrial electrification and consequently on investment and economic growth especially during the first third of the XXth century. The importance of the new energy source is reflected in the performance of the process of electrification in industry. We want to approach the impact on economic growth during this period by focussing on the importance of the new energy in the countries with bad resources in the most important energy of the XIXth century, that is, steam from the combustion of coal. The conclusions show the relevance of the new energy source for the countries without coal resources, which had an industrialization process during the XXth century.

## 1. Natural Resources and Electricity

The most important energy sources during the XIXth century and the first half of the XXth century were coal, water and oil. The first one, converted into steam power, characterized "the first industrial revolution" by its importance in the possibility of

Trajtenberg (1995) and the different works contained in the book edited by Helpman, E. (1998).

mechanizing the main manufacturing sectors such as textile and iron and steel and also transport: railways and shipping. Not all countries had abundant and good coal deposits in their subsoil and even the cost of extraction could differ widely depending on the position of the coal vein. Coal resources were important because the cost of transport was very expensive, as the volume of coal was superior to the energy capacity per weight unit.

Even if countries had waterpower, they did not have the same advantages. Steam power was better in its applications than the water one. The disadvantages of waterpower were that it is dependant on weather conditions and the disposability of the water, its being less efficient as a power, and also the location of industry must often be in places far away from the markets or demand.

In that way, electricity changed the possibilities of the energy resources of countries because, at that time, electricity, as a secondary energy, could be produced from coal, thermoelectricity, but also from water, hydroelectricity. The latter favoured countries both with and *without* coal resources if they had good water resources. The important problem with hydroelectricity was the dependence on weather conditions to provide enough water to produce electricity, however, this problem could be solved by the construction of dams to stock and regulate the water, but this meant a substantially greater investment cost for the hydroelectric countries. Also, the possibility of transporting electricity long distances, by means of the alternating current, reduced considerably many inconveniences because it allowed for better administration of the water resources allowing different areas to receive the quantity of electricty it demanded. These improvements were even bigger with the construction of the electricity networks. Consequently, in the beginning, most electricity was thermoelectricity and then as the situation improved for the use of hydroelectricity, each country used one or other kind of primary energies depending on its natural resources. Thermoelectricity was also improved with the use of the steam turbine and efficiency rose with the use of coal, the consumption of coal per kWh was reduced during the period. In the beginning, the majority of electricity consumption was selfproduced but in the second decade of the XXth century this was completely substituted by electricity utilities[8].

We will describe the characteristics of the natural resources, coal and water, in relation to the kind of primary energy used to produce electricity (thermo, from coal, and hydraulic,

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[8] For example in the USA, in 1909, two-thirds of electricity consumption were self-produced, in 1929, two-thirds were purchased, Mortara, G. (1934). p. 58.

from water) and their locations in the countries being compared of this study. In a broad sense, in relation to coal deposits, the UK and the USA had abundant and good stocks. France had adequate stocks of good coal but extraction was difficult, and for that reason expensive, and also its production was not sufficient to supply the demand. On the contrary, Spain and Italy especially did not have as abundant stocks of coal, as the UK, the USA and Germany and neither were they of high quality. Furthermore, Spain and France had high costs of extraction and thus production. Regarding water, the USA and Canada had abundant resources of that too, however, the UK did not, and Italy, above all, and Spain had more abundant water resources than coal resources.

The consequence of these natural resources was the kind of electricity power used in these countries[9]. In the case of the USA, the main thermoelectricity power plants were in the regions of the Mid Atlantic coast and the North East Central industrial belt. They represented 57 percent of the total generated power and 65 percent of the electricity production in the USA and also 70 percent and 75 percent of the generated power and production, respectively, of thermoelectricity in 1932[10]. The main hydroelectricity power plants were concentrated in the coastal regions of the Atlantic (New York State, Pennsylvania, Maryland, North and South Carolina, Georgia and Alabama) and the Pacific (California). The first region represented 45 percent of the hydroelectricity production and the second one 30 percent in 1932.

In the UK, as mentioned above, the coal resources were big and of good quality. This country had one-fourth of the European reserves of lignite and anthracite, but it had scarce waterpower with the exception of the Highlands in Scotland[11]. Even the location of the deposits was favourable as they were distributed all over the country. This meant a great advantage in terms of the low coal price. When electricity came, the main primary source was steam power producing thermoelectricity, and small local plants were established where the deposits were located.

However, in France, the coal stocks were located in the regions of the Pas de Calais, the North, Lorraine (Mosella), and the Central Massif (Saint-Etienne, Creusot, Gard, etc.) and the Saar (only from 1925-1935). The national production represented around two-thirds of the needs of the country, the rest was imported from the countries near to these centres of

[9] We have followed the description of the Mortara's study in Mortara, G. (1934).
[10] Mortara, G. (1934). pp. 35-36.
[11] Mortara, G. (1934). p. 205.

production, and also consumption. The regions mentioned were important industrial centres with disposability of coal and so used thermoelectricity. The water resources were substantial in the regions of the Alps and the Pyrenees both of them with high falls of thin flow, and in the Central Massif with wide rivers. These regions far from the important coal stocks used hydroelectric energy and were centres of the electrochemical and the electrometallurgic industries, which need cheap and abundant electric energy. The proportion of thermoelectricity was 57.3 percent and the remainder hydroelectricity[12].

The situation was worst of all in Italy because of the scarcity of coal and its low calorific power, and as a result it had to be imported[13]. For that reason the electricity generated was hydroelectricity when the long distance transport of electricity could be resolved by the alternating current. The most important hydraulic resources were concentrated in the Alps and the Po Valley, between the Alps and the Apennines, in the North of the country. The regions with the most important waterpower were Piemonte and Lombardia, the Po Valley (Adda, Adige, Ticino, Tevere, etc.), the Veneta region and also the region of Umbria was distinguished for its resources.

The position in Spain was different. The coal resources were better than in Sweden and Italy. However, they were very much less than in the United Kingdom and Germany but similar to the case of France. The problem was the quality of this mineral and its difficult extraction and, so, the high cost of production. The most important coal resources were located in the Asturias region, in the north of Spain, near the sea but with difficult access by land because mountains enclose the region. Consequently, an important part of the consumption of this mineral came from foreign trade. The hydraulic resources were better than the coal ones, but not so abundant as in Italy, Sweden, Norway and Switzerland. They were in the Pyrenees and the Penibetica ranges. With regard to the rivers, they had little flow. However they did occupy high grounds, an advantage for electricity production. The rivers with the best flow conditions were The Ebro, The Duero and The Tajo. The inconvenience of a low flow was the dependence on the weather, making a substantial investment in dams necessary in order to stock water[14].

[12] Mortara, G. (1934). p. 121.
[13] On the implications for Italian economic development until 1913 see Bardini's work (1997).

[14] For the case of Spain see the works of Sudrià, C. (1987, 1990, 1995, 1997), Maluquer, J. (1987) and a less successful view of the spanish process of electrification from the point of view of regulation and market structure in Antolín, F. (1999)

The natural resources endowments of these countries can be described indirectly in two ways. One of them, is the distribution of the total energy consumption by primary energy sources of each country based on coal equivalents in solid fuels (coal), liquid fuels (crude oil), natural gas and hydroelectric power. Parts of the solid fuels were used to produce steam. The UK did not use a significant amount of hydroelectric power, however, this was important in Italy, Canada and Spain. Crude oil was more important in the USA and Canada than in the rest of the countries. The proportion of coal was greater in the UK and France. The change to hydroelectric power was important in Spain (from 2% to 7.2%), Canada (from 3.5% to 7.8%) and Italy (from 6.9% to 9.7%), in this order. Spain is first because it began with a low level of 2% in 1925. Meanwhile, the UK, the USA and France had extrememly low participation in the first year, 1925, and in the last year, 1937, this was still below 2%, although it did grow a lot in France.

The other way to describe the natural resources endowments is the proportion of hydroelectricity and thermoelectricity in the total electricity production. The countries which use more hydroelectricity are: Norway, Sweden, Canada, Italy and Spain, over eighty per cent, and, on the contrary, the coal intensive ones are: the United Kingdom, the USA, and France. The distribution of the different primary energies in the regions of the countries depending on their resources endowments.

## 2. Energy Prices: Electricity and Coal and the Relative Prices between both

The data set has been composed for each of the countries from different sources which appear in the appendix at the end of the paper. The following sections introduce the evolution of the price of the different energies and the principal comments we have made.

### 2.1. The evolution of electricity prices

As we have commented before there are different kinds of prices for different users: households, power, traction, etc., and also differences in the source of these prices: tariffs, average prices and revenues over sales. The price policy of the electricity companies varied depending on the kind of consumer. Consumption was more important in industry, followed by the household and traction. We can show this pattern for the countries we have data for. In the UK the industry consumption in 1929 was 60.8 percent of the total consumption, in the

US this percentage was 53.67 percent, and in Italy, in 1931, it was 74.54 percent[15]. Prices are higher in the household use because there are much more expenditures in distribution and because of the short duration of the consumption and its concentration during the same period of time.

We observe two main things of the evolution of the different prices of the countries: firstly, the evolution in each country we have data for is the same for the different users, the only difference is the level (in the case of the USA and Canada) and the size of the slope (in the case of the UK) between them. The household prices (residential, lighting) are higher than the other ones (industrial use or power). Thus, we can use the lighting prices as proxy of the electricity prices to compare with the alternative energy, steam, which has a bias against the use of this energy. Second, the evolution during this period, more or less, is also similar in every country, that is, the fall in real prices from the beginning of the series until WWI and the stability during the 20's. In the 30's decade, there are two tendencies: an increase in prices until around 1933, and after they fall.

Another important thing to highlight is the different periods of time for which we have data for each country and the origin of the source. Thus, in the case of the United Kingdom, for which we have series of electricity prices from sales over incomes for each kind of consumer and the overall average, we see the beginning of the series in 1921, and the fall from that date until the 40's. Also, in Canada, with the same kind of calculated prices, the series starts in 1930, and from 1933 there is a fall during the whole the period of time under consideration. To sum up, there is a difference in the behaviour of the prices during the 20's between the UK and the rest of the countries (except Canada which we have no data for in this period): the fall in the former and stabilisation in the latter.

### 2.2. The evolution of coal prices.

The principal and important alternative energy to electricity was steam from the combustion of coal, therefore, we may approach the cost of this energy by means of the price of coal. With regard to coal prices, there are different qualities and kinds of minerals. We can see in the appendix how these sources can differ. The bituminous and anthracite are the most usual types of coal. The first has the highest calorific value. The series presented in the yearbooks and official statistics vary across countries and perhaps this indicates which coal

[15] See the sources of statistics in the appendix. The proportion also varied because of the importance of the consumption of the electric domestic appliances and that increased the lighting use, which were very developed in the USA.

was more generally used for each of them which moreover depends on its natural resources stocks.

We observe an increase in the price of coal in 1920 in all the countries, with the exception of the pronounced increase in Spain during WWI. The explanation for the latter could be that Spain was neutral in the war and did not have enough coal to supply the necessities of the Spanish economy as it had a poor coal endowment. Also, we can find in all of them that during the twenties there was a diminution of the prices to pre-WWI levels. Certain stability followed, with the exception, again, of Spain where prices were higher than the levels prior to WWI, although they followed a stable evolution, and of France where prices grew a lot in the thirties'.

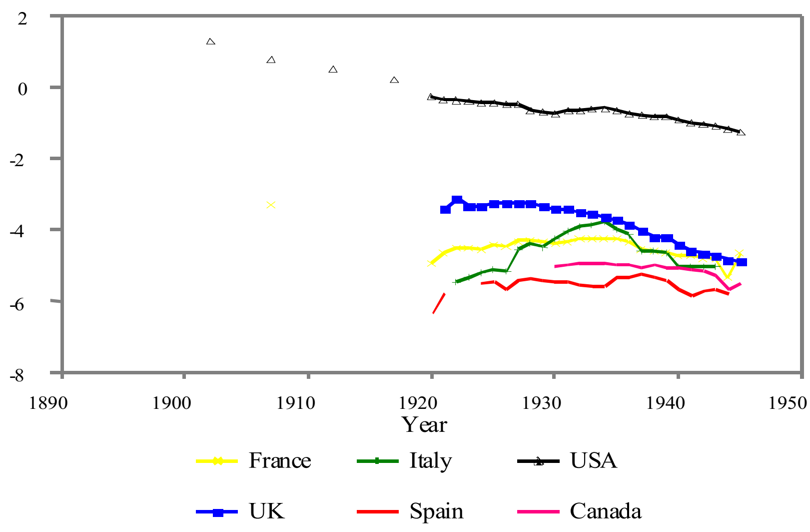
The international coal market was in stagnation. There was an expanding market before WWI, but after, the demand declined and this was further accentuated by an increase in efficiency. The diminution of the demand was due to the appearance of new energy sources, electricity and oil, and the consequent substitution, for example, from coal-burning to oil-burning ships and from steam engines to electric motors. However, the thermoelectricity industry did increase the demand for coal. But, there was also a lower demand for coal due to the recession of the intensive industries which used this mineral, such as the iron and steel, and shipping industries. However, there was also an improvement in the techniques of using coal, such as the improvements in the steam turbine or the fuel efficiency of the blast furnaces that reduced the consumption of coal per kWh or other power unit.

### 2.3. Relative prices: electricity and coal

Having looked at the evolution of the prices of electricity and coal, we are now going to look at the relative prices between these two energies in the countries of the study. We use lighting electricity prices to do this as we have data for all of them. That is a problem as it affects the level and perhaps, although to a limited extent, the size of the slope of the electricity prices but not the performance and the bias is against the predicted behaviour. We are also comparing a primary energy, coal, with a secondary energy source, electricity, because electricity can be obtained from waterfalls or from the steam used to work the electric generator. In the last case, coal was an input too and we are also measuring the improvement in efficiency in thermoelectricity and thus the advantage in favour of electricity. However, because the countries of the dataset were thermoelectric or hydraulic we know when we are in each case. Thus, the coal price is used as a proxy of steam, the alternative energy to electricity.

The relative price between electricity and coal means the quantity of coal that we can buy with a unit of electricity, in short, the number of tons per kWh[16]. The more expensive coal is with respect to electricity, the less quantity of coal we are able to buy per unit of electricity, and viceversa. Therefore the relative prices were lower in the countries without coal than in the richer ones. In Figure 1, we can see the relative prices of some of these countries: France, Italy, the USA, the UK, Spain and Canada. We can observe how in the countries with better coal resources, the level of these relative prices was higher than in the countries with less resources or with much better conditions in hydroelectricity in relation to steam or thermoelectricity. The former were the USA and the UK, with France in an intermediate position, and the latter were Spain, Italy and Canada.

**Figure 1: Relative prices (ton/ kwh)**
Lighting/ Coal ( Ln)




We are now going to comment on the evolution of these relative prices by country. The countries can be divided into three groups depending on the importance of the coal resources: with abundant coal, the USA and the UK, with intermediate stocks, France, and without coal, Italy and Spain. In general there are not very many differences in the evolution of the prices between countries. There was a great fall around WWI and afterwards a slow decrease or stagnation depending on the countries. Firstly, the USA and the UK had descendant relative prices over the whole period this being more accentuated at the beginning of the twentieth century in the case of the USA. France also had an important diminution towards the beginning of the century, however, this stabilized in the 20's. In the case of Italy there was an increase from 1920, the year from when we have data, to 1934, but if we had data for the early years we would expect there to have been a decrease in these first years. From 1934 to the end of the series, the relative prices fell. The fall happened in Spain during the IWW, but the relative prices remained stable during the 20's. The rise of the relative prices in Italy was above all due to the fall in coal prices from 1921 to 1930, something that did not happen in Spain because of the high protection tariff[17]. Therefore, the relative prices were more favourable to Spain and Italy for electrification, or the substitution of steam by electricity.

## 3. Elasticity of Demand: Price, Income and Substitution

Electricity had the advantage in relation to another energies of the great variety of its uses: power, lighting, traction, and so on. Gas, on the other hand, could only be used for lighting, so it was a competitor in the early years, but soon the relative prices favoured the new energy[18]. In the case of traction, there was competition with another new energy at that time, oil or petrol, and the relative price changes did not favour this new energy for its use in traction[19]. However, electricity was very important in the new urban means of transport such as the subway and the tramway. The most important competitor for power use and also for heating use was steam by the combustion of coal. Notwithstanding, electricity could meet the new demands not satisfied by the old energies, such as the demand from the small and craft manufacturers or the high added value industries that had not been able to mechanize beforehand. This fact was very important for the increase in productivity of these kinds of manufacturers. Furthermore, the new machinery with less weight and more precision, because of the new steel alloys, as well as the new possibilities of organising production allowed for important improvements in industry productivity. Added to this were the previously mentioned advantages of easy transmission, flexibility and cleanness[20].

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[16] The relative prices, electricity over coal, have been used by Svennilson, I. (1954).
[17] See Coll, S. and Sudrià, C. (1987).
[18] Regarding such competition see, for the case of Spain, Calatuña, Arroyo, M. (1996), Sudrià, C. (1983), and Hanna, L. (1979) for the United Kingdom.
[19] Hannah, L. (1979). pp. 157-159.
[20] There is a very good explanation of all of these advantages in Devine, W.D. (1983).

There are several factors which contributed to the rapid development of the electricity industry. Firstly, the quick succession of different inventions and exploitations to improve the generation and application of electricity (Svennilson, 1959). Secondly, at about the time of the IWW, the increase in the efficiency of thermal power stations, which in the early phases of the development of electrification had retarded the spread. And thirdly, and most importantly, was the invention of the high voltage current that allowed the transmission of the energy over long[21]. The latter allowed the consumption of electricity to increase as it could be used in places other than those of production.

We are going to assess the importance of this technological change, by the way to calculate for the electricity demand, the price elasticity, income elasticity and substitution elasticity for the countries under consideration. We estimate the different elasticities using the following equation:

$$PREi = a + b\ PEi + cYi + d\ PCi + u$$

where PRE is the production of electricity, PE, the electricity price, Y, the per capita income, PC, the coal price, for each considered country i. All the variables are in natural logarithms. The coefficient *b* is the price elasticity, the *c* one, income elasticity and the *d* one, substitution elasticity (in this case we have considered the price of coal). We have also considered the total production of electricity but using only the lighting prices as electricity prices because we do not have data for every kind of demand for each studied country.

We expect a negative sign of the coefficient *b*, because electricity is a normal good. We also expect a positive sign of the *c* coefficient, because of its importance in the industrial sector and in the economy in general because of the process of electrification. In the case of the sign of the *d* coefficient, this may depend on the kind of primary energy used in the production of electricity. If it is thermoelectricity the sign could be negative, because coal is input, and if it is hydroelectricity it could be positive, because coal is a substitute energy.

The results appear in Table 1. The price elasticity is negative in the USA (-0.41), the UK (-0.08) and Spain (-0.18), however, it is positive and thus inelastic in Italy (0.40) and France (0.20). The most elastic demand was that of the USA followed by Spain. Perhaps, the positive sign of Italy can be explained by company price policies during this period when the

[21] The first transport of energy over a long distance happened in 1873, and then in 1882 using the high voltage current. The transformation of the current to high voltage was invented in 1884, but until 1893 the high voltage current was not considered better than the continuous current because the importance of long distance transport had not yet been measured.

demand was under the supply because of the great investment on installed capacity during the IWW in spite of great economic growth[22], and above all given the high cost of the investment when 90 percent of production was hydraulic. We will see in the next section the decrease in the ratio of electricity production over power. The positive sign in the case of France is due to the fact that there was regulation after the IWW in 1919, which established that the electricity price should follow the behaviour of an indicator based on coal prices and wages[23].

**Table 1: Demand for Electricity**

Dependent variable: Electricity production

| Countries:<br>Period:<br>Variables: | UK<br>1921-45<br>(1) | USA<br>1920-45<br>(2) | France<br>1920-45<br>(3) | Italy<br>1921-45<br>(4) | Spain<br>1920-45<br>(5) |
|---|---|---|---|---|---|
| C | 7,074<br>(2,88) | 9,67<br>(10,26) | 6,82<br>(4,54) | -20,68<br>(-5,32) | 2,07<br>(0,62) |
| Pe | -0,08<br>(-0,72) | -0,41<br>(-5,20) | 0,20<br>(2,60) | 0,40<br>(4,05) | -0,18<br>(-0,94) |
| Y | 0,59<br>(2,31) | 0,35<br>(3,58) | 0,58<br>(3,75) | 3,74<br>(6,89) | 0,74<br>(1,81) |
| Pc | -0,15<br>(-1,379) | 0,04<br>(0,58) | -0,37<br>(-2,32) | 0,14<br>(0,61) | 0,10<br>(0,55) |
| R2 centered | 0,997 | 0,993 | 0,980 | 0,942 | 0,951 |
| DW | 1,546 | 1,767 | 2,563 | 1,253 | 2,591 |
| N (usable obs.) | 24 | 25 | 25 | 21 | 24 |

Note: Method of estimation Cochrane- Orcutt. The t-statistic figures in parenthesis.
Variables: Endogenous variable, electricity production; the exogenous variables: Pe, electricity price (real), Y income per capita, and PC, coal price (real). All the variables are in ln.

The substitution elasticity appears to be negative in the countries that produce electricity from coal, such as the UK (-0.15) and France (-0.37). The price of coal had an effect on the price of the kWh of electricity, an important factor in France because the industrial centre was close to the coal resources (in the North) and because the price regulation based on coal. In Italy and Spain, clearly, with hydroelectricity, the sign is positive, electricity production could increase as the coal price did because as it was a substitute energy

[22] In the case of Italy Giannetti, R. (1985) says that after the IWW, inflation meant that the electricity companies had important financial problems and they had to increase the electricity tariffs. The demand was completely inelastic. See also about the financial problems of companies Storaci, M. and Tattara, G. (1998) .
[23] Morsel, H. (1987) also explains the high debts incurred in this investment process.

but also because it was not very important for the relevance of hydroelectricity and, for that, even this variable is not significant. Not all of these variables are significant in the regressions as can be seen in Table 1. However, the income elasticities are all significant. The highest are Italy (3.74) and Spain (0.74), after the UK (0.59) and France (0.58), and the last one the USA (0.35). The importance of income elasticity is greater in the less developed countries such as Italy and Spain.

## 4. Price determination: the utilization capacity

As long as electricity was increasing demand, the electricity supply was reacting by reducing the costs of production and prices, and, at the same time, consumption was being stimulated as part of an accumulation process, at least this is what happened in the UK[24]. This industry is considered to have important increasing returns in generation and distribution. These were possible because the electricity laying and the interconnection of power systems were expanded and improved. There was also a better combination between two primary sources: thermo and hydropower.

The economies of scale increased with the extension of consumption through the development of the electricity network and because electricity cannot be stored demand must coincide with supply or production. The growth of the electricity demand depended on the level of economic development as well as the industrialisation of the country. We are interested in looking for the relation between the electricity prices performance and the economies of scale measured by the proxy of the degree of the installed power utilisation or the utilisation capacity. The cost of production varied with the utilisation capacity[25]. This proxy is calculated by the proportion of electricity production over installed power, and indicates the number of worked hours by the production plants. It also measures the efficiency in the utilization of the installations.

The installed power utilisation shows up if there is a good installation of electricity, because electricity can not be stored, the increase of this ratio means the reduction of the cost of production. The performance of this ratio depends on the electricity demand and thus

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[24] Hannah (1979), p.161.

[25] The cost of electricity production of each unit depends on the fixed cost and the variable cost. The former is the expense in financial capital, interest rates and amortisation, administration, insurance, etc. The latter depends on the utilisation capacity, (Hutte's *Handbook of the engineering*).

economic development and also the business cycle. But we can also suppose that the size of the production allows the generation of important economies of scale. When there is an important size, it is also possible to coordinate more stations and plants, invest in better installations, improve and better exploit dams and so on. The importance of this varies according to the kind of plant. The hydraulic plant has more installation costs than the thermoelectric one because of the construction of dams. We will try to approach this size by means of a dummy that indicates a threshold in the electricity production or demand which could generate these economies because of the importance of the minimum demand for producing in presence of fixed costs. We have estimated it by the performance of the demand of electricity which has the downward slope when the quantity of production is close to the log of 8. We have constructed a dummy for each country, which takes the value 1 when this quantity is definitively reached.

We have done a regression of the electricity prices on installed power utilisation and the mentioned threshold dummies. We expect a negative sign of this variable because the better (worse) the utilization of the installed capacity is, then the cost of production and prices will fall (increase). We also expect a negative sign of the coefficient of the threshold dummy, that is, if the size of the market also contributes to the apparition of economies of scale and that this could be more important in hydraulic countries. We add a dummy for the IIWW. We can see the estimation in Table 2. We run the regression with a different dummy for each country, when the threshold in electricity production was reached. This means that it is zero in the years before reaching a certain level of production and 1 after this level. Of course there are some countries which reached this size of production beforehand, such as the USA, but the rest during the 20's. But, however, definitively, Spain did not reach it until 1939. The IIWW dummy whose value is one from 1939 to 1945 and zero in the others years, has a zero coefficient in all the countries, with the exception of Spain because this dummy coincides with its threshold dummy.

**Table 2: Electricity price determination**

Dependent variable: Electricity price

Period 1920-1945

| Countries:<br>Variables: | UK<br>(1) | USA<br>(2) | France<br>(3) | Italy<br>(4) | Spain<br>(5) |
|---|---|---|---|---|---|
| C | -382,85 | -3,41 | -2,36 | 0,22 | -1,63 |
| | (-2,04) | (-0,59) | (-2,24) | (0,23) | (-2,77) |
| UC | -0,74 | -0,82 | 0,31 | -0,30 | -0,11 |
| | (-2,30) | (-4,62) | (0,93) | (-1,08) | (-0,61) |
| DLN8 | 0 | 0 | 0 | 0 | -0,83 |
| | | | | | (-13,52) |
| R2 centered | 0,97 | 0,97 | 0,53 | 0,93 | 0,96 |
| DW | 1,36 | 1,79 | 1,79 | 1,28 | 1,34 |
| N (usable obs.) | 22 | 24 | 24 | 19 | 19 |

Note: Method of estimation Cochrane-Orcutt. The t-statistic figures in parenthesis.
Variables: endogenous variable: electricity price; the exogenous variables: UC, index of capacity utilization (production/power), the variables are in ln, DLN8, dummy which takes the value 1 when the production reaches the ln of 8.

In the estimation not all the coefficients of the variables are significant, above all in the case of Spain and Italy. The main outcomes are the importance, significant, and the correct sign of the installed capacity index in the USA and the UK (-0.82 and –0.74, respectively). In the case of France, the positive sign of the coefficient (0.31) reflects the influence of public price policy on the price policies of companies[26]. For this reason, the evolution of the electricity prices in France was independent of the use of the installed capacity. In Italy, this coefficient (-0.30) is negative and lower than the former countries. The reason also could be the price policy of the electricity companies in the presence of excessive installed capacity. However, Spain differs from the rest because it is the only country with a significant threshold dummy. The coefficient (-0.11) is lower than the USA, the UK and Italy but the dummy is very significant and high (-0.83). The problem of this dummy is that when this production size was finally reached it coincided with a peculiar phase of the Spanish economy, "the autarquia", when some prices were controlled and there was high inflation. In that way, it is difficult to separate the two effects. Furthermore, because the restrictions of electricity production began in 1945 we have estimated without this last year but the results are the same. The origin of the restrictions was the lack of rain while demand was increasing

[26] Morsel, H. (1987). The regulation of electricity prices affected the hydroelectric and thermoelectric companies to different degrees as this was based on the price of coal.

considerably[27]. In the case of Italy, the other hydroelectric country, it was going through an excessive production capacity phase and for that the dummy had no effect.

We have wanted to see the possible influence of economies of scale; an increase in scale reduces unit cost of operation and consequently electricity prices. The economies of scale were greater in the more development countries. We also see how it could be important to reach a certain level of production or size of the market for important economies of scale to appear, above all in the countries which used hydroelectricity. Spain had low economies of scale because of its low level of development, but it seems that those appeared when it reached the threshold size.

## 5. The importance of the new energy source: industrial electrification

We have shown the differences between countries with respect to the evolution of energy prices. Now, we are going to look at the effect this evolution had on the electrification process in the industrial sector, from which came the most important demand at that time, and where electricity competed with another energies. The degree of electrification depended on several factors the most important being the following. Firstly, economic development: the size of the industrial sector, the possibilities of investment in mechanisation, and the energy price, and this more so as economies of scale appeared. Secondly, the composition of the industrial sector: above all the importance of the manufacturings belonging to "the second industrial revolution", that is, electricity intensive industries, or the importance of industries where electrification is necessary, such as the electrochemical and electromechanical industries. The importance of the latter in a country depends on its having abundant and cheap energy resources, and so, they were located near the hydroelectric sources, and so they were important in Switzerland, Italy, Sweden and Norway. Thirdly, the location of the manufacturing sector in a country. Usually, with the first industrial revolution technology, industry was located near the coal deposits especially those who used it intensively, such as the iron & steel industry. For example in the case of the UK (spread over all the territory), France (the North and Paris) and the USA (Central NorthEast) but also near the demand which usually coincided due to accumulative development. With electricity, once the installation of the network is made, the location is less restricted, however, this also depends on the demand, which is path-dependent on the first industrial location.

[27] See Sudrià, C. (1990, 1997).

In Table 3, we can see the degree of electrification in the industrial sector, as the proportion of the electric motor driven machinery of total machinery (horsepower of the machinery), in percentages. We can observe these data for the years belonging to the first third of the XXth (1900, 1913, 1925, 1929 and 1938) and for 11 countries from Europe, the USA, Canada and Japan. In this way, we can observe the evolution of the electrification process. The advance of this process happened between 1913 and 1925 for all the countries which improved substantially, over 50 percent, the UK and France being less with 49 percent. For example, the USA and Sweden achieved a degree of 77 percent from 40 and 48 percent respectively in 1913 and Italy reached 74 percent, when in 1913 it had had a percentage of 48. In 1929 the level of industrial electrification was quite high, greater than 75 percent with the exception, again, of the UK (61 or 66.3 percent depending on the source) and Germany (70)[28]. In 1938, for the countries we have data, the percentage rose to more than 85 percent. We do not have data for the UK for this year.

**Table 3: Electrification** (% motor driven machinery/total horsepower)

| Country | 1900 | 1913 | 1925 | 1929 | 1938 |
|---|---|---|---|---|---|
| UK* | | 23 | 49 | 61/66,3** | |
| France | | | 48,8 | | |
| Germany | | | 66 | 70 | |
| USA | 11,6 | 36/38,9*** | 77 | 79,1/82,3*** | 85/89,84*** |
| Canada | | | 67 | | |
| Sweden | | 48 | 77 | 82,5 | 89 |
| Switzerland | | | | 87,8 | |
| Norway | | | 67 | 73,8 | |
| Finland | | 32 | 63 | | 87 |
| Italy* | | 48 | 74 | 77,8/79**** | 88 |
| Japan* | | 30 | 86 | | 82 |

Note: *Japan (1914, 1926, and 1940), USA (1904, 1926, and 1937), Italy (1911, 1927), and Britain (1912, 1924)
Source: ** UK (first calculated from Svennilson , second from Mortara (1934))
*** USA (in 1913: first from Mortara(1934), second, in 1914, from Schurr&Netschert (1977))
*** USA (in 1925: first from Segreto, L. (1992), second from Schurr&Netschert (1977))
*** USA (in 1938: first from Mortara (1934), second, in 1939, from Schurr&Netschert(1977))
**** Italy (in 1929: first, in 1927, from US Department of Commerce, second, 1929, from Mortara (1934))
Germany (1925 from Mortara), Japan from Mortara (1934)
The rest of them from Myllyntaus (1991).

As mentioned above, the path of this process is slower depending on the endowment factors of the countries and also the production structure of the economy. The countries with

[28] We do not have data for France for 1929, but it was perhaps very low too.

better water resources in relation to coal began the electrification of industry earlier, with the exception of the USA, which began early too. The weight of intensive industries using coal was also an important factor as in the case of the UK. It also happens with the weight of intensive industries using electricity in the countries with abundant water resources, which have outstanding advantages in the electrochemical and electromechanical industries, because of the necessity of cheap raw materials and electric waterpower.

In the following paragraphs I shall concentrate on the electrification by manufacturings in order to see the differences between them and to compare these with Spain as we do not have overall data, but only for some manufacturings. In the USA the least electrified sector was woodworking (58.3%), as it was in Sweden and Norway, and the most electrified sectors were publishing and rubber (about 95%). Publishing was highly electrified in all the countries, for example, in Germany, Italy, Switzerland and Norway. The chemical industry was also highly electrified if we include the electrochemical sector above all in the countries with hydraulic resources such as Germany, France (in the Alps) and Norway. Something similar happened in some metal constructions related with the electrometallurgy sector in Italy, Switzerland, Sweden and Norway. However, the food, iron & steel and even textile sectors, but not apparel, were less electrified in Germany, the UK, France, Italy and outstandingly so in the USSR (23.8%) where economic policy did not favor the consumption goods industry. These manufacturings had low-income elasticity demand at that time and this may have delayed investment.

In the case of Spain, there is no data for all the industries, but only for several branches. In textile manufacturing, which represented a high proportion of the total industrial sector (31% in 1913, and 18% in 1929, of the industrial added value), the electrification process advanced greatly during the twenties' and the same happened in the sawing manufacturings and workshops. In 1929 in the chemical industries, where data is very incomplete, 64 percent of the horsepower was used by electric motors, while in 1913 most of them were propelled by steam and in 1922 the electric powered ones began to exceed the others. The electrochemical sector in Spain had not advanced very much as this would have required lower electricity prices. 74.9 percent of the horsepower used in the artificial cement industry was of electric origin, however in the natural cement industry, which was less important, was 60.4 percent. The iron and steel industry was located near the coal deposits and a great investment was needed to electrify this industry. Electrification took place in the rolling stage, but this was much lower in the electric blast furnaces, where cheaper energy is needed, employed to produce new special steels. In 1929, 69.1 percent of total machinery, excluding furnaces, consumed electricity as compared with 34.5% in 1913. In the metallurgy industry, the participation of electric motors in the production of copper, lead, zinc and aluminum was of 65%, 87%, and 100%, respectively, in 1929.

Comparisons are difficult because the division by manufacturing subsectors is not homogeneous and in the case of Spain we have only partial data. However, despite these difficulties we are going to compare the case of Spain. In Spain, electrification in the textile and iron and steel industries was not far behind the other countries. It was important too in the woodworking, cement, ceramic and glass industries, however the data is incomplete for the chemical indusrty. According to the information we have, we can say that the process of electrification, at that time, in Spain was not retarded in relation to its lower level of economic development.

## 6. Electricity and economic growth

In this section estimates the importance of the new energy, electricity, on economic growth. We have looked at the relative prices of both energies (electricity and coal) and the changes these underwent for the countries relevant to our investigation and it would seem that there were advantages for the countries with a worse coal endowment in terms of opportunities to mechanize and improve industry. We have also dicussed the advance of electrification in the manufacturing sector and the repercussions this had on the increase in productivity in industry (Woolf, Devine) and consequently on economic growth. Now, we want to see the effect of electricity by the way of the energy relative prices on the economic growth during the period 1921-1945. We construct a panel data with the five countries[29] (France, the UK, the USA, Italy and Spain) for five periods 1921-25, 1925-29, 1929-35, 1935-40, 1940-45. We regress growth of the GDP per capita on the initial level of GDP per capita, the ratio of investment over GDP, as a proxy of capital accumulation, the relative prices of both energies and the dummies for each country, in the following equation:

$$GY = a + b\ Yt\text{-}1 + c\ INV + d\ PPt\text{-}1 + u$$

GY is the annual growth rate of GDP per capita, Yt-1 the GDP per capita in the initial level for each period in natural logarithms, INV the investment share on GDP is an average

[29] We have not included Canada because we only have data for the thirties'.

for each period, PPt-1 energy relative prices (electricity over coal) in the initial level for each period.

In Table 4, we can see the results of the relevant regressions[30]. In the first regression we consider the initial GDP per capita, the investment share on GDP and the significant dummies of the countries[31]. The dummies capture the omitted variables related with the differences in the level of development: structural change, schooling, such as human capital. In the second regression we add the energy relative prices.

**Table 4: Relative Prices and Economic Growth**

| Dependent variable: Per Capita GDP Growth<br>Period: 1921-45 | | |
|---|---|---|
| Variables: | (1) | (2) |
| C | 0,5488<br>(1,795) | 0,6088<br>(2,003) |
| ln Y1 | -0,0815<br>(-2,110) | -0,0910<br>(-2,349) |
| INV | 0,0069<br>(3,886) | 0,0082<br>(4,520) |
| PP1 | | -0,2173<br>(-3,758) |
| DUK | 0,1035<br>(3,726) | 0,1192<br>(4,130) |
| DUSA | 0,0659<br>(1,936) | 0,1887<br>(3,276) |
| R2 centered | 0,5216 | 0,5711 |
| N (usable obs.) | 24 | 24 |

Note: OLS estimation corrected by heteroscedasticiy, White Method. The t-statistic figures in parenthesis. Variables: endogenous variables: annual growth rate of GDP per capita exogenous variables: Y1, initial per capita GDP in natural logs, INV investment share on GDP, PP1, initial relative price: electricity over coal, DUK, dummy for the UK, DUSA, dummy for the USA.

We get the negative sign of the initial level per capita which means a relative convergence as we control for the dummies and the rest of the variables, the positive sign of INV (Barro (1991), De Long and Summers (1991)), although not very high, and in the second regression the negative sign and important coefficient of the energy relative prices. The latter means that the countries with lower relative energy prices (electricity over coal), that is,

[30] We get the same outcomes using three periods, 1921-1929, 1929-35, 1935-1945, but we prefer 5 periods because we have more freedom grades.

[31] We have only considered the significant dummies for the countries for not losing degrees of freedom.

where electricity was cheaper than coal, could grow more during the period once we control for the other variables and dummies. Thus, the new energy had a positive effect on economic growth and was important for the countries without good coal endowments whose relative prices were lower.

## Conclusions

The main conclusion of the paper is the importance of electricity, which could be created from different primary energies, both water and coal, in reducing the dependence on the natural resources of coal for the countries without that important mineral.

We show the different natural resources endowments of water and coal for five countries with and without coal as the primary sources used to produce electricity. We construct a database of the prices of electricity, with the proxy of *lighting* prices, and the old and alternative energy, with the proxy of coal prices. The relative prices of these two energies show the advantages for the countries without coal deposits in their subsoil.

We calculate the price, income and substitution elasticities of demand for each country. The price elasticity varied a lot between countries. The income elasticity was high and higher in the less developed economies. The substitution elasticity behaviour depended on whether coal was input or an output. In the first case it was negative, because it affected the output, and in the second case it was positive because it favored the substitution of energies.

Then, we approach the cost of production and thus the price determination factors. The importance of the economies of scale in this industry allows us to prove the relevance of the level of economic development in achieving greater advantages in electricity prices and so in the production cost for the industry and the economy as a whole. In the case of the hydroelectric plant the cost of installation was greater than in the thermal ones which made the size of production an important factor in reducing the cost per kWh.

The degree of electrification advanced substantially during the first third of the twentieth century, the height of the processs being in 1925, with the exception of the UK and France, and again very high in 1929. The advance of electrification in the manufacturing sector, where electricity competed with the steam, and the behavior of the relative energy prices in the countries without coal resources produced important opportunities for economic growth. The relation between the relative energy prices and the economic growth during this period has been negative once we control by the initial level of per capita income, the accumulation of capital, and the country dummies. This means that countries with lower relative energy prices, where electricity was cheaper than coal, could grow more during these years.

References


Antolín, Francesca (1999): "Iniciativa privada y política pública en el desarrollo de la industria eléctrica en España. La hegemonía de la gestión pivada, 1875-1950*", Revista de Historia Española*, XVII, 2, pp. 411-445.

Arroyo, M. (1996). *La industria del gas en Barcelona, 1841-1933. Innovación tecnológica, territorio urbano y conflicto de intereses*. Barcelona, Ediciones del Serbal.

Bardini, C. (1997). "Without Coal in the Age of Steam: A Factor-Endowment Explanation of the Italian Industrial Lag Before World War I", *The Journal of Economic History*, vol. 57, No. 3. pp. 633-552.

Barro, R. J. (1991). "Economic Growth in a Cross Section of Countries", *Quaterly Journal of Economics*, 106, 2, (May), pp. 407-443.

Bresnahan, T. and M. Trajtenberg (1995). "General purpose technologies: Engines of Growth", *Journal of Econometrics*, 65, p 83-108

Coll, S. and Sudrià, C. (1987). *El Carbón de España, 1770-1961. Una Historia Económica*. Turner.

David, P.A. and G. Wright (1999). "General Purpose Technologies and Surges in Productivity: Historiacal Reflections on the Future of the ICT Revolution", *Discussion Papers in Economic and Social History*, 31, University of Oxford.

De Long, B. and Summers (1991). "Equipment Investment and Economic Growth", *Quaterly Journal of Economics*, 106, 2, (May), pp. 445-502.

Devine, W.D. (1983). "From Shafts to Wires: Historical Perspective on Electrification", *The Journal of Economic History*, vol. XLIII, No. 2. pp. 347-372.

Giannetti, R. (1985). *La Conquista della Forza. Risorce, Tecnologia ed Economia nell'Industria Elettrica Italiana (1883-1940)*. Milano, Franco Angeli Libri.

- (1986). "Elettricità e Industrializzazione dall'"Età del Decollo" alla Seconda Guerra Mondiale", *Società e Storia*, 3. pp.595-618.

Hannah, L. (1979). *Electrification before Nationalisation. A Study of the Development of the Electricity Supply Industry in Britain to 1948*. London, The Johns Hopkins University Press.

Helpman, E. (1998). (ed.) *General Purpose Technologies and Economic Growth*. Cambridge, Mass, The MIT Press.

Hoover, E.M. (1948). *The Location of Economic Activity*, New York, McGraw-Hill.

Hugues, T.P. (1983). *Networks of Power. Electrification in Western Society, 1880-1930*. Baltimore and London, The Johns Hopkins University Press.

Isard, W.(1956). *Location and Space-Economy*. Cambridge, MA., The MIT. Press.

Krugman, P.(1991). *Geography and Trade*. Cambridge MA, The MIT Press.

Landes, D. S. (1969). *The Unbound Prometheus*. Cambridge, Cambridge University Press.

Lösch, A.(1940). *Die raumliche Ordnung der Urtsschaft*. New Haven Yale University, Press. English version (1954, and sixth edition, 1973): *The economics of Location*. New Haven and London, Yale University Press.

Maluquer de Motes, J. (1987). “L’électricité, facteur de développement économique en Espagne: 1900-1936”, (Caron, F. (ed.). *Un siegle d’electricité dans le monde 1880-1980*. Paris, Press Universitaire de France. pp. 57-67.

Morsel, H. (1987). “Panorama de l’histoire de l’électricité en France dans la première moitié du XX^e siècle”, (Caron, F. (ed.). *Un siegle d’electricité dans le monde 1880-1980.* Paris, Press Universitaire de France. pp. 85-117.

Mortara, G. (1934). *Nel Cinquentenario della Societá Edison, 1884-1934*. Milano, Societá Generale Italiana Edison. 4 volumes.

Myllyntus, T. (1991). “The Transfer of Electrical Technology to Finland, 1870-1939”, *Technology and Cultures*, 32 (2/1), April, pp. 293-317.

Nelson, R.R. and Wright, G. (1992). “The Rise and Fall of American Economic Leadership: the Postwar Europe in Historical Perspective”, *Journal of Economic Literature*, 30, 4, pp. 1931-64.

Schurr, S.H. and Netschert, B.C. (1960). *Energy in the American economy, 1850-1975. An economic study of its history and prospects*. Westport, Connecticut, Greenwood Press.

Segreto, L. (1992). Vol. . Castronovo, V. (dir). *Storia dell’industria elettrica in Italia*. Editori Laterza.

Storaci, M. and Tattara, G. (1998). “The External Financing of Italian Electric companies in the interwar years” in *European Review of Economic History*, vol. 2, part. 3, pp. 345-375.

Sudrià, C. (1983). “Notas sobre la implantación y el desarrollo de la industria del gas en España, 1840-1901”, *Revista de Historia Económica*, I, 2, pp.97-118.

- (1987). “Un factor determinante: la energía”, Nadal, J. Carreras, A. y Sudrià, C. (comp.). *La Economía Española en el siglo XX. Una perspectiva histórica*. Barcelona, Ariel. pp. 313-327.
- (1990). “La Industria Eléctrica y el Desarrollo Económico en España”, Garcia Delgado, J.L. (dir*.). Electricidad y Desarrollo Económico: Perspectiva Histórica de un siglo*. Oviedo, Hidroeléctrica del Cantábrico.
- (1995). “Energy as a Limiting Factor to Growth” in Martín-Aceña, P. and Simpson, J. (eds.). *The Economic Development of Spain since 1870*. Aldershot, Edward Elgar, pp. 268-309.
- (1997). ”La restricción energética al desarrollo económico de España”. *Papeles de Economía*, No. 73. pp. 165-188.

Svennilson, I. (1954). *Growth and Stagnation in the European Economy*. Geneve, United Nations Economic Comission for Europe.

U.S. Department of Commerce (1931). *Power-Using Industries of Italy*. Trade Information Bulletin, No. 772. Washington, Goverment Printing office.

Wright, G. (1990). “The Origins of America Industrial Success, 1879-1940”. *The American Economic Review*, vol. 80, No. 4, pp. 651-667.

Wrigley, E. A. (1988). *Continuity, Chance and Change. The Character of the Industrial Revolution in England*. Cambridge, Cambridge University Press.

Wylie, P. J. (1989). “Technological Adaptation in Canada Manufacturing, 1900-1929”, *The Journal of Economic History*, vol. XLIX, No. 3. pp. 569-591.

**APPENDIX: Data sources**
Main found sources:

Prices of energy
All the series have been deflated by their correspondent wholesale price indexes from Mitchell, B.R. (1988)

Electricity:

1) France
- *Annuaire Statistique de la* France, 1946: Résume Rétrospectif. *Tableau XI. Prix moyen de l'electricite pour l'eclairage privé*. Average Lighting. (1914, 1920, 1928, 1930-1945). In francs and cents per Kwh.

2) Italy
- *Somario di statistiche storique dell'Italia*, (*energia elettrica per illuminazione, Comune di Milano*),1861-1965, Rome 1968. Lighting (1921-1942). In lire per Kwh.

3) USA
- *Historical Statistics of the US Colonial times to 1970. U.S*. Department of Commerce. Bureau of the Census. p.827. Household (residential service, like in Svennilson (1959)) (1902, 1907, 1912, 1917, 1920-1945), Large light and Power (average price, the same in Svennilson (1959), (1917, 1922, 1926-1945). Average prices all services (1907, 1917, 1922, 1926-1945), these average indicate the average revenue from electric service and will vary with the average use and the rate levels. In cents per kWh.

4) UK
- Hanna, Leslie (1979). *Electricity before nationalization: a study of the development of the electricity supply industry in Britain to 1948*. Average prices per kWh. Sold (Average revenue per kWh sold): Total, Lighting & Heating, Power and Traction. (1921-1948). (In Svennilson, I. (1959), the same data). In pence per kWh sold.

5) Canada
- *Historical Statistics of Canada*. Urquhart et al., 1983. From the revenues and sales we calculate the Average price (Revenue/Sales), Average revenue per kWh. sold: Residential and Farms, Commercial, Industrial, Street Lighting, and Total Domestic. (1930-1944). In millions of dollars (can.) per kWh.

6) Spain
- *Anuario Estadistico de España*, several years and *Precios al por mayor y números índices 1913 a 1941*, *Boletin de la Estadística*. Ministerio de Trabajo. Dirección general de Estadística. Lighting (Fluido Eléctrico)(1913-1941). In pts per kWh.

Coal:

1) France
- Barjot, D. (1991). *L'energie au XIXe et Xxe siecles*. Prix de la tonne de houille sur les marchés intérieurs, 1901-1944. (Francs per ton.).

2) Italy
- *Sommario di Statistiche Storiche dell'Italia*. *Carbone fossile da gas in Prezzi all'ingrosso*. (lire/ton.). (1881-1890, 1891-1900, 1901-1910, 1911-1920, 1921-1943, the last period by year, the others an average).

3) USA
- *Historical Statistics of the US. Colonial times to 1970*. Vol.1. Coal (anthracite) in Wholesale prices selected commodities: 1800 to 1970. (Dollars/ton).

4) UK
- Mitchell, B.R. (1962, 1971). Coal (All exports). (Shillings/ton). (Conversion 5pence=1shilling).

5) Canada
- *Historical Statistics of Canada*. Urquhart et al., 1976. Coal (in production of fuels). From the quantities and values, we calculate the prices (dollars/ton), (1890-1945).

6) Spain
- *Anuario Estadístico de España*, several years, and *Precios al por mayor y números índices 1913 a 1941, Boletin de la Estadística*. Ministerio de Trabajo. Dirección general de Estadística. Coal (national production):*carbón cribado*, (1913-1941). In pts per ton. The imported coal is more expensive than the asturian coal (Spanish coal). We choose the Spanish one because there was a reduction in prices for special consumers.
- Coll, S. (1987). *El carbón en España, 1770-1961. Una historia económica*, Madrid. pp.422-423.
-

Energy production: electricity, by sources, and coal for each country in Bouda Etemad and Jean Luciani (1991), *World Energy Production, 1800-1985*. Paul Bairoch and Jean Claude Toutain (eds.). Geneve, Libraire Droz.

Consumption by uses: USA, *Statistics of the US Colonial times to 1970*. U.S. Department of Commerce. Bureau of the Census, p. 132, UK, Sales, Hannah, L. (1979), pp. 427-429, and Canada, Sales, *Historical Statistics of Canada*. Urquhart et al. (1983), Q102-106.

Electricity installed power: USA, Installed generating capacity, *Statistics of the US Colonial times to 1970*. U.S. Department of Commerce. Bureau of the Census, p. 824. UK, Installed capacity at end of the year, Ministry of Power. *Statistical Digest*, 1966, p. 118, and Hannah, L. (1979), p. 432-433. France, Puissance Installée, Barjot, D. (1991). *L'Énergie aux XIXe et XXe siècles*, Paris, Presses de l'École normale supérieure, serie 2.8.1 A and B, Italy, Giannetti, R. (1985). *La conquista della Forza*, Milano, Franco Angeli Libri, p. 248-252. Spain, Potencia instalada en Sudrià, C. (1990), "La industria eléctrica y el desarrollo económico de España" Garcia Delgado, J.L. (dir.), p. 164 and 173, from 1901 to 1935 the self-production is not included. Canada, Electric generating capacity, *Historical Statistics of Canada*. Urquhart et al. (1983), Q81-84.

G.D.P. per capita: (in Gheary-Khamis dollars and P.P.P.) from Maddison, A. (1995). *Monitoring the World Economy*, Geneva, O.C.D.E.

Investment share on GDP: USA, Net Capital Formation, current prices from Kuznets, S. (1961). *Capital in the American Economy. Its formation and Financing*. Princeton University Press, pp. 572-574, France, investment ratio from Carré, J.J., Dubois, P., Malinvaud, J.P. (1975), *French Economic Growth, Stanford, Stanford University Press*, pp. 528, Spain, from Carreras, A. (1997):"La industrialización una perspectiva de largo plazo", *Papeles de Economía Española,* 73, pp. 35-60, p 42. The rest of countries from Mitchell, B.R. (1988).

Electrification: sources figure quoted by authors and appear in the References soft Spain, which belongs to A.E.E., *Anuario Estadístico de España*, and E.M.M., *Estadísticas Mineras y Metalúrgicas de España*.