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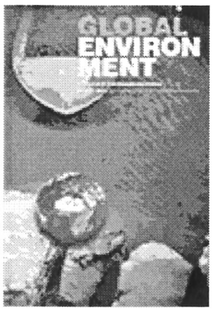

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Energy Transition and CO_2 Emissions in Southern Europe: Italy and Spain (1861-2000)*

Silvana Bartoletto and M.d.Mar Rubio

Because of the lack of long-term series, the ever-increasing literature on the environmental effects of economic growth typically relies on post-1960 cross-section data referring to sets of countries with different levels of per capita GDP and energy consumption. Most studies, however, usually focus on a single country or region over time (generally short periods, from 10 to 20 years), or conduct cross-country analyses of benchmark years.[1]

The present study investigates energy consumption, the transition from organic to fossil energy carriers, and the consequent emissions of CO_2 in Spain and Italy over a period of almost 150 years (1861-2000). It relies on new data that so far have been mostly used in analyses of long-term trends in energy consumption and energy intensities.[2] Although alternative historical series of CO_2 emissions do exist (notably those of the CDIAC), for several reasons, which we explain in the second part of this article, we decided to recalculate statistics on CO_2 emissions in Italy and Spain using these new energy series,[3] which we believe to be more reliable and consistent than any of the ones used so far. That

* The authors are grateful for the scientific feedback received from members of the EGP-network, especially Paolo Malanima and Astrid Kander, and of the GlobalEuroNet, a Research Networking Programme in Economic History funded by the European Science Foundation (ESF). The authors are also grateful for the comments of the anonymous referees, which improved this article. All remaining errors are solely ours.

[1] For Spain see O. Carpintero, *El metabolismo de la economía española: Recursos naturales y huella ecológica (1955-2000)*, Fundación César Manrique, Madrid 2005; id., *La sostenibilidad ambiental de la economía española: Flujos de energía, materiales y huella ecológica, 1955-1995*, Paper read at the IX Simposio de Historia Económica: Condiciones medioambientales, desarrollo humano y crecimiento económico, Universitat Autónoma de Barcelona, Bellaterra 2002. Also useful are L. Murilllo-Zamorano, "The role of energy in productivity growth: a controversial issue?", in *Energy Journal,* 26, 2, 2005, pp. 69-88; J. Roca, V. Alcántara, "Energy intensity, CO2 emissions and the environmental Kuznets curve. The Spanish case", in *Energy Policy*, 29, 7, 2001, pp. 553-556 .

[2] See for instance: A. Kander, "Economic Growth, Energy Consumption and CO2 Emissions in Sweden 1800-2000", in *Lund Studies in Economic History*, 19, 2002; P. Malanima, *Energy Consumption in Italy in the 19th and 20th Centuries. A Statistical outline*, Cnr-Issm, Napoli 2006; M.d.M. Rubio, "Economía, Energía y CO2: España 1850-2000", in *Cuadernos económicos de ICE*, 70, 2005, pp. 51-71; B. Gales, A. Kander, P. Malanima, M.d.M. Rubio, "North versus South: Energy transition and energy intensity in Europe over 200 years", in *European Review of Economic History*, 11, 2, 2007, pp. 219-253.

[3] The most widely used international statistics on CO_2 emissions are those of the Carbon Dioxide Information Analysis Center (CDIAC): G. Marland, T.A. Boden, R.J. Andres, "Global. Regional, and National CO2 emissions", in *Trends: A Compendium of Data on Global Change*, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge (TN, USA) 2000.

said, it should be noted that the CDIAC series are entirely consistent with the ones presented here for the 1950-to-present period; however, the further we go back in time, the more distant our estimates appear from the CDIAC's published CO_2 emissions.

An additional feature of our work is that it takes into consideration all forms of energy, not just modern ones. The precondition for a comparative exercise like this is that series of energy consumption data be calculated according to homogeneous criteria and including every primary energy source having an economic cost. Research carried out by the EGP-Network, pioneered by Malanima (1996) and Kander (2002) has proved that including traditional forms of energy changes our perception of the relationship between the economy and energy inputs.[4] Even when traditional energy carriers are regarded as "clean", this is just because their CO_2 emissions are not being taken into account (see discussion below), whereas they should be included in long-run series of pollution intensities of energy and other indicators.

In this work, we begin by presenting series of primary energy consumption and energy intensities in Italy and Spain from 1861 to 2000. Then we introduce several CO_2 indicators for both countries. We look at total emissions, emissions per capita, pollution intensity of energy (decarbonization), and pollution intensity of the economy. In the following pages, we examine cross correlations between some of the variables. Our aim is to ascertain whether a decoupling of emissions, economic growth, and per capita energy consumption can be observed historically; and, if this proves to be true, what factors underlie this phenomenon. Last but not least, our findings may allow us to draw some conclusions on potential future development paths; notably, as to whether or not it is possible to consume more energy per capita and produce more output per capita at lower levels of emissions.

Finally, we have used a Divisia index perfect decomposition analysis to scrutinize differences in total emissions. Decomposition analysis, particularly Divisia index based decomposition, has been applied to a wide range of subjects: aggregate energy intensity in

[4] P. Malanima, *Energia e crescita nell'Europa preindustriale*, La Nuova Italia Scientifica, Roma 1996; Kander, "Economic Growth" cit.

the industry, national energy consumption, aggregate energy index measuring, total energy-related carbon dioxide, carbon dioxide per unit of GDP, etc.[5] In future research, however, decomposition analysis will need to be applied at the per capita level if we are to understand the forces behind different trends in CO_2 emissions.

Long-run energy consumption in Italy and Spain

Italy and Spain are similar in many ways, notably in climate, the almost complete absence of domestic sources of modern energy and, to some extent, economic development paths.

Both are Mediterranean countries most of whose regions are blessed with a benevolent climate. Heating (and, more recently, cooling) and lighting needs are therefore quite similar in Italy and Spain.

Both countries lack substantial domestic sources of modern energy. Neither coal nor oil or gas are found in significant amounts within their territories and the existing deposits are of poor quality (as are, for instance, those of the heavily subsidized coal mines of Northern Spain). Thus, Italy and Spain entirely depend on external supplies of fossil fuels. Both can count on a limited supply of hydroelectricity, which is subject, however, to the vagaries of an irregular hydrological year with severely dry summers.

As regards their economy, both countries were late comers to the industrialization process. Until the First World War, their paths ran almost parallel, as we will be showing later in this section. The Great War, the Spanish Civil War, and the Second World War caused them to drift apart, with Italy forging ahead strongly during the 1950s and 1960s. Spain only managed to catch up from the late 1980s onwards, after joining the European Community.

Turning to demographics, Italy almost doubled the population of Spain at the beginning of the period we are concerned with here, but

[5] For an excellent summary of work in this field, see B.W. Ang, "Decomposition analysis for policymaking in energy: which is the preferred method?", in *Energy Policy*, 32, 2004, pp. 1131-1139.

Table 1. Population and population density in Italy and Spain 1850-2000 (thousands of inhabitants per km²)

	Italy		Spain	
	population	Population density	population	Population density
1850	24,603	84	14,894	30
1875	28,258	96	16,267	32
1900	33,343	113	18,594	37
1925	38,715	132	22,433	44
1950	46,768	159	27,976	55
1975	54,764	186	35,548	70
2000	57,844	197	40,933	81

by 2000 its population was only a third larger. The Spanish population grew faster from the 1920s to the 1980s. Nevertheless, Italy almost systematically tripled the population density of Spain over the past 150 years. This provided Italy with greater economic opportunities, but also put greater pressure on its environment. The respective evolution of the populations of the two countries is outlined in Table 1.

To some extent, the two countries' similarities have resulted in parallel energy histories, although with some subtle differences. In the remaining part of this section we look at the energy basket, the transition from traditional to modern sources of energy, and the evolution of levels of primary energy consumption in both economies.

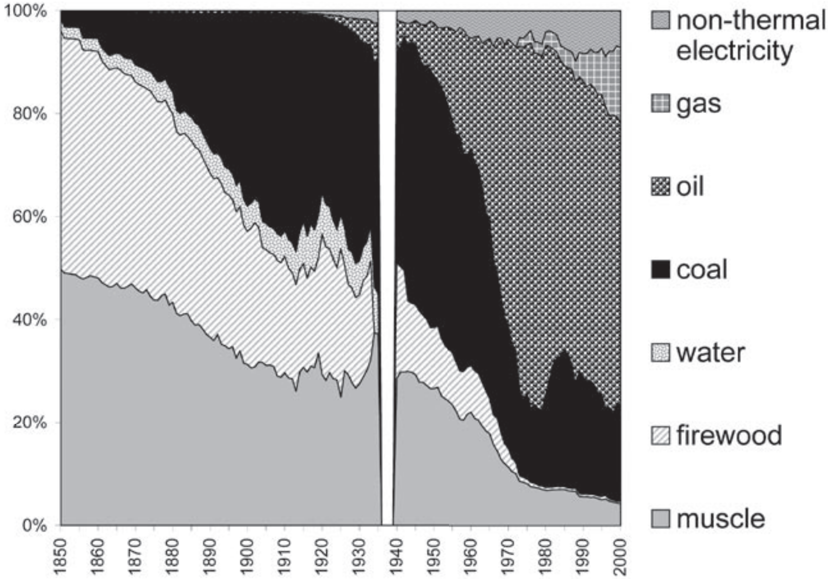
Changes in the energy basket: The energy transition

Although the transition from organic forms of energy to the mineral forms prevalently used today was a crucial watershed, we know very little about it. Historically, energy statistics and analyses have always focused on the new forms of energy. We know all about the introduction of mineral coal, the beginning of railways, and the spread of automobiles and electricity. Hence the false impression that industrial economies made a swift transition from organic to mineral energies late in the 19th century or in the early 20th century at the latest. Nothing is farther from the truth, as the statistics presented here show. Until well into the 20th century, most Western economies remained vastly dependent upon organic forms of energy (human and animal labor, firewood, and wind and water power). Animals carried out most agricultural tasks and provided transportation. In urban and rural dwellings, one mainly relied on firewood, peat, and organic oils for cooking, heating, and lighting. Early industrialization was based on firewood and wind and waterpower, and in some areas these remained the main sources of energy for the industry until the late 19th century. Even during the coal period of the industrial revolution, human and animal power continued to play a significant role; in fact, railways and steam engines actually increased the absolute demand for human and animal labor. The organic economy was expensive in energetic terms: much energy was spent to produce relatively little added value. There are no direct estimates of the amounts of organic energy consumed in the past. However, there are sufficient indirect indicators to allow time series of organic energy consumption to be drawn up. The pioneering work of Malanima (1996) – for Italy – and Kander (2002) – for Sweden – have provided us with a number of instruments, assumptions, and shortcuts for the calculation of historical organic energy consumption.[6] They used historical series of data on population, draft animals, and wind and water mills, as well as a few informed assumptions regarding firewood use.[7] Following the same methods and assumptions, and making use of extensive data

[6] Malanima, *Energia e crescita nell'Europa* cit.; Kander, "Economic Growth" cit.

[7] Going into detail as regards the underlying assumptions and methods is unfeasible within the scope of this article and has already been done elsewhere (see text). Nevertheless, it is worth pointing out that by total food intake for humans we mean here the total food intake of the total population – calculated at as a constant per person for Italy, and using figures of caloric intake estimated by X. Cussó, *Alimentació, mortalitat i desenvolupament. Evolució i disparitats regionals a Espanya des de 1860*, Doctoral Thesis, Facultat de Ciències Econòmiques i Em-

Graph 1. The Spanish energy transition 1850-2000



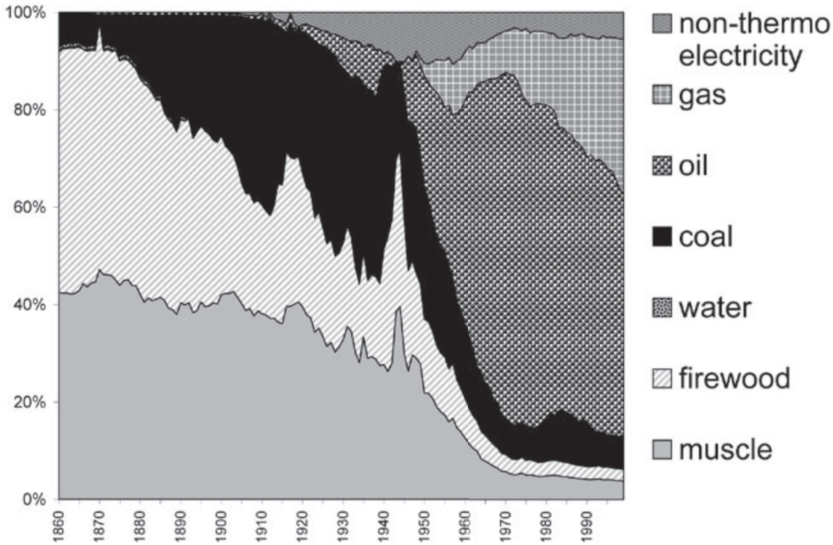
Source: data originally from Rubio, "Economía, Energía y CO_2" cit., here taken from Gales et al., "North versus South" cit. No data available for the period of the Spanish Civil War.

collections put together by Spanish economic historians – particularly Sudrià (1987; 1995), Nadal (2003), Carreras (2005), and GEHR (1991) – Rubio (2005) was able to make a first estimation of the use of organic energies in Spain.[8]

presarials, Universitat Autònoma de Barcelona, Bellaterra 2001, for Spain, supplemented with other data provided in Rubio, "Economía, Energía y CO_2" cit.

[8] C. Sudrià, "Un factor determinante: la energía", in *La economía española en el siglo XX. Una perspectiva histórica*, J. Nadal, A. Carreras, C. Sudrià, Ariel, Barcelona 1987, pp. 313-363; id. "Energy as a limiting factor to growth", in *The Economic Development of Spain since 1870*, P. Martin-Aceña, J. Simpson (eds), Edward Elgar, London 1995, pp. 268-309; J. Nadal, *Atlas de la industrialización de España, 1750-2000*, Crítica/Fundación BBVA, Barcelona 2003; A. Carreras, X. Tafunell, *Estadísticas históricas de España (siglos XIX-XX)*, Fundación BBVA, Madrid 2005; Grupo de Estudios de Historia Rural (GEHR), *Estadísticas históricas de la producción agraria española, 1850-1935*, Ministerio de Agricultura, Pesca y Alimentación. Secretaría General Técnica, Madrid 1991; Rubio, "Economía, Energía y CO_2" cit.

Graph 2. The Italian energy transition 1861-2000



Source: original data from S. Bartoletto, "L'energia", in Rapporto sulle economie del Mediterraneo, P. Malanima (ed.), Il Mulino, Bologna 2005, pp. 231-256; and Malanima, Energy consumption in Italy cit., here taken from Gales et al., "North versus South" cit.

Graphs 1 and 2 and the tables below illustrate changes in the structure of energy consumption in Italy and Spain over the last century and a half, including both traditional/organic and modern energy carriers.[9] The common feature is that in both countries traditional energy carriers accounted for a large share of global energy consumption until rather late.

We classify as traditional energy carriers firewood, wind, water, and the food requirements of men and working animals. On the eve of the 20th century, traditional energy carriers as thus defined accounted for something between 70 to 80 per cent of the total energy consumed in Southern Europe.[10] The contribution of

[9] Data for the Spanish Civil War period (1936-1939) are lacking.

[10] In Italy, firewood consumption varies considerably between the southern regions and the Alpine area. Some estimations concerning Naples and Rome con-

Table 2. Structure of energy consumption in Italy 1870-2000 (%)

	1870	1913	1950	1973	2000
Firewood	50.04	21.17	16.50	3.08	2.39
Food for human beings	22.89	19.77	15.37	4.56	3.89
Feed for animals	18.74	15.99	11.62	0.50	0.00
Wind, water	1.04	0.28	0.11	0.00	0.00
Fossil fuels	7.29	41.67	46.94	88.70	88.19
Primary electricity		1.11	9.46	3.16	5.53

Source: S. Bartoletto, "I combustibili fossili in Italia dal 1870 ad oggi", in *Storia economica*, 2, 2005, pp. 281-327; P. Malanima, *Energy Consumption in Italy* cit.
Note: In this table, primary electricity includes hydroelectricity, geothermal, solar, wind, wood, waste and nuclear electric power. To estimate it, we have assumed a coefficient of 1 kwh=860 kcal. Some researchers use a higher coefficient (2,200-2,500 kcal per Kwh), computed on the basis of the kcal required to produce electricity by means of fossil fuels. Of course, if we used this higher coefficient, the contribution of primary electricity would be greater.

traditional energy to the total energy input of Italy and Spain fell below 50 percent only immediately before World War II,[11] and in

firm an average of about 1.5-2 kg per capita per day during the 19th century. See S. Bartoletto, "Dalla legna al carbon fossile. I consumi di combustibile a Napoli nel corso dell'Ottocento", in *Mélanges de l'Ecole française de Rome*, 116, 2004, pp. 705-721; id., "L'approvvigionamento energetico della città di Napoli tra XIX e XX secolo", in *Per una storia ambientale di Napoli fra '800 e '900*, I. Zilli (ed.), ESI, Napoli 2005, pp. 139-175.

[11] Bear in mind that in the present paper hydroelectric contribution is measured by its heat content. This is an important difference with respect to previous estimates of energy consumption for Spain, especially those of Sudrià, "Un

Table 3. Structure of energy consumption in Spain 1870-2000 (%)

	1870	1913	1950	1973	2000
Firewood	40.0	20.7	11.9	1.1	0.4
Food for human beings	19.7	13.0	12.7	6.2	4.3
Feed for animals	26.4	13.2	14.0	2.4	0.1
Direct waterpower	3.3	6.3	0.0	0.0	0.0
Fossil fuels	10.6	46.6	59.0	85.1	88.0
Primary electricity	0.0	0.2	2.4	5.2	7.2

Source: Rubio, *Economía, Energía y CO_2: España* cit., plus some revised statistics compiled for Gales et al., *North versus South* cit.
Note: Primary electricity is an umbrella term for hydroelectric and nuclear production electricity. Primary electricity does not actually exist, electricity being in any case a secondary form of energy. Electricity is calculated here by its heat content -1 kWh of electricity output = 3.6 MJ = approx. 860 kcal – and not by the energy content of the water or uranium used for its production.

the 1960s a fourth of the two countries' total energy input was still of organic origin. In 1973, firewood accounted for only 3 percent of Italy's total energy input, fossil fuels for more than 88 percent. In Spain, in the same year, firewood accounted for 1 per cent of the total energy input, fossil fuels for 84 per cent. Thus, in Southern

factor determinante" cit.; id., "Energy as a limiting factor" cit., and his tables in *Nadal, Atlas* cit., where hydroelectricity was measured by its coal equivalent, which required making assumptions as to conversion efficiency, a method which exaggerates the total energy consumption in Spain and the contribution of hydroelectricity, in particular for the 1940s and 1950s. See the discussion in Rubio, "Economía, Energía y CO_2" cit.

Europe the transition from organic to mineral sources of energy only came about around the mid 20th century and was far from a sudden change.

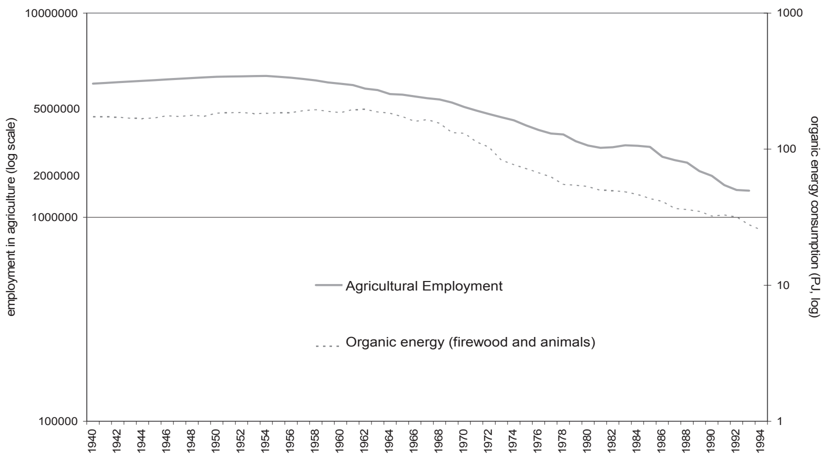
Traditional energies did not lose ground in Spain until the 1940s, when their share in total consumption declined to less than 50 per cent. Although over the ensuing decades the availability of modern energies per capita doubled, the level (not the share) of traditional energy sources in the Spanish system did not decline until the 1970s.

A look into the Spanish economic structure helps to explain this phenomenon. There is little historical evidence on energy consumption in the various sectors of the Spanish economy. Nevertheless, it seems clear that modern energy consumption was concentrated in the industrial and transportation sector, while traditional energies remained the basic input in rural areas and agriculture. Indeed, the rate of reduction of employment in the agricultural sector as a consequence of the modernization of the sector and of the economy as a whole is the best explanatory variable for the trend in the consumption of organic energies in the second half of the 20th century, as can be seen in Graph 3.

As the graph shows, in Spain the decline in agricultural employment went hand in hand with that of organic energy (firewood and draft animals). Towards the end of the period, the organic energy input declined at a faster rate than employment. This was a consequence of the increasing use of modern energy in agriculture. Since the 1960s, mechanical traction rapidly replaced draft animals and human labor in agricultural production. This example reveals the close relationship between energy consumption and the economy. We will come back to economic aspects later on in the article.

Our data show that it took more than a century since the introduction of coal at the beginning of industrialization for it to become the main energy carrier. In Southern Europe, coal is very much a 20th century phenomenon. Furthermore, its share in the energy basket varied considerably. In Italy, the maximum share of coal in the total energy input was around 40 percent, between 1935 and 1940. In Spain, the coal share peaked almost a decade earlier, from 1927 to 1930, at a higher level, 46-49 percent, and coal held its

Graph 3. Employment in agriculture (left) and organic energy (right) in Spain 1940-2000



Source: Rubio, *Economía, Energía y CO2: España* cit.

own against oil for longer than in Italy, remaining the main energy carrier down to the end of the 1960s. In Italy, instead, the coal share was drastically reduced in favor of oil after World War II.

By the eve of the energy crisis of the seventies, oil was the first source of energy in both countries. In Italy it accounted for 80 per cent of overall consumption. The contribution of oil to primary energy consumption in Italy later fell to 48 per cent in 2001, while the contribution of natural gas rose from 9 to 32 per cent.[12] In Spain, by 1973 oil was the most important energy carrier, accounting for almost 70 per cent of total consumption, with coal at 13 per cent.

Let us now look at renewable energy sources. Italy is currently the first producer of hydroelectricity in Southern Europe. Much of Italy's industrial growth from 1880's to 1913 depended on the introduction of hydroelectricity, whose expansion was extraordinary. On the eve of

[12] S. Bartoletto, "L'energia", in *Rapporto sulle economie del Mediterraneo*, P. Malanima (ed.), Il Mulino, Bologna 2005, pp. 231-256.

the First World War, Italy was producing even more hydroelectricity than France. Until the 1960's, in Italy hydroelectricity remained more important than thermoelectricity. Today, Italy is still the third producer of hydroelectricity in Europe, after France and Norway, and in 2005 its production and consumption of hydroelectricity, in absolute terms, was about double that of Spain. Nevertheless, in Italy the role of renewable energies, including wood and geothermal energy, is still marginal. Both in Italy and in Spain, in 2005 renewable energies accounted for about six percent of total primary consumption. Neither country will be able to meet its 2010 Kyoto Protocol targets.[13]

In Spain, nuclear generation of electricity began in the late 1960s. At its maximum, at the end of the 1980s, it accounted for 17 per cent of primary energy consumption.[14] However, the decision to halt the extension of nuclear power has progressively reduced its contribution. In 2005, nuclear power accounted for about 8 per cent of total consumption and 40 per cent of total domestically produced energy.[15] In Italy, nuclear generation of electricity began in 1962, but ceased completely in 1987 following a national referendum that put a stop to the nuclear program in the wake of the Chernobyl disaster of 26 April 1986. At any rate, up to then the country's nuclear energy production had been negligible.

All in all, fossil fuels dominated the second half of the 20th century.

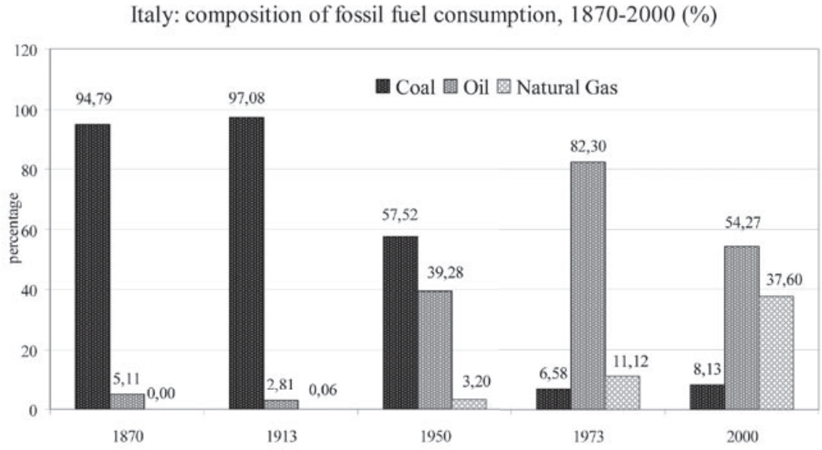
The decades following the oil crisis of the 1970s show a proliferation of significant energy carriers in Italy and Spain. The portfolio was thus less determined by one prime energy carrier than in the past. There are, however, some differences between the two countries in the relative importance of individual carriers. As remarked above, coal

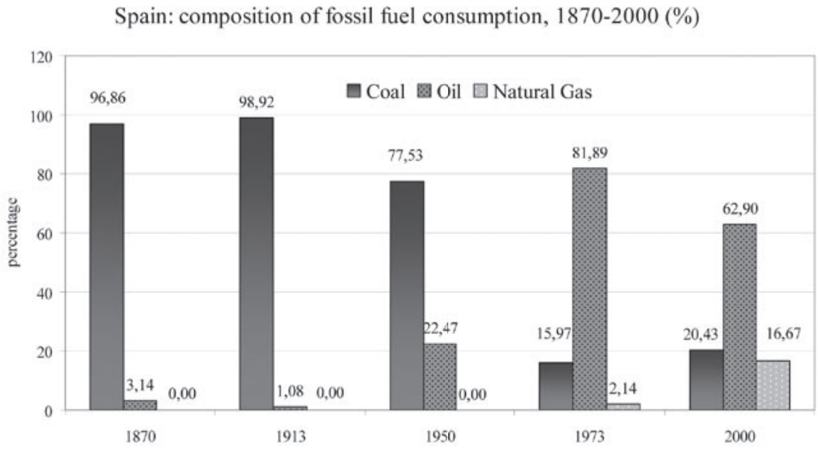
[13] S. Bartoletto, "Produzione e consumo di energie rinnovabili", in *Rapporto sulle economie del Mediterraneo*, P. Malanima (ed.), il Mulino, Bologna 2008, pp. 201-227.

[14] MICYT, *La energía en España 2006*, Ministerio de Industria, Turismo y Comercio, Madrid 2007.

[15] S. Bartoletto, "Produzione e consumo di energie rinnovabili" cit., p. 221.

Graph 4. Composition of fossil fuel consumption in Italy and Spain





Source: for Italy, Bartoletto, "I combustibili fossili in Italia dal 1870 ad oggi" cit., pp. 303-309; for Spain, Rubio, "Economía, Energía y CO2" cit.

consumption has always been more important in Spain, especially after the Second World War. In Italy, gas consumption increased rapidly after the oil crisis. Spain, in contrast, reverted to burning coal to produce electricity, partly because of its policy of heavily subsidizing the domestic production of coal. Indeed, coal consumption doubled in Spain between 1979 and 1985. Coal came to substitute oil whenever possible, particularly in thermal electric production. In the year 2000, about 90 per cent of the coal consumed in Spain was used in the production of thermal electricity. The evolution of Spanish fossil fuel consumption can be observed in Graph 4.

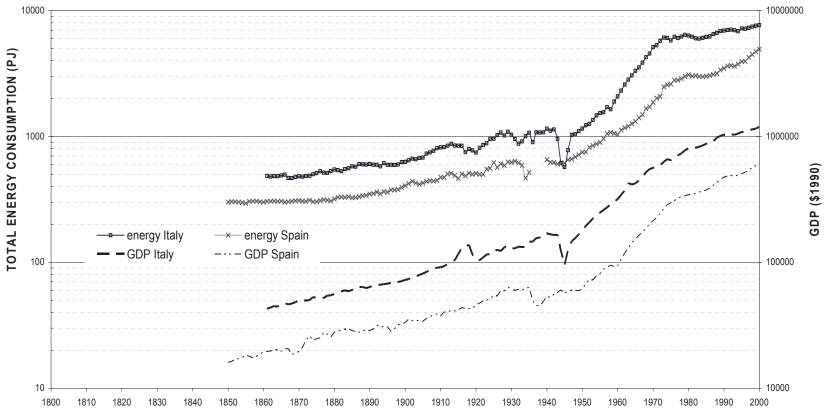
From our analysis of the energy basket of Italy and Spain over the last 150 years, we have learned that in these countries the transition from organic to mineral sources of energy only occurred around the middle of the 20th century and was far from sudden. It is also clear that, once traditional energy carriers are taken into account, the predominance of coal as the main energy carrier in Southern Europe appears as an intense but short-lived phenomenon of the mid decades of the 20th century. Finally, oil never achieved the primacy of coal as the single major energy carrier. Indeed, towards the end of the 20th century, the portfolio was no longer dominated by any single energy carrier. In general, we find more similarities than contrasts in the structures of the energy systems of Italy and Spain.

Levels of energy consumption

Having observed the similarities and contrasts of the energy baskets of Italy and Spain over the last 150 years, we can now turn to these countries' levels of energy consumption, both in aggregate and per capita terms. Clear similarities can be observed in the long-term patterns of total energy consumption. In both cases the aggregate energy consumption grew exponentially over the last two centuries, but especially in the second half of the 20th century.

The graph shows a clearly similar pattern: modest rates of increase in energy consumption until World War II, followed by a period of faster growth in 1950-1973. The highest increase of energy consumption occurred in those years, which in both countries was also the period of fastest economic growth. Italy, however, grew much faster than Spain. In absolute terms, its consumption of energy sources in 1973 was about 5 times higher than in 1950 (12.6 times

Graph 5. Total primary energy consumption (left) and GDP (right): Italy vs. Spain 1850-2000



Source: energy as in previous section; GDP figures for Italy: Malanima, *Energy consumption in Italy* cit.; for Spain: L. Prados de la Escosura, *El progreso económico de España 1850-2000*, Fundación BBVA, Madrid 2003; the data in these series are expressed in 1990 international PPP dollars following A. Maddison, *Monitoring the World Economy, 1820-1992*, OECD, Paris 1995.

higher than in 1870), while Spain's consumption in 1973 was only 3.7 times higher than in 1950 (7.7 times higher than in 1870).

While Italy's total energy consumption began to decline right from the beginning of the oil crisis, the slowdown of the Spanish aggregate energy consumption came slightly later. This delay of the impact of the oil price increase on the Spanish economy was due to internal policy measures taken to counteract the effects of the increase. Partly as a consequence, the second round of price increases was more heavily felt.

Spain shows a stronger growth in energy consumption in the 1990s, during the period of economic expansion that ensued after it joined the European Community in 1986. The Spanish energy consumption of 1997, about 4000 PJ, doubled that of 1971. Over the whole 20th century, Spain multiplied its energy consumption by ten.

These data match the overall economic growth patterns shown in Graph 5 and lend some credibility to the idea that more growth requires more energy and more energy allows further growth. It should be noticed that Italy and Spain's levels of aggregated economic activity, as measured by their GDPs, run parallel throughout, and basically so do their levels of aggregate primary energy consumption. Furthermore, in both countries the rate of increase of the economy was faster than the corresponding increase in energy input; the result, as Gales et al. have shown,[16] was a long-run decrease in the energy intensity of their economies.

The use of new energy sources stimulated and, at the same time, came about as a result of, the employing of new technologies, which in their turn had an impact on productivity, the prices of commodities, and their consumption. Technical improvements also contributed to a general income increase, and hence to changes in the economic demand and the productive structure.

One could speculate about the forces behind the growth of energy consumption. Common candidates include changes in the economic structure, demographic growth, the rise of motorization and electrification – technological change in general –, and general improvement of the economic situation.

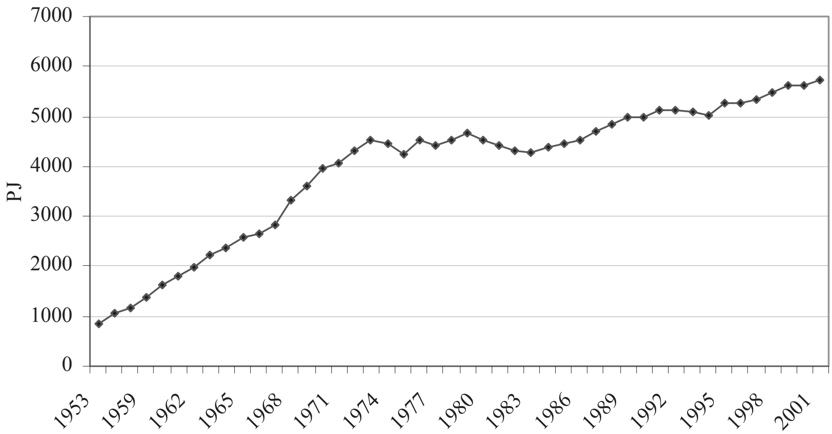
As mentioned above, in Italy and Spain the agricultural sector has lost ground to the industry, transportation, and service sectors; industry and transportation, in particular, being more intensive in energy use and making almost exclusive use of modern energies.

Structural changes can occur both at the sector and subsector level, or even in smaller subdivisions thereof. To gauge the impact of changes at the sector level we would need data on energy consumption for each sector. In Italy, however, such statistics are available only from the 1950s onward, when final energy consumption increased to an extraordinary degree as the result of a phase of intense industrialization and strong expansion in the transportation sector and in the demand for energy for household use.

From 1953 to 2001, final energy consumption (bunkers included)

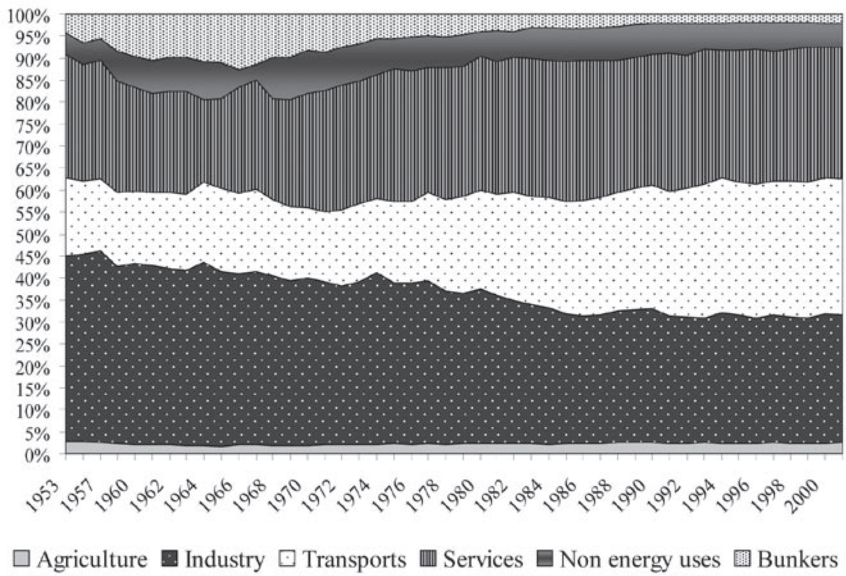
[16] Gales, Kander, Malanima, Rubio, "North versus South" cit.

Graph 6. Final energy consumption in Italy, 1953-2001 (PJ)



Source: S. Bartoletto, "I combustibili fossili in Italia" cit., pp. 293-294, 323-327.

Graph 7. Final energy consumption by sector in Italy, 1953-2001 (%)



Source: S. Bartoletto, "I combustibili fossili in Italia" cit., pp. 293-294, 323-327.

increased about sevenfold, rising from 862 PJ to 5,738 PJ (Graph 6). But the highest growth was in 1953-1973. In this relatively short period, energy consumption increased more than fivefold. After 1973, it continued to grow, but at a much slower pace.

As figure 7 shows, in 1953 the highest levels of energy consumption were attained in the industrial sector, which accounted for 44 percent of the overall consumption, followed by the service sector, with about 29 percent; the transportation sector, with 18.5 percent; the chemical and petrochemical sectors, which employed fossil fuels for non-energy uses; and finally the agricultural sector, with less than 3 percent.

Twenty years later, energy consumption had greatly increased. However, there had been no major changes in its distribution among sectors, with the exception of the industry, where energy consumption had continued to grow in absolute terms, but had lost four percentage points of the total to non-energy uses.

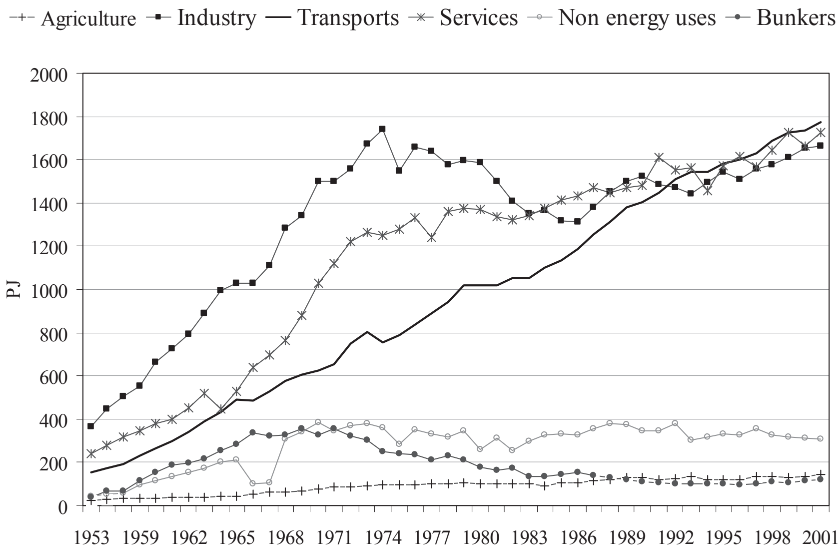
At the end of the period under study, instead, there were some significant structural changes. By 2001, the industry had slid down from the first to the third position, behind the transportation sector and the tertiary and residential sector. By then, energy consumption in the industrial sector had decreased compared to 1973, not only percentage-wise (about ten points), but also in absolute terms.

Energy consumption in the industrial sector fell sharply in 1973-74, when the oil crisis determined a 130-140 percent increase in the price of oil, and then again following the second oil crisis in 1979, which caused a further price increase. Only around the middle of the 1980s did energy consumption swing up again, although so far it has not reached again the peak attained on the eve of the first energy crisis.

During the 1990's, there was an acceleration in energy consumption, but in 2001 the industrial sector was surpassed by the transportation sector and the service (tertiary and residential) sector, whose energy consumption was higher both in absolute terms and percentage-wise.

Energy consumption in the service sector increased rapidly throughout the period analyzed here. In absolute terms, it rose from 242 PJ in 1953 to 1,724 PJ in 2001 (Graph 8). Percentage-wise, its

Graph 8. Final energy consumption by sectors in Italy, 1953-2001 (PJ)



Source: S. Bartoletto, "I combustibili fossili in Italia" cit., pp. 293-294, 323-327.

contribution to final consumption was approximately the same, i.e., 29.4 percent in 1953 and 30.7 percent in 2001. The service sector remained the second most important sector. From the Eighties onward, however, it consumed about as much energy as the transportation sector.

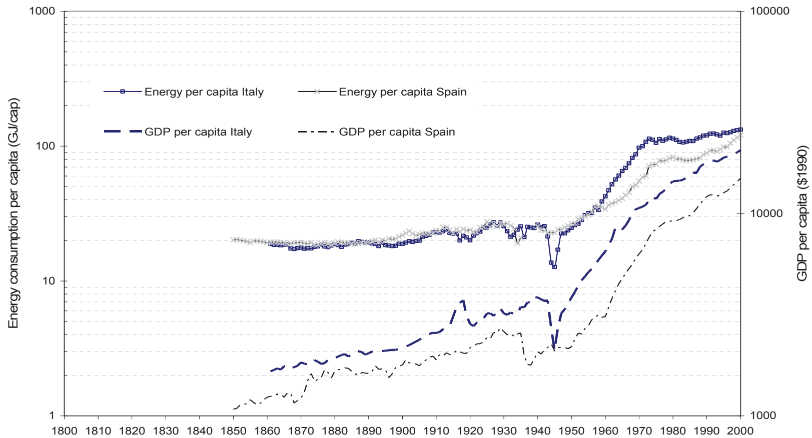
Growth in the transportation sector was impressive. In 1953 it accounted for 18.5 percent of overall energy consumption, coming third after industry and services. By 1994 it had become the first consumer of energy. In 2001 it accounted for about 31 per cent of overall consumption, with an absolute consumption of 1,774 PJ.

During the period under examination, energy consumption in agriculture increased only slightly. The use of fuels for non-energy-producing purposes, instead, grew especially from 1953 to 1973. After this period, it decreased in relative terms: in 1973 it accounted for 9 percent of total energy consumption, in 2001 for about 5 percent.

The data is still not sufficiently disaggregated to test for the weight of structural change in the increase of energy consumption, either primary or final. Gales et al. use the Commoner-Ehrlich formula to unpack the forces behind the growth of primary energy consumption in four countries, including Spain and Italy. According to their results, demographic change shows too little variation and is hence incapable of explaining such large fluctuations in energy consumption. Also, they find that the rise in per capita GDP was the strongest variable in determining growth in energy consumption, even though declining energy intensity inhibited this upward trend. The role of technological change – motorization, electrification, etc. – is double-edged and deserves separate investigation that is beyond the scope of this paper. On the one hand, it is true that the spread of these technologies allowed an increase of the overall energy input into the system. On the other, it is also true that inanimate machines are on the whole more efficient than animal converters of vegetable energy sources. The end result of technological change was that more energy entered the system, but at higher efficiency rates – that is, higher output of useful energy relative to the input –, resulting in a decrease of primary energy intensity (PJ per unit of GDP) in the long run.

In per capita terms, Italy and Spain are even more similar than in aggregate terms. For the reasons explained at the beginning, it is not surprising to find evident similarities in the long-term patterns of primary energy consumption in Italy and Spain; yet the similarities in primary energy consumption per capita up to 1930 are especially striking. There are at least three possible explanations for this similarity in behavior, which are not mutually exclusive. In the first place, since income per capita seems to be the major determinant of levels of energy consumption, this may be the main reason for the similarity. Up to 1930, the levels and growth rates of income per capita of Italy and Spain remained very similar, as can be observed in Graph 9. The gap in GDP per capita between the two countries first widened as a consequence of the Spanish Civil war (1936-1939) and the long lasting dictatorship that followed it. The two economies drifted apart, with Italy forging ahead – after the short-lived shock

Graph 9. Primary energy consumption per capita (left) and GDP per capita (right): Italy vs. Spain 1850-2000



Source: same as Graph 5.

of World War II –, and so did per capita energy levels. Secondly, similar economic structures contributed to this similarity in primary energy consumption per capita in the earlier period of our analysis. The third explanation could be that, for this earlier period, both Italian and Spanish estimations of firewood consumption rely on identical assumptions regarding per capita consumption per year. Given that between 45 to 20 per cent of the overall energy input at this early stage came from firewood, this may be the driving force behind this similarity in levels of energy consumption per capita.

Differences in per capita consumption of primary energy become more pronounced in the second half of the 20th century. Italian consumption per capita took off in the second half of the 1950 and in the following decade almost doubled that of Spain. The oil price shocks of the 1970s had a similar impact on both economies, determining a slowdown of growth in energy consumption per capita. This was, however, only temporary; growth soon picked up speed again in both countries. However, while Italy thereafter grew at a slow rate, Spanish growth accelerated in the last decade of the 20th century. Between 1970 and 2000, Spain more than doubled its energy consumption per capita, half of this growth taking place in the last decade. In the same period, Italians only increased their energy consumption by one third.

This section corroborates that the correlation between economic output and energy consumption is strong and positive. Yet, as Rubio et al. pointed out,[17] not all forms of energy have the same impact on economic output. Remaining trapped in traditional/organic forms of energy seems to have a negative correlation with a country's economic development. Countries with higher ratios of traditional forms of energy to total energy consumption achieve lower levels of GDP per capita. The explanation can most likely be found in Wrigley's original thoughts (1962) on the limits of organic economies.[18] If, as we stated earlier, more growth requires more energy and more energy allows further growth, reliance on any form of energy with severe limits to its growth potential (such as organic energy) will limit economic growth. Yet, as the following section points out, expanding energy possibilities by means of fossil fuels has severe consequences in the form of CO_2 emissions, which may themselves eventually affect economic growth and have a negative impact on standards of living.

Long run CO_2 emissions

The passage from an economy based on traditional energy sources to one based on fossil fuels had significant consequences.[19] On the one hand, it resulted in an increasing availability of energy. Coal, oil,

[17] M.d.M. Rubio, C. Yañez, M. Folchi, A. Carreras, "Energy as an indicator of modernization in Latin America, 1890-1925", in *Economic History Review*, in press.

[18] E.A.Wrigley, "The supply of raw materials in the Industrial Revolution", in Economic History Review, 15, 1, 1962, pp. 1-16.

[19] This entire second section relies heavily on M.d.M Rubio, S. Bartoletto, "Long run decomposition of CO2 emissions in several European countries: 1850-2000", paper presented at Session 49 of the International Economic History Congress, Helsinki 2006.

and natural gas, unlike wood, are non-renewable energy resources. The rise in fossil fuel consumption has immensely increased carbon dioxide emissions, giving rise to one of the most serious environmental problems of our time: global warming. Compared to other gases, carbon dioxide is not a very potent greenhouse gas, but due to the magnitude of its emissions it presently accounts for about half of the anthropogenic contribution to the greenhouse effect.

In this section we use the energy data described in the previous section as the basis for a long-run analysis of CO_2 emissions in Italy and Spain. Although alternative historical series of CO_2 emissions exist (see CDIAC) and have been used in scholarly articles with similar aims as this one, we chose to recalculate CO_2 emissions on the basis of these new energy series, for two reasons: in the first place, because existing historical series of energy consumption are not fully reliable, and secondly, because once the data for individual countries have been compiled, the series – both of energy and of emissions – need to be calculated in a consistent manner. We believe this aim has been achieved and our new series are far more reliable and consistent with one another than any of the previous ones. That said, we must point out that the CDIAC series are entirely consistent with the ones presented here as far as the 1950-2000 period is concerned; however, this consistency diminishes the further back we go in time from 1950.

In this section, we begin by presenting time series for several CO_2 indicators for Italy and Spain. We look at total emissions (from non-renewable carriers in all cases), emissions per capita, the pollution intensity of energy (or decarbonization, i.e., CO_2 emissions per unit of primary energy used), and the pollution intensity of the economy (defined as CO_2 emissions per unit of GDP). In a second set of tables, we present cross correlations between some of the variables. All this is done taking into account both the input of modern energies and that of traditional (organic) energies.

Finally, we have employed a Divisia index perfect decomposition analysis to highlight differences in total emissions. In this computation, population differences across countries take the lion's share, indicating that further decomposition analysis is needed at the per capita level if we are to understand the forces behind the different trends in the evolution of CO_2 emissions in Spain and Italy.

The evolution of CO_2 emissions

Composite Graph 10 provides time series for several indicators of CO_2 in Italy and Spain. As Graph 10.1 shows, there was a steep rise in both countries after World War II, with a steeper increase in Italy, the country with the larger population. After the oil crisis, both countries reduced their emissions, but only temporarily. Graph 10.2 offers a more balanced contrast, taking into account differences in population. In per capita terms, the story is quite similar. Italy and Spain were at very similar levels of emissions per capita until the Italian takeoff of the 1950s. The increase in emissions per capita in Spain over the last two decades of the 20th century is remarkable. It has to do with the growth in energy consumption during the last decade, but also with the aforementioned increase in the share of coal in the country's energy basket since the oil crisis.

Changes in the composition of the energy basket have an important effect on CO_2 emissions, because different energy carriers emit CO_2 to varying degrees. Perhaps the single most important transition in global energy systems is the increase in energy quality. As an indicator of energy quality, one can use the carbon intensity of energy, which is also used here as an indicator of relative environmental quality.

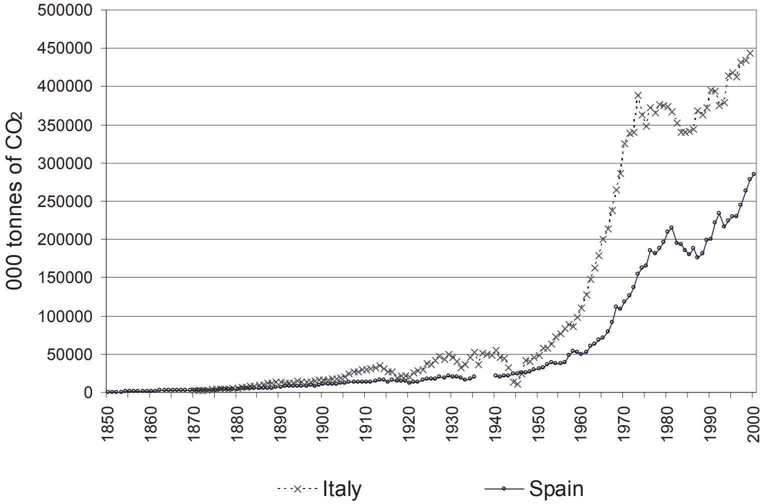
As Grüble explains,[20] the historical transitions from firewood to coal, oil, and gas in the primary energy supply can be conveniently summarized as a gradual transition from fuels with low H/C ratios to fuels with high H/C ratios. For traditional energy carriers such as firewood, this ratio is 0.1:1;[21] for coal, 0.5-1:1 (depending on the type of coal); for oil, 2:1; for natural gas (CH4), 4:1. The more hydrogen relative to carbon, the more energy is obtainable with fewer emissions. H/C ratios also reflect the *exergetic* properties of

[20] A. Grüble, "Transitions in Energy Use", in *Encyclopedia of Energy*, C.J. Cleveland (ed.), Elsevier, Burlington (MA) 2004, pp. 163-177

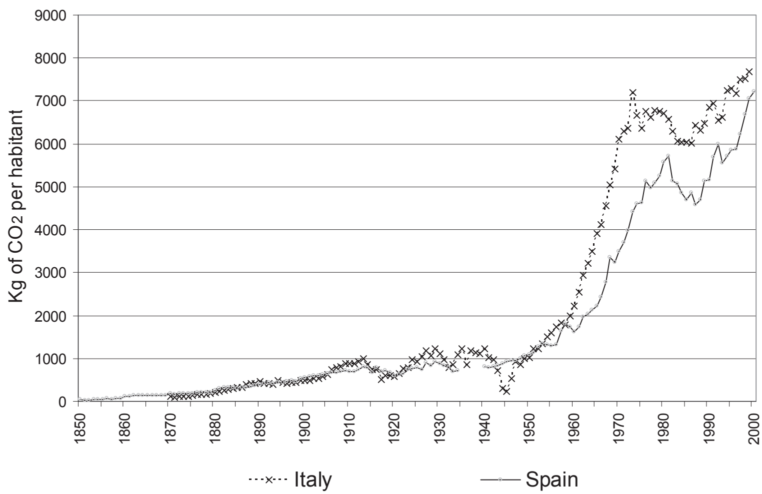
[21] Ibid.

Graph 10. Time series comparisons of CO_2 indicators for Italy and Spain 1850-2000

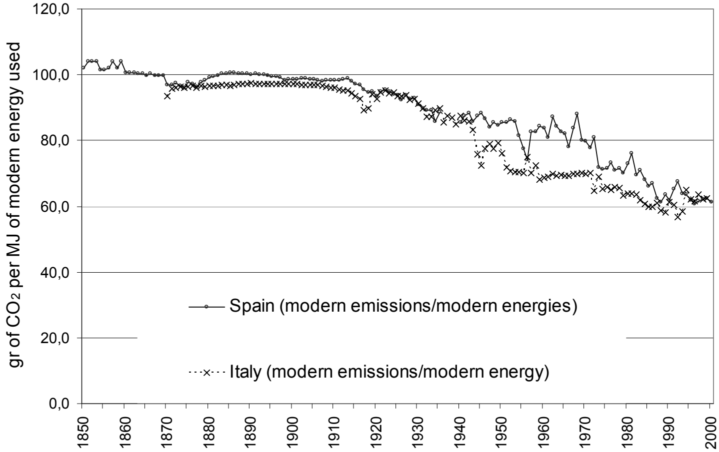
10.1 Total CO_2 emissions 1850-2000



10.2 CO_2 per capita 1850-2000

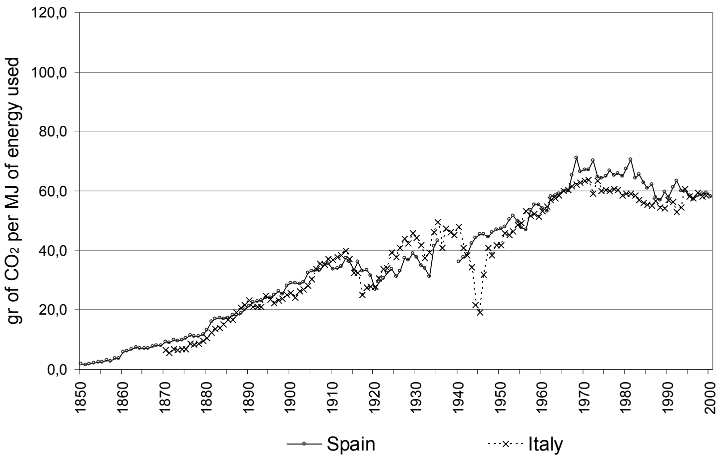


10.3 Pollution intensity of *modern* energies1850-2000 (CO2/E) (CO2 emissions per unit of modern energy consumed)



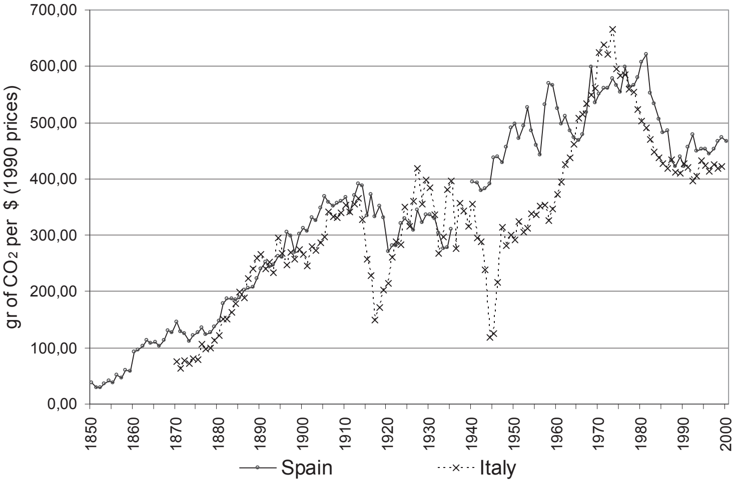
Notes: Modern energies include fossil fuels, hydroelectricity, nuclear and other typical 20th-century forms of energy (district heating, pulp liquor) .

10.4 Pollution intensity of *all forms* of energy1850-2000 (CO2/E) (CO2 emissions per unit of energy consumed)



Notes: all forms of energy include modern energy plus traditional forms of energy used before modern industrialization; traditional forms of energy include firewood, human and animal muscle power. No emissions are associated with traditional energies, see text.

10.5 Pollution intensity of the economy1850-2000 (CO2/GDP) (CO2 emissions per per dollar produced)



carbon-based fuels, and this is an important explanatory factor for the different efficiencies at which these fuels are used throughout the energy system.[22] Although some authors have pointed out that the secular trend toward ever higher H/C ratios has come to a standstill since the mid-1970s, basically as a consequence of the limited growth of the use of natural gas and continued heavy reliance on coal (Grüble, 2004), our findings are slightly more optimistic.

Graph 10.3 plots the pollution intensity of modern energy carriers; that is, CO_2 emissions per unit of modern energy consumed.

[22] Exergy measures the useful work obtainable from an energy source or material and has been proposed as a method for aggregating heterogeneous sources of energy in historical investigations. See B. Ayres, L. Ayres, B. Warr, "Energy, power and work in the US economy", INSEAD working papers 2002/52/EPS/CMR, http://www.iea.org/Textbase/work/2004/eewp/Ayres-paper3.pdf. But exergy does not necessarily reflect attributes of fuels that determine their economic usefulness, such as energy density, cleanliness, cost of conversion, and so on. For a discussion on energy quality see C.J. Cleveland, D. Budikova, "Energy quality", in *Encyclopedia of Earth*, C.J. Cleveland (ed.), *Environmental Information Coalition*, National Council for Science and the Environment, Washington (DC) 2007, http://www.eoearth.org/article/Energy_quality.

While there is a clear trend towards decarbonization following the replacement of coal with oil and later with natural gas and other sources of energy that do not produce CO_2 (such as hydroelectric, nuclear, and renewable sources), the trend does not flatten out completely and only stops declining in the last decade of the 20th century.

The trend of CO_2 intensity changes significantly if we also include traditional energy carriers. Graph 10.4 shows that in this case the trend is reversed: decarbonization does not appear as a long run phenomenon but only prevails from the 1970s onward. Surely this reflects the fact that current standards of CO_2 accounting do not take emissions from firewood or other forms of biomass into consideration. Most international protocols, including that of the Intergovernmental Panel on Climate Change (IPCC), regard biomass emissions as neutral.[23] The IPCC views biomass emissions as part of the natural carbon balance and states that such emissions do not add to the atmospheric concentration of carbon dioxide. Energy-rich biomass carbon – derived from woodchips, bark, sawdust, and pulping liquids recovered from the harvesting and manufacturing processes – is atmospheric carbon dioxide that is transformed and sequestered by trees during their growth. When these biomass fuels are burned, the CO_2 that is emitted is in fact the atmospheric carbon dioxide that has been sequestered during growth, and it becomes part of the natural carbon cycle that includes trees, air and other normal CO_2 emissions. When this cycle functions as a closed loop, a new tree grows and keeps absorbing atmospheric carbon dioxide; hence, according to the standard view, there is no net contribution to the atmospheric CO_2 level.

It is not clear, however, in a historical perspective, whether this loop was actually sustained, considering the rate of deforestation over the past 200 years.[24] Nevertheless, in line with international standards, Graph 10.4 does not include emissions from firewood. This approach

[23] Intergovernmental Panel on Climate Change, Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3, paragraph 6.28, Paris 1997.

[24] At the global level, the loop is not closed due to net deforestation; but in most European countries during the last 50 years we actually observe an increase in woodland as

sees decarbonization as limited to the last 30 years of the 20th century, thus challenging the notion that it is a secular trend.

Finally, Graph 10.5 shows the relationship with economic output. Here, again, the different weight of coal in the respective energy baskets turns out to be important. Observe that the pollution intensity of the Spanish economy was much higher than that of the Italian one for most of the second half of the 20th century. While Italy and Spain reduced their per dollar emissions after the end of the oil crisis, neither economy managed to maintain this downward trend. As a consequence, the pollution intensity of their economies was only able to go down to the levels of the 1950s, but no further reduction was achieved by the end of the 20th century.

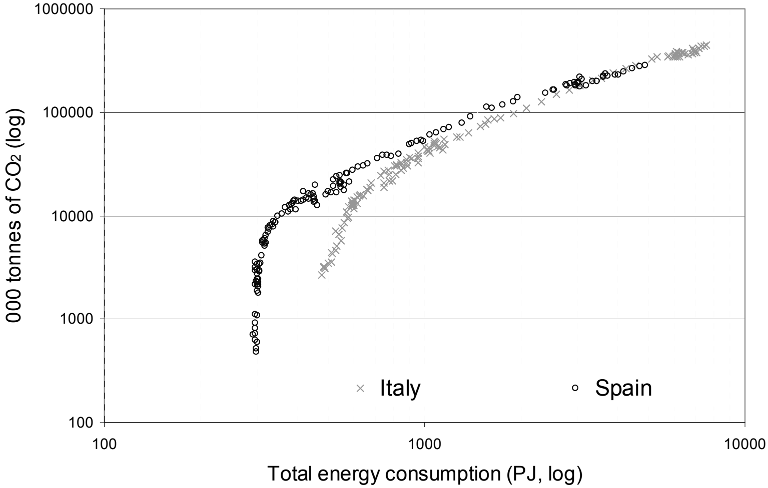
However informative time series may be, cross correlations are also needed to highlight connections between variables that help us improve our understanding of levels of CO_2 emissions in a given country. These cross correlations are shown in composite Graph 11.

Graphs 11.1 and 11.3 illustrate an interesting point: at low levels of energy consumption, small increases of the overall energy of the system were obtained at the price of high increases of emissions; at higher levels of energy consumption, it was possible to increase energy consumption without proportional increases in emissions. Graph 11.2 tells us that in Spain and Italy more income per capita always resulted in more pollution per capita. On the other hand, Graph 11.4 shows that an economy does not need to be intensely pollutant to improve the income of its citizens. Italy and Spain were able to move towards higher levels of income while maintaining constant, or even reducing, the pollution intensity of their economies. In other words, they were able to produce more dollars per capita at lower levels of CO_2 emissions per dollar produced. Yet the trend is not systematic: at lower income levels – from 1000 to 4000 dollars per capita – the trend was clearly upwards, implying that in the early stages of the industrialization

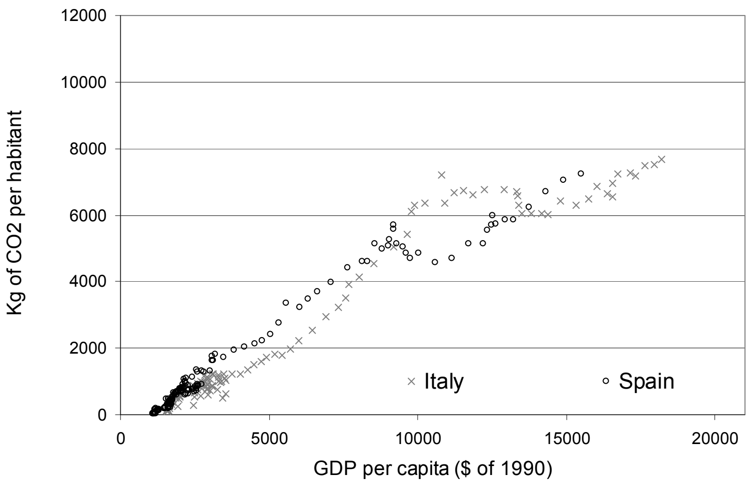
a consequence of the abandonment of rural land. On the concept of 'forest transition' see A.S. Mather, C.L. Needle, "The forest transition: A theoretical basis", *Area*, 30, 2, 1998, pp. 117-124. See also A.T. Grove, O. Rackham, *The Nature of the Mediterranean Europe. An Ecological History*, Yale University Press, New Heaven (CT) 2001.

Graph 11. Cross-correlations of CO_2 indicators for Italy and Spain 1850-2000

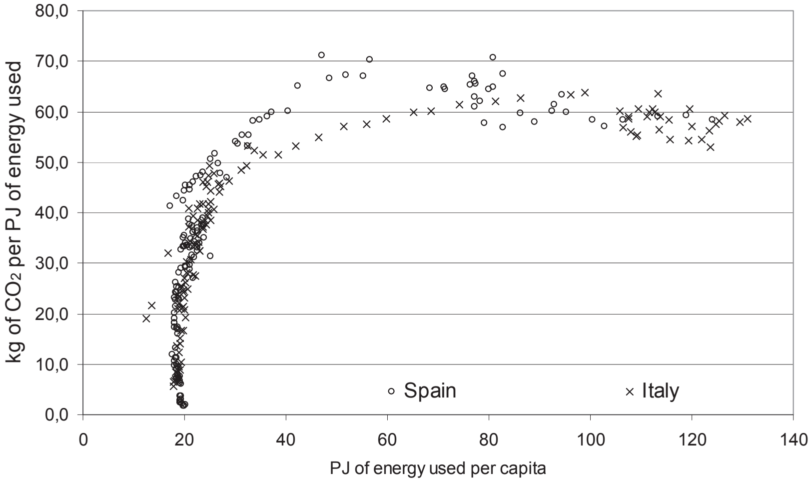
11.1 Total CO2 emissions vs total energy consumed (1850-2000)



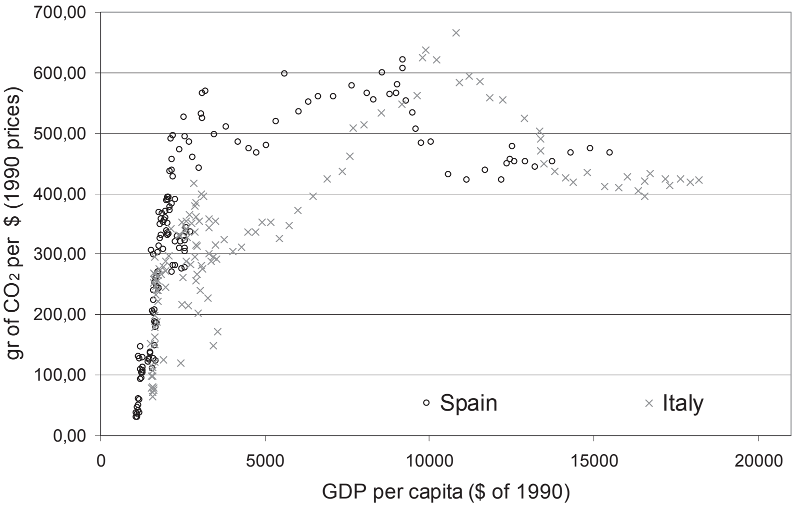
11.2 Pollution per capita vs income per capita (1850-2000)



11.3 Pollution intensity of energy (CO_2/E) vs energy per capita



11.4 Pollution intensity of the economy (CO_2/GDP) vs income per capita



process production per capita could only be increased at the cost of heavy pollution (high CO_2 emissions per dollar produced).

In order to gain further insights into the causes of these variations between countries, researchers have used different methods of decomposition analysis. Decomposition has been applied to almost every field of energy economics. In the following section, we look into the specificity of cross-country decomposition, trying to understand the forces behind the different levels of CO_2 emissions observed in Graph 10.1.

Decomposing CO_2 emission: A log-mean weight Divisia method

Cross-country decomposition studies allow analysts and decision-makers to gain a better understanding of the underlying causes of variation in an aggregate of countries. There are, however, some specific problems in cross-country decomposition that do not normally arise in the decomposition of changes over time in an aggregate within a single given country. These problems were addressed by Zhang and Ang.[25] Cross-country decomposition is often characterized by large variations in explanatory factors, such as GDP and fuel shares in energy consumption, which arise from inherent differences between the countries compared. In such a situation, application of conventional decomposition methods may lead to a large residual, making the interpretation of results very difficult. To overcome this problem, Zhang and Ang proposed several complete decomposition methods that do not leave a residual.[26] A review of decomposition methodology in energy studies can be found in Ang's works.[27]

Scholars have proposed various decomposition methods, generally either in the additive or multiplicative form. The analyses

[25] F.Q. Zhang, B.W. Ang, "Methodological issues in cross-country/region decomposition of energy and environment indicators", in *Energy Economics*, 23, 2, 2001, pp. 179-190.

[26] Ibid.

[27] B.W. Ang, "Decomposition of industrial energy consumption: the energy intensity approach", in *Energy Economics*, 16, 3, 1994, pp. 163-174. See also B.W

and discussions in our paper are based on the additive form, i.e., decomposition of the difference in total CO_2 emissions between two countries – Italy and Spain – into contributions from various pre-defined explanatory factors. Following Zhang and Ang, we define the following variables for each country:

E Total energy consumption of all fuel types

Ei Energy consumption of fuel type *i*

C Total CO_2 emissions from all fuel types

Ci CO_2 emissions from fuel type *i*

Y GDP

P Population

The CO_2 emissions from each country can be written as

$$C = \sum_i C_i = \sum_i (E_i / E)(C_i / E_i)(E / Y)(Y / P)P = \sum_i S_i F_i IGP$$

where *Si*=*Ei*/*E* is the consumption share of fuel type *i*, *Fi*=*Ci*/*Ei* the CO_2 emission coefficient for fuel type *i*, *I*=*E*/*Y* the aggregate energy intensity, and *G*=*Y*/*P* the GDP per capita, or income. The decomposed components of a change in *C* that are associated with these factors are respectively referred to as fuel share effect Δ*C*fsh, emission coefficient effect Δ*C*emc, intensity effect Δ*C*int, income effect ΔCypc, and population effect Δpop.

Let subscripts 1 and 2 denote variables for the two countries being compared. The difference in emission levels between them can be expressed as

$$\begin{aligned} \Delta C = C_1 - C_2 &= \sum_i S_{i1} F_{i1} I_1 G_1 P_1 - \sum_i S_{i2} F_{i2} I_2 G_2 P_2 \\ &= \Delta C_{fsh} + \Delta C_{emc} + \Delta C_{\text{int}} + \Delta C_{ypc} + \Delta C_{pop} + \Delta C_{rsd} \end{aligned}$$

where Δ*C*rsd is a residual, which does not exist if decomposition is perfect. For the sake of convenience, the choice of which country is identified as 1 and which one as 2 is made in such a way that Δ*C* is a positive number. The different effects (Δ*C*fsh, Δ*C*int, ΔCypc and Δpop) can be calculated in different ways, but in order to obtain a

Ang, "Decomposition analysis for policymaking in energy: which is the preferred method?", in *Energy Policy*, 32, 2004, pp. 1131-1139.

perfect decomposition, Zhang and Ang recommend the logarithmic mean weight Divisia method. Using this method, the formula for the calculation of Δ*C*fsh can be written as:

$$\Delta C_{fsh} = \sum_i \frac{C_{i1} - C_{i2}}{\ln(C_{i1} / C_{i2})} \ln \frac{S_{i1}}{S_{i2}}$$

For other effects, one can simply substitute the appropriate variables for *Si j*.

Note that the decomposition method offered by Zhang and Ang is indicated for answering the question: what is the driving force behind the different CO_2 emission levels between any two countries at a given point in time? The answer as resulting from the application of the log-mean weighted Divisia method is plotted in Graph 12.

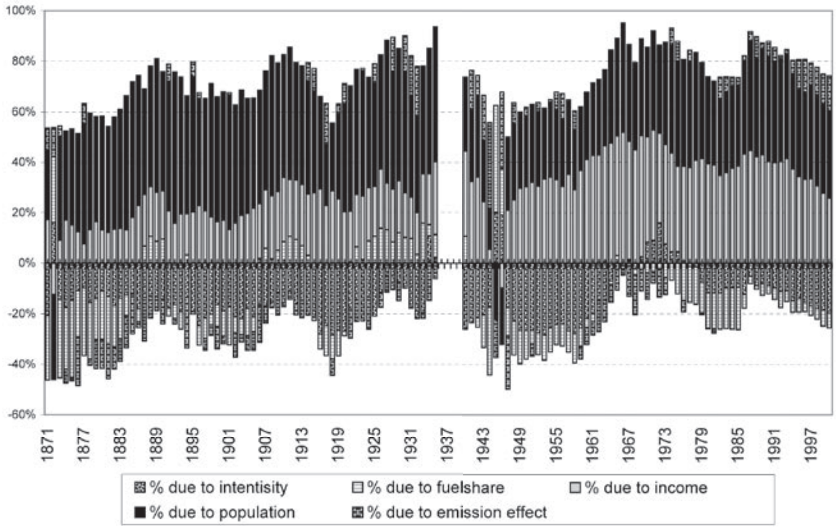
As in Zang and Ang's comparisons between OECD countries and the rest of the world, differences in income (GDP per capita) and population appear to have been mainly responsible for different emission levels in Italy and Spain from 1871 to the year 2000. However, the weights of the different forces changed over time.

Italy's larger population prior to the Spanish Civil War (1936-1939) mainly accounts for its higher CO_2 emissions than Spain in that period. Italy's higher income per capita also played a role. These two forces are compensated by the lower energy intensity of the Italian economy and, in the earlier part of this first period, a cleaner fuel basket and a combination of fossil fuels with lower emissions (more oil and less coal).

After World War II, Italy's higher income per capita outweighs its larger population as a cause of its higher CO_2 emissions. Once again, the lower energy intensity of the Italian economy and the country's cleaner basket of energy carriers act as counter forces, except in the 1960s, when the rapid growth of the Spanish economy pushed the country's energy intensity below that of Italy. The emission effect plays a very small role.

Overall, population differences across countries turn out to be decisive, indicating that further decomposition analysis is needed at the per capita level if we are to understand the forces behind the

Graph 12. Divisia decomposition of the total difference in CO_2 emissions between Italy and Spain: 1870-2000 (as a percentage of the difference to be explained)



different trends of CO_2 emissions in these two countries. But this goes beyond the scope of the present article.

Concluding remarks

This article investigates energy consumption, the transition from organic to fossil energy carriers, and the consequent emissions of CO_2, over a period of almost 150 years (1861-2000) in Spain and Italy. We have used new data, including an estimation of the use of energy from organic sources prior to the introduction of modern energy sources. Previous works have shown that including traditional forms of energy transforms our perception of the relationship between the economy and energy inputs. In this paper we show that traditional energy sources should also be taken into account in long-run series of pollution intensities of energy use, pollution intensities of the economy, decarbonization, and other indicators, in order to achieve a clearer interpretation of the processes involved.