Energy Transitions, Economic Growth and Structural Change: Portugal in a Long-run Comparative Perspective

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Energy Transitions, Economic Growth and Structural Change

Portugal in a Long-run Comparative Perspective

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Abbreviations

AC	Alternating current
ADENE	Agência para a Energia
AP	Amoníaco Português
BIRD	International Bank for Reconstruction and Development
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CCS	Carbon Capture and Storage
CDIAC	Carbon Dioxide Information Analysis Center
CNE	Companhia Nacional de Eletricidade
CPE	Companhia Portuguesa de Electricidade
CRGE	Companhias Reunidas de Gás e Electricidade
CRW	Combustibles, Renewable and Wastes
DC	Direct current
DGE	Direcção Geral de Energia (Portugal): Energy Agency
DGEG	Direcção Geral de Energia e Geologia: Energy and Geology Agency
DGOP	Direcção Geral de Obras Públicas.
DGSE	Direcção Geral dos Serviços Eléctricos
DIY	do-it-yourself
EC	European Community
EDMC	Energy Data and Modelling Center (Japan)
EEC	European Economic Community (1957-1993)
EFTA	European Free Trade Association
EIA	Energy Information Administration
EKC	Environmental Kuznets Curve
ENE	Estratégia Nacional para a Energia
ENEA	Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile (Italy)
Esc.	Escudo, Portuguese currency (1910-2001)

EU	European Union
EU KLEMS	EU KLEMS (database) stands for EU level analysis of capital (K), labour (L), energy (E), materials (M) and service (S) inputs
FAO	Food and Agricultural Organization
FDI	Foreign Direct Investment
FEUP	Faculdade de Engenharia da Universidade do Porto
FIT	Feed-in-tariffs
FOB	Free on Board
FSW	Fuel switching
GDP	Gross Domestic Product
GGDC	Groningen Growth and Development Centre (The Netherlands)
GPT	General Purpose Technology
GVA	Gross Value Added
ICT	Information and communication technologies
IEA	International Energy Agency
IFDC	International Fertilizer Development Center
IMF	International Monetary Fund
INE	Instituto Nacional de Estatística (Portugal): National Statistic Agency
IPAT	Impact= Population×Affluence×Technology (*in Environment studies)*
IPCC	Intergovernmental Panel on Climate Change
LD	Linz and Donawitz (converter)
LEG	Long-term Energy Growth
LPG	Liquified Petroleum Gas
LMDI	Logarithmic Mean Divisia Index
LNG	Liquified Natural Gas
MOP	Ministério das Obras Públicas (Portugal) Ministry of Public Works
MOPCI	Ministério das Obras Públicas, Comércio e Indústria (Portugal): Ministry of Public Works, Commerce and Industry
MTBE	methyl tertiary butyl ether

NAICS	North American Industry Classification System
OECD	Organisation for Economic Co-operation and Development
PAL	Physical activity level
PNAER	Programa Nacional de Acção para as Energias Renováveis (Portugal)- National Action Programme for Renewable Energies
PPP	Power Purchasing Parities
R&D	Research and Development
SACOR	Sociedade Anónima de Combustíveis e Óleos Refinados
SMGEP	Serviços Municipalizados de Gás e Electricidade do Porto
UFA	União Fabril do Azoto
UNEP	United Nations Environment Programme
UNIPEDE	Union internationale des producteurs et distributeurs d'énergie électrique (French). In English: International Union of Producers and Distributors of Electrical Energy.
UNIDO	United Nations Industrial Development Organization
UNU	United Nations University
WHO	World Health Organization
WW	World War

Conversion factors

kilo (k) = 10^3
Mega (M) = 10^6
Giga (G) =10^9
Tera (T) =10^{12}
Peta (P) =10^{15}
1 calorie (cal) = 4.19 Joule (J)
1 watt-hour (Wh) =3600 J
1 horse-power (hp) = 0.736 kW
1 ton oil equivalent (toe) = 41.868 GJ
1 ton coal equivalent (tce) =29.307 GJ
1 ton crude oil = 42.161 GJ
1 ton firewood =12.56 GJ
1 ton imported coal = 29.31 GJ
1 ton domestic coal = 17.166 GJ

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Lund, June 2011

Sofia Teives Henriques

Chapter 1

Introduction

Modern economic growth previously implied a shift in the quantities and quality of energy, from renewable energy sources towards fossil fuels and electricity. This shift brought stress to the environment with climate change being one of its most serious consequences. Another shift from fossil fuels to low carbon energy now seems to be an essential pre-condition for a sustainable future. The changes in the energy system that accompany economic growth are normally referred to as energy transitions. This thesis aims to analyze, in an international comparative context, Portugal's energy transitions in the period 1856-2006. The analysis will contribute to two strands of debate: one in economic history, on the role that energy plays in boosting industrialization, and the other in environmental history, on the environmental consequences of long-run economic growth.

1.1 Energy and industrialization - the role of energy in boosting economic growth

"*The history of energy is the secret history of industrialization*"
R. Sieferle, 2001

The transition from a low-energy and vegetable-energy based society towards a high-energy and fossil-fuel based society is considered by many authors as a necessary, although not sufficient, condition for industrialization to proceed[1]. The distinction between an organic and mineral economy was popularized by Anthony Wrigley[2] and was motivated by his quest to understand the major changes operating in England – changes that became known as the Industrial Revolution. In organic economies most of the energy available to man (heat and muscle) is dependent on the limits of the plant photosynthesis process, *i.e.*, of what land can produce. As the efficiency of the process is low and transportation costs high, these economies were unable to grow beyond the

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[1] Wrigley(1988); Wrigley (2010); Cipolla (1962); Malanima (2006b).

[2] Wrigley (1988); Wrigley (2010).

limits of a certain area[3]. By contrast, industrial England of the 1800s was a mineral economy and the wealthiest nation in the World. England's growth was possible because technological innovations allowed vast deposits of coal to be used for the provision of cheap heat and mechanical energy; she was thus able to break away from the energy constraints of organic economies[4]. For Robert Allen, coal is also a central argument for explaining the emergence of the Industrial Revolution in Britain[5]. He suggests that the Industrial Revolution emerged from a path-dependent process where a unique combination of high wages and very cheap coal gave incentives for innovations around coal to occur, as there was a need to save the most expensive production factor. Because energy was so expensive in relation to labor in most other countries, innovations around coal only made sense in England. As the capital-intensive path was the most fruitful in technological terms, these innovations allowed England to develop a competitive advantage over other nations. Only after improvements in the energy efficiency of steam engines was the Industrial Revolution diffused to other nations[6]. The First Industrial Revolution became known for the replacement of animate energy by machines, which dramatically increased the scale of production and labour productivity. It was associated with a cluster of industries (cotton, iron, railways, mining) using the common input of coal and its converter, the steam engine. These industries have been credited by many as an engine of growth that should be considered as a whole entity, due to its interdependences and multiplier effects on the rest of the economy[7].

The role of coal as an engine of growth in England has its objectors. Clark and Jacks argue that coal could not have made such a difference for economic growth. Although Britain would have lost competitiveness in the most energy intensive branches of the Industrial Revolution, no more than 2% of GDP would have been lost by not having the access to cheap coal[8]. Energy costs would not have mattered for most of the economy, and gains in energy efficiency would have occurred if energy had been expensive[9]. Crafts questions the role of coal as a General Purpose Technology (GPT)[10] during the Industrial Revolution, claiming that the major contribution of steam to economic growth occurred

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[3] Wrigley (1988); Wrigley (2010).

[4] Wrigley (1988, 2010).

[5] Allen (2009).

[6] Allen (2009).

[7] Grübler (1998); Schön (2010).

[8] Clark and Jacks (2007).

[9] Clark and Jacks (2007).

[10] GPT is defined as a radical innovation with a wide impact on all branches of the economy.

much later, at the end of the nineteenth century[11]. For Mokyr, the important issue was not the coal reserves but human ability to transform natural resource endowments, and that was only possible with some useful scientific knowledge which had its roots in the Age of Enlightenment. He recognizes the revolutionary nature of the steam engine but he does not defend the idea of "no coal, no Industrial Revolution". After all, enormous improvements in water and wind technology were also taking place; and coal was not even a must that came with the steam engines – it could be either transported or substituted by wood[12].

More than coal, natural resources as a whole are credited with having an influence in 19th century American industrialization and subsequent leadership in technology in relation to Britain. Habakkuk became known as the first author to address differences in factor endowments as an explanation for the more capital intensive methods of production in America compared to England[13]. As land was more abundant in the US than in the UK, the US had a high wage economy due to the attractive alternatives which were offered in agriculture. That made the US adopt more capital intensive technologies than the UK. In trying to prove Habakkuk's speculative assertion, Paul David put forward a model that explained the persistence of the advantages regarding technology and the impact on economic performance. [14] He considered capital and resources as being non-separable and argued that the opportunities for future technological change accumulation in the nineteenth century were biased in favor of the choice which was more capital intensive[15]. As America had chosen the most capital resource intensive path of development, opportunities for technological development were greater in America. He saw technological progress as a path dependent process where the final choice of technique depended on the initial factor endowments[16]. Countries that chose a labor intensive technology could be locked-in on a labour-intensive path, without much potential for technical change.

While the role of natural resources in building American leadership and the role of coal in the emergence of the Industrial Revolution in England have led to lively debate, the role that energy and fossil fuels played in the industrialization of coal-deprived countries is much less considered. And yet, a study of how different natural resources endowments contributed to the industrial

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[11] Crafts (2003).
[12] Mokyr (2009), p.100-104.
[13] Habakkuk (1967), Saul (1970).
[14] David (1975).
[15] David (1975).
[16] David (1975).

development of those countries could help to better understand how limiting the renewable energy sources were. The recent long-run series on European energy systems increase the possibilities for questioning the role of fossil fuels. For instance, Gales et al. show that fossil fuels had differentiated impacts on the energy systems in four coal-poor countries: the Netherlands, Spain, Sweden and Italy[17].

Was the access to cheap fossil fuels a necessary condition for industrialization to proceed, or could coal-poor countries rely on indigenous natural resources? Different perspectives exist on the matter. The contemporaneous view could probably best be expressed in a passage from Jevons' essay "The Coal Question": "The Newcastle mines are almost as high a benefit to the French, Dutch, Prussian, Danish, Norwegian, Russian, Spanish, and Italian coast-towns, as to our own" (...) "It has often been repeated, for some time past, that there is one simple means of competing with England in her manufactures. It is to buy coal from her (…)"[18]. In this view coal was the cheapest of all fuels and no other fuel could surpass it. Landes points out that the countries which largely succeeded during the First Industrial Revolution did so because they emulated British patterns of industrialization, which had given England a large competitive advantage that put the survival of traditional industries in Europe at risk. Continental reliance on water power or charcoal, due to unfavorable relative prices, is almost seen as an obstacle to successful technological adoption. More than in England, coal and iron were the leading sectors of European industrialization.[19] Pollard also sees regional industrialization as an imitation of the British Industrial Revolution. Regions with similar factor endowments to England, such as Belgium or the Ruhr, with cheap coal and iron, successfully industrialized while regions with different endowments remained agricultural or de-industrialized[20]. Some environmental historians would disagree with the proposal, though. Kunnas and Myllyntaus suggest that in the early phases it is possible to industrialize by means of renewable energy sources if that growth is accompanied by technological change[21]. They give the example of Finland, which managed to industrialize by resorting to wood and water-power, without putting so much stress on their energy resources, as the improvement of efficiency in household stoves and the decline of slash-and-burn cultivation allowed the freeing of wood for industrial

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[17] Gales *et al*. (2007).
[18] Jevons (1865).
[19] Landes (1969).
[20] Pollard (1981), pp. 105-107.
[21] Kunnas and Myllyntaus (2009).

needs. Sweden has also been presented as a case of successful industrialization without coal resources. Rydén shows that English technology and organizational processes were successfully adapted to a charcoal environment, "implying that industrial production was possible even when no coal was available"[22] Later, according to Lennart Schön, charcoal and wood price rises put Swedish heavy industry in a difficult position, which was an incentive to explore hydro-power[23]. Cheap hydro-power was the basis of Swedish industrialization.

Other authors situate themselves in the intermediate position. According to Bardini, the lack of coal was a serious disadvantage for Italian manufacturing until World War I, as coal arrived at Italian ports at exorbitant prices. He argues that Italy's lack of competitiveness in relation to England could not be solved by hydro-power or cheap labour either, as steam acted as a General Purpose Technology (GPT) for the most advanced industrial sectors. Italian factor endowments made them avoid the industrial sectors where steam acted as a GPT. The use of relatively more electricity only constituted an advantage in a few backward sectors, as electricity was merely used as a substitute for generic power. The Italian catch-up only occurred later, when the unit drive enhanced the technological advantages of electricity[24]. Along the same lines, a popular approach among some Spanish economic historians is to see high-coal prices as a factor that simultaneously delayed Spanish industrialization and gave an incentive for early electrification[25].

This thesis seeks to analyze the role played by energy in the Portuguese industrialization process. Portugal was one of the most backward countries around 1850 and failed to converge with the European core for almost one century. It is a fossil-fuel-poor country with limited mineral resources, and renewable energy sources such as wood, wind, and water were the only alternatives to a fossil-fuel based industrialization. To understand the role of energy, a comparison of how the different energy resources were used is needed. I will assess whether the lack of coal was an obstacle to industrial growth, and investigate whether traditional renewable energy resources and hydro-power compensated in any way for the lack of fossil fuels. Were energy costs an important factor that delayed Portuguese industrialization? If so, how was the problem eventually solved?

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[22] Rydén (2005), p.127.

[23] Schön (2010).

[24] Bardini (1997).

[25] Sudrià (1990b).

1.2 The environmental consequences of modernization of energy systems

The modernization of energy systems, which occurs with economic growth, brought impacts to the environment in the form of overuse of natural resources, pollution and CO_2 emissions.

1.2.1 Energy and CO_2 emissions

The combustion of fossil fuels, which occurred with industrialization, led to an increase of anthropogenic CO_2 emissions. Although the relationship between CO_2 emissions and temperature increases on Earth was discovered by the Swedish scientist Svante Arrhenius in the late nineteenth century, it was not until the 1980s that this relationship was seen as potentially threatening to the environment[26]. The first IPCC report in the 1990s stressed that climate change was real, that most of the anthropogenic emissions were caused by the accumulated emissions due to the burning of fossil fuels since the Industrial Revolution, and that there was a need for a global commitment to reduction of CO_2 emissions[27].

The Kyoto Protocol, adopted in 1997 and ratified in 2005, committed a group of industrialized countries to cut down CO_2 emissions by 5%, in relation to the 1990 baseline levels, by 2008-2012. As a group, the European Union agreed to an 8% reduction of 1990 baseline emissions in the period of 2008 to 2012. The EU-15 established a burden-sharing agreement that allocated different reduction targets to its members. Portugal was allowed to increase emissions by 27% in relation to the 1990 level due to lower per capita historical emissions, lower income and expectation of higher economic activity growth rates than other member states in this period.

CO_2 emissions from fossil fuels are a function of both energy consumption and the energy basket. There are only two ways of reducing CO_2 emissions from fossil fuels. One is to reduce energy consumption which can be done by reducing economic growth, or population, or by changing the relationship between energy and economic growth[28]. The other option is to change the composition of the energy basket to sources with a lower CO_2 content. This can be done switching

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[26] Arrhenius (1896).

[27] IPCC (1990).

[28] This includes technical energy efficiency but also structural changes towards sectors of lower energy intensity and substitution of production factors, among others.

from coal or oil to natural gas, or by increasing the share of renewable or nuclear energy[29].

Only since the 1990s has climate change mitigation been a clear objective in the energy policies of industrialized countries. This means that most of the changes in CO_2 emissions back in time were a result of the uninformed actions of human societies. However, from an environmental history perspective, a study of why and how CO_2 emissions from fossil fuels changed in the past is an important tool for understanding the drivers of both past and present energy transitions in the global environment.

This thesis makes a contribution to understanding the drivers of historical CO_2 emissions changes by decomposing CO_2 emissions changes into various components. Furthermore, we connect the study of the historical role of energy in boosting economic growth with the recent challenges of a necessary transition from fossil fuels towards renewable energy.

1.2.2 Energy intensity as an indicator of environmental stress

The prospects of finite reserves of fossil fuels, high energy costs and environmental degradation motivated a series of studies of the relationship between energy and economic growth. The ratio between energy and GDP (energy intensity) has been applied as an indicator of relative environmental stress. Comparing this ratio over time gives us an indication of the evolution of the economic efficiency of energy use. If the ratio increases over time, this means that the country in question needs more units of energy to produce one unit of GDP; if the ratio decreases, the inverse is true, and the impact of economic growth on the environment seems less detrimental.

The mainstream view of how energy intensity will behave at various stages of economic growth originates in long-run statistical data available for countries such as the US, the UK, Germany, France and Japan; the data only includes commercial energy sources[30]. Schurr and Netschert were probably the first authors to study the long-run energy intensity of an industrialized country. Their

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[29] A third option which is not dealt in this thesis consists in capturing the carbon dioxide emissions from fossil fuels. This process can occur naturally (e.g., by an increase of the forest area); or with the resource to Carbon capture and Storage (CCS) technologies. This last process is still in an experimental phase and it consists in capturing carbon dioxide from fossil fuel power plants by storing it in a way so that the CO_2 is not release into the atmosphere; for example by injecting the CO_2 in geological formations. The process can reduce the release of CO_2 in 80% when compared with conventional power plants, but is more energy intensive. Considerable financial costs and the risk of leakage are some of the bottlenecks of this process.

[30] Martin (1988).

study “Energy in the American Economy 1850-1955” included an estimation of firewood but they decided to exclude it from the energy intensity ratio, arguing that firewood was a household fuel[31]with a comparatively lower effect on economic growth than the energy which was transformed for mechanical purposes[32]. They found an inverted U-shaped relationship with a peak around 1913 and a decline after that. Schurr’s study and most of the following works on American energy intensity have argued that the effect was strongly connected with the increasing share of electricity in the energy system, even if the production of electricity entailed significant thermal losses. According to those studies, the switch from steam to electricity allowed enormous increases in overall manufacturing productivity after World War I, due to the possibility of organizing the production process more efficiently, at the same time as reducing transmission losses[33]. Humphrey and Stanislaw analyzed energy intensity in the UK for the period 1800-1975, and also found an inverted U-shaped pattern with a peak around 1870. They attributed the growth around 1830-1870 to a phase of strong investments in infrastructures (railways) and heavy industry, and interpreted the decline as the result of the decreasing share of iron in energy consumption and GDP and to an increase of thermal efficiency of coal consumption. They conclude, “UK experience seems to endorse the conclusion that periods of industrialization, involving rapid structural change in the pattern of output, and, more important, the capital stock, are accompanied by a relatively high growth of energy”[34].

A study by Martin in the 1980s, using information from various countries, indicated that the evolution of energy intensity assumed the shape of an inverted U with early peaks for countries which industrialized first and later peaks for late-comers[35]. This evidence led to a theorization of a general pattern of energy intensity evolution, dependent on the stage of development of each country. In the first phase of industrialization, the energy intensity will grow as a result of structural effects related to the transformation of an agricultural society to an industrial one. In this stage, countries invest in infrastructures and direct their productive structure to heavy industries. Economic growth is dependent on the intensification of energy use[36]. In a second stage, after an inefficiency peak,

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[31] Latter they were criticized by Melosi (1982) who argued that fuelwood could not be considered merely a pre-industrial fuel, as wood was also used in steamboats and manufacturing.

[32] Schurr and Netschert (1960). However, there is a logical mistake in it, because the commercial energy also included household uses.

[33] Devine (1983); Rosenberg (1998); Sonenblum and Schurr (1990).

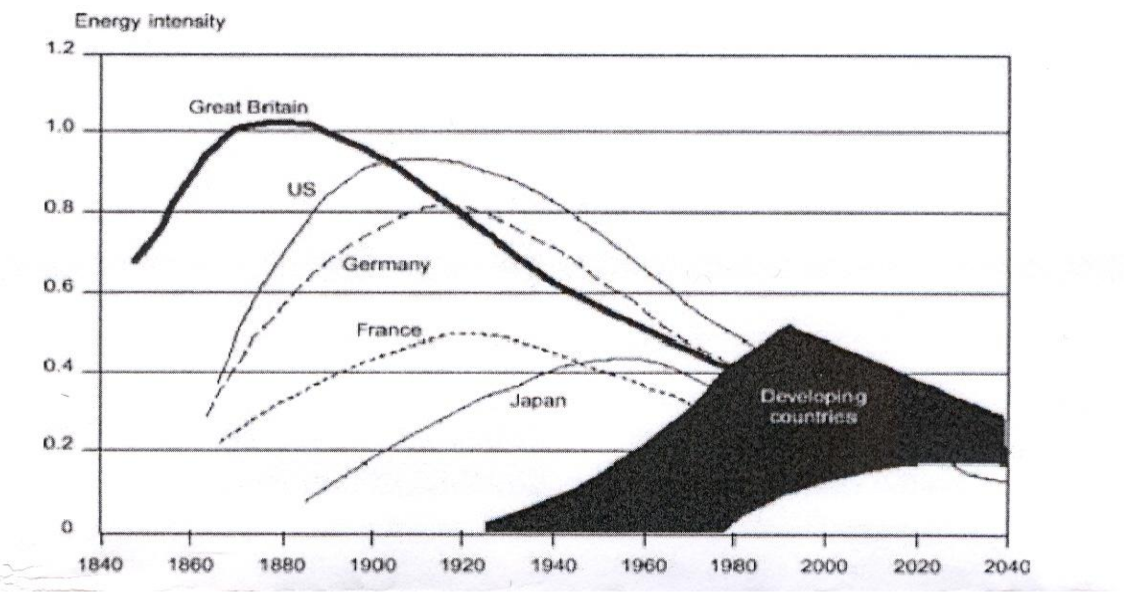
[34] Humphrey and Stanislaw (1979).

[35] Martin (1988).

[36] Percebois (1989).

there is a decline in energy intensity that is explained by technological reasons (improvements in the efficiency of the energy chain), substitution of energy carriers and by transition from an industrial society to a services society that is less energy intensive[37]. Concepts such as *dematerialization*, *i.e.*, decoupling materials from growth due to a transition to post-industrial growth, emerged. In this post-industrial scenario, information technologies and recycling reduce the material input of the economy as well as an increase of environmental awareness; there is also a shift of consumption patterns towards low intensive activities such as recreation, home entertainment or health[38]. Reddy and Goldemberg include the idea that, by incorporating new and modern technologies, developing countries would have an opportunity to avoid the dirty and intensive path of their predecessors, *i.e.*, they may leapfrog.[39] Because of the possibilities of benefiting from a cleaner and more efficient stock of technology when they industrialize, which was not available to forerunners when they industrialized, developing countries are expected to peak at lower levels of energy intensity[40].

Fig 1.1 Mainstream portrait of Energy Intensity evolution



Source: Gales *et al.* (2007), adapted from Reddy and Goldemberg (1990).

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[37] Percebois(1989).

[38] Bernardi and Galli (1993).

[39] Reddy and Goldemberg (1990).

[40] Reddy and Goldemberg (1990); Goldemberg (1998).

This type of relationship between energy and economic growth was later also generalized to the relationships between environment and growth. In parallel studies in the early 1990s, an inverted U-shaped curve between environment and income was also proposed and the concept of the Environmental Kuznets Curve (EKC) was born. The proponents argue that, in earlier stages of development, the environmental stress increases but, in later stages, structural changes to services, information technologies and improvement of environmental awareness lead to a gradual relative decline in environmental degradation[41]. The idea is quite intuitive; as countries industrialize they need a larger quantity of machines and energy and, when their economic structure goes to services, the process is reversed, resulting in less energy use. Despite the optimism of these views, we should note that decoupling energy from growth is merely a weak hypothesis of improvement of the environment; energy consumption can decrease relatively to GDP but can increase in absolute terms.

A second view of energy intensity incorporates not only modern energy but also traditional energy carriers (wood, muscle power, wind & water). Some of the long-run studies that include non-commercial energy were recently published and are available for some countries[42]. These studies do not confirm a generalized hypothesis of an inverted U-shaped curve as a general pattern of development. Very different patterns were found. Warde (2007) did find an inverted U-shaped pattern for England and Wales, even when traditional energy carriers were included, while the trend for the US exhibited a sharp long-run decline if wood was included[43]. Gales *et al*. show a spectacular long-run decline in energy intensity in Sweden, a decline of about 50% in Italy and Spain, and an almost flat trend in Netherlands with a peak in 1973[44]. The long-run decline has been interpreted as the result of continuous technical change surpassing the effects of structural change (industrialization). The intuition of the argument is strongly related not only to the transition from traditional energy carriers (less efficient) to modern energy carriers (more efficient), with continuous improvements in the efficiency of energy converters throughout history, but also to technological change in the broad sense, that is, improvements in total factor

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[41] Panayoutou (1993).

[42] There exists a set of studies within the LEG (Long term Energy Growth) network, which use the same methods: Kander (2002) for Sweden; Malanima (2006b) for Italy; Rubio (2005) for Spain; Gales (2007) for Netherlands; Warde (2007) for England & Wales. For different methodology, see for example, Kraussman and Haberl (2002); Schandl and Schulz (2003) on Austria or UK or Kunnas and Myllyntaus (2007) for Finland; Grübler (1998)for the US.

[43] Grübler (1998).

[44] Gales *et al*. (2007).

productivity with the use of new technologies[45]. This type of long-run energy intensity has been less acknowledged in the literature, maybe because of the difficulty of finding a common pattern, a stylized fact.

Astrid Kander went behind the simple intuition and decomposed long-run energy intensity in the Swedish economy in four-sector context (Agriculture, Industry, Transportation and Services) using shift-share analysis methods. Those methods enable the separation of energy intensity into structural changes (changes in the shares of sectors, keeping energy intensity constant) and technological factors (changes in sector energy intensities, keeping the structure of economy unchanged). She found an increase of energy intensity due to structural change in the most intense period of industrialization (1870-1913) but no impact of structural change towards a transition to the service sector in a later period (1970-1998)[46]. Instead, dematerialization of the Swedish economy was found within the industrial sector, presumably due to the impact of the third Industrial Revolution. She used the concept of Baumol´s cost disease to explain that absence of structural change impacts from the service transition: employment and the shares of GDP in current prices grew, while the real share of services did not. Baumol argued that labour productivity gains occurred mainly in the industrial sector as machines were introduced in order to save time. In the service sector, labour time cannot be reduced to the same degree, so labour productivity does not rise as much as in industry[47]. However, service wages tend to follow those of the manufacturing sector, and so accompany the productivity gains of the manufacturing sector. As a result, the prices of services will increase when compared to the prices of manufactured goods. This would be the reason why, in terms of real production, the share of services in the GDP did not change that much, at least in the case of Sweden[48].

More country studies on the causes of energy intensity changes are needed to identify whether or not there is a common pattern in the evolution of energy intensity. Most historical studies do not convincingly explain the main determinants that lead to transformations in long-run energy intensity. Energy intensity is too vague and broad a concept for a decrease or increase in the ratio of energy to GDP to be interpreted as a simple deterioration or improvement in environmental conditions. The contribution of structural effects or technological effects has been more theorized than measured, apart from the mentioned

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[45] Gales *et al*. (2007).

[46] Kander (2002); Kander (2005).

[47] Baumol (1967); Kander (2005).

[48] Kander (2002); Kander (2005).

exceptions[49]. It is assumed that countries follow the same pattern of development, but this is, of course, deterministic. In order to establish meaningful patterns, the study of the structure of energy systems has to be interconnected with the study of the structural shifts in a broad sense. Scientifically speaking, the understanding and quantification of the factors that make energy intensity vary are important for the debates on Environmental Kuznets Curves and *dematerialization*.

This thesis will establish historical energy intensities for Portugal and compare it with the experiences of pioneers in order to look for differences and common patterns. It will further explore the hypothesis, put forward by Kander, that the service transition is an illusion when it comes to real production structure, by decomposing energy intensity into structural and technological effects[50].

1.3 Aims, scope and research questions

The thesis aims to analyze Portugal´s energy transition in the period 1856-2006 in an international comparative context, and seeks to understand the long-run interrelations of energy, economic growth and the environment.

My point of departure, or initial hypothesis, is that energy played and still plays a distinct role in Portuguese society, when compared with countries that industrialized earlier on. The hypothesis is derived from both the fact that Portugal is a late-comer in the development process and that natural resources might have influenced the pattern and intensity of Portuguese industrialization in a distinct way. If this is the case, the transition from an industrial towards a service society can also produce differentiated stress in the environment, depending on the historical path of each country.

A group of three research questions is formulated in order to test the hypothesis of the specificity of Portuguese energy transition:

How can we characterize the Portuguese energy transition in the long-run? Does the Portuguese energy transition share common trends with other countries? To which countries was the Portuguese energy pathway similar or different? What do long-run energy intensities look like? How different are the impacts of the type of transition in CO_2 emissions?

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[49] Kander (2002); Kander (2005).

[50] Kander (2002); Kander (2005).

What was the role that energy played in Portuguese industrialization? Was industrialization delayed due to the lack of fossil fuels? If yes, in which way? What was the role of indigenous renewable sources in contributing to economic growth?

How does the relationship between energy and economic growth change with the transition from an industrial to a service society? Do structural changes play a fundamental role in the decoupling of energy from economic growth? Or are other factors more important?

1.4 Comparative perspective

Without a quantification of the total energy system, it remains difficult to understand the nature and the pace of the energy transition itself. To answer the questions outlined above, a database, which includes traditional energy carriers along with modern energy carriers, has been constructed. The methodology used to construct this database for Portugal can be found in Chapter 2. In order to position Portuguese energy transition in a comparative framework, I have benefited from a pool of data on European Energy Systems kindly provided to me by the members of the Long Energy Growth (LEG) network. The database includes long-run primary energy data for Spain[51], France[52], Italy[53], England & Wales[54], the Netherlands[55], Germany[56] and Sweden[57]. I thank Ben Gales, Paolo Malanima, Astrid Kander, Paul Warde and Mar Rubio for sharing their databases with me. I have added Canada and the US as comparative countries as well. The diversity of development experiences and natural resource endowments in each country is essential for an understanding of the specificity of Portuguese energy transition. In relation to Portugal, all of these countries industrialized early on, although Spain shares many of the characteristics of Portuguese economic growth, especially during the post-war period. Nowadays, all the countries are considered post-industrial societies, although there are still disparities in income per capita. This means that we analyze historical energy transitions from the point of view of a late-comer.

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[51] Rubio (2005).

[52] Gales and Warde, unpublished database.

[53] Malanima (2006b) .

[54] Warde (2007).

[55] Gales et al. (2007).

[56] Gales, Warde and Kander, unpublished database.

[57] Kander (2002).

1.5 Structure

Chapter 2 provides the calculations for the energy quantities for Portugal.

Chapter 3 characterizes long-run Portuguese energy transition from a comparative perspective. The goal of the chapter is to address, in a comparative framework, how different Portuguese long-run energy transition was in the pace and magnitude of the shift and in the environmental consequences associated with that shift.

Chapter 4 addresses the question of whether the scarcity of natural resources delayed and shaped the Portuguese industrialization process.

Chapter 5 forms a chapter that results from a joint publication with Astrid Kander in the Journal of Ecological Economics[58]. It challenges the idea that a transition to a service society is the main cause of relief for the environment, by decomposing energy intensity changes of Portugal and other developed and developing countries into technological and structural factors. The chapter is adapted to stress the Portuguese experience.

Chapter 6 summarizes the main conclusions and contains a general overview of how we should understand the Portuguese long-run energy transition in a wider comparative context.

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[58] Henriques, S.T. and Kander, A. (2010), The modest environmental relief resulting from a transition to the Service Economy, *Ecological Economics*, **70** (2), 271-282.

Chapter 2

Energy Quantities[59]

2.1 Introduction

The availability of fossil energy has been considered as one of the most important foundations of modern economic growth. Societies around the world have gone through a generalized process of energy transition from vegetable and animate sources to mineral forms of energy. This passage meant that societies are no longer dependent on the renewable but limited supply of land to grow food, fodder and firewood for their energy needs but that can augment their energy basis through the use of non-renewable but vast and dense subterranean forms of energy amassed over millions of years in the form of coal and oil[60]. The use of fossil energy sources has shaped our society and allowed for great increases in income per capita, industrialization, urbanization and globalization. However, the magnitude and speed of the process have varied in different regions of the world.

While the developed countries are today almost totally dependent on fossil fuels, most of the underdeveloped regions in the world still rely mainly on traditional energy carriers such as biomass and muscular energy. The transition to fossil energy was also very different for European countries. For the British and Dutch economies, this process can be traced back to the 16th or 17th century, while for others it occurred only in the 19th or 20th century. Until very recently, however, no attempts were made to quantify traditional energy carriers; most of the research has concentrated only on modern sources. Without a quantification of traditional energy sources it remains difficult to understand the nature of the transition itself. Was the transition process a revolutionary break, with fossil fuels quickly replacing the old ones? Or was the energy transition a slower and smooth process, with traditional sources coexisting with modern ones? Energy quantification cannot explain *per se* the reasons behind adoption or rejection of different energy carriers by different strata of society, but it is an important step

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[59] This chapter is a revised reproduction of Henriques, S. T. (2009), *Energy consumption in Portugal 1856-2006,* Consiglio Nazionale delle Ricerche, Naples, pp.11-92. I would like to thank Paolo Malanima for advice on this chapter. Section 2.2 and Section 2.3 are common to the other volumes in the series; see Malanima (2006) and Warde (2007).

[60] On this subject see Cipolla (1962); Wrigley (1988) and Sieferle (2001).

to identify the main uses, the speed and the magnitude of the transition and the relation between energy use and economic growth.

The purpose of this chapter is to quantify all energy carriers of the Portuguese energy transition from 1856 to the present day. In 1856 Portugal was, along with the majority of the European countries, an essentially organic society. The steam machine, steam ship, railways and the brilliant gaslight were already introduced in the country, but the traditional energy carriers still accounted for 95% of total energy consumption. It was still the windmill that ground the majority of the cereals of the nation, the fireplace that heated the houses and cooked the meals, the ox and cow that performed the work in the fields. In the beginning of the 21th century a very different situation emerges, and 90% of energy consumption is from modern energy carriers; 86% from fossil fuels. Fossil fuels and electricity replaced firewood and muscular energy in every dimension of daily life. New energy carriers enabled the Industrial Revolution and an economic and social growth never imagined. However, fossil fuels also bring pollution and environmental damage. While societies in the past were concerned with the capacity to grow according to the limited availability of vegetable energy, the world today is increasingly aware of its limits to growth due to a non-renewable and environmental damaging energy basis. This new context of environmental degradation, global warming and the prospect of high oil prices has given rise to other questions. Industrialized countries are now attempting to begin another energy transition, from fossil fuels to renewable sources. Hydrogen, biofuels, wind, wave and solar electricity seem to be the energy of the future. Technology is developing, but most of the denominated new energy sources were considered traditional once before. Can economic growth still be maintained with the transition to renewable sources? Smil gives five reasons for the transition to be more difficult than expected: the scale of the shift; the lower energy density of renewable fuels; the lower power density of energy production; the intermittency of supply due to climatic variation dependence; the uneven geographical distribution of renewable sources and the difficulty to making it available to all regions in the world[61]. All those constraints to growth were present in *pre-fossil* fuel societies. From an historical point of view, this shift is to be followed with attention, since fossil fuel use seems to have been a necessary but not a sufficient condition for modern economic growth[62]. Thus, the quantification and the study of the role of

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[61] Smil (2006).

[62] Malanima (2006b).

traditional sources of energy in the economic growth of past societies provide economic historians with tools to participate in the environmental debate.

2.2 Definitions

The objective of this investigation is to provide an account of every form of energy exploited directly by human beings in the past and in the present. The intention is to quantify on an annual basis the following list of primary energy carriers.

1. *Food for human beings*
2. *Firewood*
3. *Feed for work animals*
4. *Wind*
5. *Water*
6. *Fossil sources*
7. *Primary electricity.*

It is important to emphasize that we only take into account energy sources that have a cost (not just in monetary terms) for human beings. The effect of solar light is not included as this imposes no costs to humans. Wind and flowing water are recorded in the following series, since, although free, their exploitation is possible only by utilizing a machine, such as a ship or mill, which has a cost. Even if part of the firewood consumed did not require any monetary payments from its users, time spent on collecting, transporting and cutting wood should be seen as an opportunity cost. In the same way, biomass not collected by human beings in a forest (or collected for construction purposes), or the grass of a meadow not consumed by the animals exploited by human beings for food or work, is not accounted for. On the contrary, the grass eaten by a cow becomes part of human energy consumption, either as "fuel" for the animal, if the animal is used for work, or as food if it or its products are eaten (whether in the form of milk, cheese, or meat).

2.3 Primary sources

In the following time series, to avoid duplications -always a risk in reconstructions of this kind- only *primary energy* will be considered. By primary energy source, we mean *a source of energy we can find in the natural environment useful to human beings and exploited, at a cost, for conversion into* *heat, light or mechanical work. A secondary source of energy* is the transformation of a primary source. The energy content of electricity or gas, produced by means of coal or oil is not included, as it is a transformation, with some losses, of the energy content of oil and gas. In the same way, charcoal is a *secondary source as it is a result of firewood combustion.* Charcoal should be excluded from the following series, whereas firewood to produce charcoal should be included.

In many other cases, it is less clear how one should recognize a primary source. Since bread could be produced by means of cereals ground by exploiting the energy of an animal, one may wonder if we should not subtract the animal muscle energy from the calories of bread to avoid duplication. However, we are not dealing with the same energy undergoing a transformation, as in the case of firewood-charcoal. Bread is a transformation of the calories of cereals, and not of the calories burned by the muscles of the animal pulling the plough. In this way, we must include both the energy of the bread and the animals' muscle energy in our calculations.

The statistics detail the input of energy into the economic system, regardless of how efficiently that energy is exploited. Thus, I will estimate the calories consumed by human beings as food, the feed consumed by working animals, the flow of wind driving a sailing ship and the flow of water driving a mill wheel. A large part of these inputs will be lost in the process of conversion and transmission and not actually be employed to do useful work. Here, I do not calculate energy yields, although improvements in the efficiency of energy use are an important chapter of energy history. Instead, I use the ratio of energy divided by GDP (energy intensity) to assess the evolution of the economic efficiency of the energy system (Chapter 3 and Chapter 5).

2.4 Territory, population and GDP

The territory used in this study comprises the current borders of Portugal. Fossil fuel consumption derived from Trade Statistics is accurately determined, as the borders of the territory did not suffer any modification during the period this study concerns. Estimates produced by the demand side (food for humans, firewood for households) account for all the resident population. Some adjustments are made for animal energy in order to correct a few census years that only include the number of animals on the mainland, excluding the Madeira and Azores Islands. It is not possible to account for firewood for industrial and power use in the Islands before 1970. This is due to the fact that statistics omit islands, a problem also encountered in the reconstruction of national accounts[63]. This is not a serious issue as the share of the Islands in industrial production is admittedly much smaller than the population share[64].

Regarding population figures, official census have been conducted in interval years[65] since 1864. For 1864 to 1991, I use the work of Valério in which annual data is given[66]. For 1992 to 2006 estimates of INE (National Statistic Agency), available online, are used[67]. The population figures for 1856 to 1864 are estimated through linear interpolation from 1849[68] and 1864 figures.

GDP figures until 1990 are taken from the work of Pedro Lains[69], in turn derived from other main GDP historical reconstructions: Reis[70], Lains[71] and Lains and Sousa[72] for the period 1856-1909; Batista *et al.* [73] for the years 1910-1952 and Pinheiro[74] from 1953 until 1989. Maddison[75] values are used from 1990 onwards.

2.5 Earlier studies

The International Energy Agency (IEA) has reported energy statistics for OECD countries since 1960 and for non-members since 1971. Historically, consumption of fossil fuels and hydroelectricity has been elaborated for a considerable range of countries and has been reproduced in well known publications[76]. On the other hand, long-run estimates of non-commercial energy are only available for a limited set of countries. Schurr and Netschert[77] were the first authors to include firewood in their analysis of the role of energy in the

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[63] For example, the reconstruction of Portuguese GDP of Batista *et al.* (1997) for 1910-1958, used here, also refers to mainland Portugal.

[64] Population shares were 7-8% during the period of 1864-1970. However, energy figures are much smaller, for example electricity production was only 1.4% in 1970.

[65] Official censuses comprise the following years: 1864, 1878, 1890, 1900, 1911, 1920, 1925, 1930, 1940, 1950, 1960, 1971, 1981, 1991 and 2001.

[66] Valério (2001).

[67] Can be found at www.ine.pt, section of products and services/time series/População e Condições Sociais.

[68] Leite (2005).

[69] Lains (2003), pp. 247-266.

[70] Reis (1986).

[71] Lains (1990).

[72] Lains and Sousa (1998).

[73] Batista *et al.* (1997).

[74] Pinheiro (1997).

[75] Maddison (2008).

[76] Mitchell (2007); Darmstader (1971) ; Etemad and Luciani (1991).

[77] Schurr and Netschert (1960).

American economy since 1850. They discovered that firewood, being preferred to coal in the beginning due to its abundance, had a very important role in the industrialization of the country until the 1860s. In the end of the 1970s, Steward made estimates for Canada dating back to the beginning of the confederation, including commercial energy, water, wind, firewood, human and animal work[78]. He used fuel-equivalent concepts to aggregate series, converting hydroelectricity and water energy into the quantities of coal that would be required to do the same work in a thermal power plant; animal direct work into the amounts of oil that would be required for an internal combustion engine to do the same work; wind energy from vessels into a steam ship. This method is used in order to not overemphasize the consumption of more inefficient energy sources in the energy structure as no efficiency losses are considered at the point of primary energy use. However, the method makes temporal or spatial comparisons difficult to interpret, since the level of consumption of non-fossil energy carriers is based on the time and space dependent efficiencies of the main energy carrier. How do we interpret a country having the same level of hydro–electricity in 1900 and 1950? Was it because production stagnated? Was it due to an improvement in thermo efficiency, despite growth of production? Or did production actually fall but a decline in thermo efficiency occurred due, for example, to the reactivation of old utilities or by a substitution of coal for oil? As one can see, the information that is gained with this procedure does not really compensate for the information that is lost.

More recently, estimates on materials and energy use have been done for Austria and the United Kingdom on the basis of land use changes[79]. The authors seek to identify the major biophysical characteristics of agrarian societies as opposed to industrial ones. However, for the purposes of our study, which only focuses on energy, these studies can be a limitation due to the fact that wood for construction purposes is included. My study relates more to the methods employed for England &Wales[80], Italy[81], Spain[82], Netherlands[83] and Sweden[84]. The authors show that the inclusion of traditional energy carriers alters the dominant paradigm of an inverted U-shaped relationship between energy consumption and income.

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[78] Steward (1978).

[79] Kraussman and Harbel (2002).

[80] Warde (2007).

[81] Malanima (2006b).

[82] Rubio (2005).

[83] Gales (2007).

[84] Kander (2002).

Portuguese research on energy history developed slowly until a few years ago. In the last fifteen years of the 20th century the research consisted of a few master´s theses on coal production of specific mines in the 19th and early 20th centuries and on two or three generic books on electricity. Most works, though valuable, address only specific regions, carry poor statistical information and cover short periods of time.

In the last decade, although most of the works are still focused mainly on one energy carrier, some historical synthesis has emerged. At company level, researchers developed studies about the electricity, gas and oil companies in the country from their foundations to the present days. From the quantitative point of view, Madureira and Teives made the first attempt to aggregate oil, coal and hydroelectricity figures in a study covering the period of 1890-1982[85]. This study will produce major revisions on these estimates and enlarge the period from 1856 to 2006[86]. My main contribution is to incorporate and estimate traditional energy carriers.

Inevitably, any research on pre-modern energy carriers is subjected to a high degree of uncertainty. We will see, however, that it is indeed possible to determine a range of magnitudes, and thus evaluate the contribution of these carriers. A range of magnitudes is already a good result when we are proceeding over untrodden ground, such as the quantification of pre-modern energy sources.

Here, I will not present information on candles or vegetable and animal oils employed in both public and private lighting. Their contribution to primary energy consumption would be negligible and its calculation better fits more specific studies[87]. Vegetable and animal oils lost importance in public lighting in the 1860s with the introduction of kerosene and coal gas[88]. Olive oil, however, remained an important source of lighting for rural households and could still be found in use, though in very small quantities, in the 1940s and 1950s[89]. Candles are the only item of artificial lighting still in use today when electricity is cut off, but especially for decoration and religious purposes. The subsequent sections will be devoted to the methodology and information available for firewood, wind, water, human and animal energy.

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[85] Madureira and Teives (2005).

[86] See Chapter 3.

[87] See Fouquet and Pearson (2006), who quantified those energy sources when studying energy use for lighting in the UK.

[88] Cordeiro (2007).

[89] Basto (1943); Barros (1947).

2.6 Food[90]

Modern statistics do not include food in their energy balance sheets. Nowadays, industrialized societies have a major part of the population employed in sedentary activities, and although an adequate nutrition is essential to survive and thus perform work, the work output, in terms of muscular power, is almost negligible. This was not true in pre-industrial years, when most of the population was employed in non-mechanized agricultural activities. At those times, the amount of muscular work one man could perform was usually compared with a horse or an ox. One draught animal would work at power rates of 500 to 800 W per hour while a man could not sustain more than 100 W per hour, making one horse or ox as valuable as 8 men[91].

There is some discussion on the manner in which one should account for food for human beings. For our purposes the aim is to include all the food intake of the whole Portuguese population, disregarding the amount that would be spent on working. There are some justifications for this methodology. Even if not all the food intake is spent while working, it is absolutely necessary for the labour force to receive nutrition to be kept alive between working hours. Even if a share of the population is not economically active, *i.e.*, the children, the elderly, the housewives, etc; they occupy positions in the society necessary for it to function[92].

I consider as *primary energy* all the digestible food that is available for consumption by the Portuguese population in a given year. This means that, for a matter of convention and comparability with the other books in the series, all animal derivates and meat will be accounted by their edible content, not accounting for conversions at the top of the food chain[93]. *Final energy* will be equal to *primary energy* minus wastage, that is, all the edible food that is effectively consumed by the population and not discarded as a residual. At the level of final energy consumption, all the extra food that is required to perform work should be distributed by productive sectors based on occupation data. On the other hand, all the food that is consumed for other motives than work- either by a working or non-working population- should be considered as household energy. Households are a final demand sector that is included in modern energy statistics in order to account for energy consumed for reasons other than

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[90] Appendix B, Table B1, col 1.

[91] Smil (1994).

[92] See Warde (2007) for a lengthy discussion on this issue.

[93] Hence the feed that is necessary to breed the domestic animals of the country involved in food production will not be accounted for, which will make figures somewhat smaller that in Kraussman and Harberl (2002), for example.

economic production. This includes all energy consumed at home to provide services such as heating, lighting, cooking, leisure or even personal transportation[94]. Households differ from other final demand sectors in the sense that their economic output equals zero, so interpretations of the shifts in energy intensity (energy consumption/GDP) should be handled with extra care.

There are several ways to approach the issue of human food consumption. One way of calculating food requirements is by the supply side, accounting for agricultural output and external trade. This was the way in which Food National Balances for mainland Portugal were done, starting in the year 1938, and produced on an almost yearly basis from 1947 onwards. This measure requires a certain level of sophistication as several corrections are required in order to reach edible consumption. Seeds, industrial uses, animal consumption, non-digestible food and stock variations have to be subtracted in order to obtain figures for edible consumption. With this method food wastage in the retail and household sector is considered as an *energy input*. In the Portuguese case, wastage is only likely to be relevant in recent decades. Back in time, food was not an abundant item, so discarding was not an option.

A desirable option would be to reconstruct Food Balances for the rest of the period (1856-1940). I have decided not to employ this method for two main reasons. First, production statistics are poorly covered. Before World War I, the most recent agriculture estimate is from Lains and Sousa[95]. The authors calculated an index of agricultural production value from 1845 to 1915, including production of wheat, rye and corn, wine, olive oil, meat and potatoes. Unfortunately, vegetables, milk, cheese, eggs, beans, fish and fruits are missing from this report. Batista et al. estimated agricultural GDP for the period 1910-1958, including more products, but adjustments would still be necessary to account for islands production. The way that some series were calculated (ex: fish, milk) reflects the absence of good national quality statistics for the period. Secondly, to the best of our knowledge, no one had systematically compiled import and exports figures for food products. It will take a long time to compile annual food figures for international trade with no certainty of better results. We would still have to make assumptions on the consumption of certain foodstuffs, on animal consumption and on the usage of food in the fabrication of industrial goods. The study of food consumption via the supply side will remain an open issue for Portuguese historians. Although I do not use this method here, taxation

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[94] For difficulties in dividing transport fuel in personal and economic activities, household transportation is in practice included in the transportation sector.

[95] Lains and Sousa (1998).

data for 1880-1910 can improve the knowledge of consumption of products like vinegar, vegetables, fish and animal products (milk, butter and cheese, for example)[96].

A second hypothesis would be to estimate food consumption through national direct inquiries. Such inquiries have been tried in Portugal, but most of the time at a local level, including few families. The majority of inquiries done before 1940 are summarized by Corrêa[97]. Conclusions are different, with some authors arguing that caloric intake was sufficient, others the opposite. The most significant survey, which took place in 1916-1917, was an inquiry into the household expenses of industrial workers families and average caloric consumption was recorded as 2 373 kcal/p.c./day[98]. The majority of the studies done in this period agreed that the Portuguese spent a large proportion of their income on food (60-70%) and that there was a huge deficit in animal proteins[99].

A third approach is to estimate food consumption through a set of population characteristics. Here, the most basic estimation is to hold an average per capita figure constant over time[100]. This kind of approach is mostly used when data is lacking, but it is dubious because it does not reflect the age and gender structure of the country or the level of activity, which can imply different food requirements. A simple way to overcome the first two problems is to convert the structure of the population into consumption units, giving different shares to population strata according to their age or gender. However, this second method still does not reflect the different working intensity of the labour population. A more sophisticated population method is to use the information generally available in the census, the food requirements according to sex, age and activity. This method is very useful to use in the absence of other data. It has a pitfall; it only indicates how much a society should consume, not how much it consumes. It ignores periods when the population was poorly fed, like in the times of wars or famine crisis. In the case of the Portuguese population, if applied to the present, it will indicate a lower consumption level than the real one, as wastage and obesity in the general population has increased. This means

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[96] See, for example, Administração Geral das Alfândegas e das Contribuições Indirectas, *Estatística do Real da Água e outros impostos indirectos,* (1888 to 1901). It includes, depending on the year, some statistics on beer production, vinegar, and fishing. It is interesting to check , only for Lisbon, Ministério das Finanças, Direcção Geral de Estatística (1916), *O ventre de Lisboa e os géneros que aqui pagam impostos de consumo ou Rial da Água*. Eggs, butter, cheese, olives and fruits are included in this report for the years 1890-1914.

[97] Corrêa (1951).

[98] Ministério do Trabalho, *Boletim da Previdência Social.* Also in Corrêa (1951), p.106.

[99] Corrêa (1951).

that the population has become less efficient in converting energy inputs into work output. However, if applied to earlier periods, I do not expect significant underestimations. Ideally this method should be used in conjunction with a supply method or food inquiries, for reason of checking-up, at least in some years.

The method employed here to calculate food consumption is then a mixture of two methods: a supply method and a population method. For 1938 onwards, employing linear interpolation in the missing years, we use the results of National Food Balances[101]. For 1961 to 2002 the average daily caloric intake figures are provided by Food and Agricultural Organization of the United Nations - FAO[102]. The figures derived by FAO follow the same method as National food balances. In these years, the average daily caloric intake of the Portuguese population varied from 2 470 to 3 740 calories. This data includes wastage in restaurants or at home, which in recent years has been high. However, wastage is a part of my definition of primary energy consumption.

For the period 1850-1938 I have followed a population method, adjusting for changes in economic activity, gender, age and physical composition. In the first place, I have calculated the *Basal Metabolic Rate* (BMR) of adult women and men. The BMR is an indicator that gives us the daily amount of calories that would be needed if a person with certain physical characteristics spent all day resting. The BMR should be multiplied by a *Physical activity level* (PAL), in order to give the total energy requirement. BMR depends exclusively on physical indicators (weight, height, age), while PAL depends on the nature of activities performed during the day. Several authors have suggested different formulas to calculate BMR. I have followed a recent joined report by FAO/WHO[103]/UNU[104] in calculating the BMR, which supports the use of Schoefield equations, proposed in 1985 for women and men[105]:

$$\textit{BMR male kcal/day (18-30 years old)} = 15.057 \times \textit{Weight (kg)} + 692.2$$

$$\textit{BMR female kcal/day (18-30 years old)} = 14.818 \times \textit{Weight (kg)} + 486.6$$

It is difficult to assess the weight of Portuguese population from 1850 to 1940. However, we have reasons to believe that it was lower than what is considered standard nowadays (70-75 kg). Just like cattle increased their weight

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[101] Campos (1977).

[102] FAO (2004).

[103] World Health Organization.

[104] United Nations University.

[105] FAO/WHO/UNU (2004).

as a result of better fodder intake, human size also increased with better nutrition. The military recruits measured in 1904 had a mean height of only 163 cm, one of the lowest in Europe[106]. By contrast the recruits examined in 1998 had a height of 172 cm[107]. Much of the increase in height seems to have occurred after 1960. In 1960 the Lisbon recruits measured 167 cm, only 4 cm higher than in 1904[108]. In 1960, the weight of Lisbon recruits was reported as 61 kg[109]. For our analysis we assume that the average weight of a Portuguese male was 60 kg, which seems to be consistent with the height evolution and Body Mass Index (BMI) figures and with the opinion of contemporaneous authors[110]. For women we have even scarcer information. We assume that the average BMR of a woman was 0.8 times that of a man, which is also consistent with their probable heights[111]. The BMRs proposed by Schoefield are adapted to the adult population in the case of males (which includes a proportion of 10-14 year-old children who worked, and were considered as adults); and from the age of 15 in the case of women[112].

The second step is to distinguish the physical levels of adult population by its occupation. Recently, authors have preferred to classify the Physical Activity Level (PAL) in relation to lifestyle intensities (and not specific occupations). We reproduce here the PAL values followed by the FAO/WHO/UNU in their 2004 study (Table 2.1).

Table 2.1 Physical activity levels according to lifestyle intensity

Category	PAL value
Sedentary or light activity lifestyle	1.4 - 1.69
Active or moderately active lifestyle	1.70 - 1.99
Vigorous or moderately active lifestyle	2 - 2.4

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[106] Padez (2002).

[107] Padez (2002).

[108] Padez (2002); Castro *et al.* (1998).

[109] Castro *et al.* (1998).

[110] BMI is a statistical measurement which compares a person´s weight and height (weight (kg)/height (m)) and is a tool to determine if a person is overweight (BMI > 25) or underweight (BMI< 18.5). See also Côrrea (1951) and Gomes *et al*. (1945).

[111] See Baten (2006) for an estimation of male heights in relation to females. According to the author Male height =24.9879 +0.9175 × female height. There are other indications that women´s weight was lower in previous periods in time. For example, the age at menarche (strongly connect with a weight of 46-48 kg) declined from 15 years (girls born in 1880-1890) to 12 years (girls born in 1970-1980), Padez and Rocha, (2003).

[112] Age structure was taken from Baganha and Marques (2001).

I have assumed a different PAL for different population occupations taking into account the indications of Table 1. Therefore, individuals working in the primary sector and construction works are assumed to have a vigorous or moderately active lifestyle; people working in manufacturing are assumed to have an active or moderately active lifestyle. The remaining population is given a PAL value that corresponds to a sedentary or light activity lifestyle.

In order to obtain total energy requirements, the figures for the adult population divided by occupation and sex are multiplied by the respective BMR and PALs[113]. Occupation PALs are considered during 300 days of the year. A PAL of 1.53, corresponding to sedentary population, was considered for the remaining 65 days. The distribution of PALs is only partially connected with the length of the working year. Reis assumed an agricultural year of only 200 days, but during the remaining days agricultural workers also performed strenuous physical activities as collecting wood or water, non-mechanic domestic activities, etc[114].

Table 2.2 Physical Activity Levels per occupation

Occupations	PAL
Agriculture, Fisheries, Mining and Forest, Construction	2.25
Manufacturing	1.76
Transports/Commerce/Administration and Defense	1.69
Services and Inactive Population	1.53

Finally, I employ the daily energy requirements of boys and girls under 15 as recommended by the joint report (Table 2.3).

Table 2.3 Daily energy requirements Boys and Girls (kcal)

Group age	Boys	Girls
0 to 4	1 129	1 035
5 to 9	1 450	1 325
10 to 14	2 175	1 925

Source: FAO/WHO/ONU (2004)

Benchmark results for some years in the period 1856-2006 are shown in the table below (Table 2.4).

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[113] Census figures given by Nunes (1989), Valério (2001) and Reis (2005).

[114] Reis (2005).

Table 2.4 Food intake per capita (1864-2000)

Year	kcal /day
1856-1878	2 268
1890	2 302
1900	2 276
1910	2 238
1920	2 228
1930	2 222
1938	2 202
1948	2 379
1961	2 473
1970	3 002
1980	2 786
1990	3 441
2000	3 751

Sources: see text

The results for the years 1864-1930 show an almost static level of per capita food consumption. As in other figures, major changes can only be observed from the World War II onwards. The improvement in income situation, an increase of obesity, height and wastage and the ageing of the Portuguese population offsets changes in the activity level.

Recent studies reveal that the status of Portuguese nutrition is not healthy. The results of a National Health Inquiry in 2003-2005 showed that 38.6% of adults (males and females) were overweight and 13.8% were obese[115]. It was recently estimated that about two thirds of the children were overweight/obese, a percentage that seems to be the second highest in Europe, only behind Italy[116].

2.7 Firewood[117]

Inedible plants have been combusted by human societies since the Palaeolithic Age. Until the discovery of fossil fuels, firewood was almost the only source of energy that provided heat for the population and industries[118]. In

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[115] Carmo *et al.* (2008).

[116] Padez *et al.* (2004).

[117] Appendix B, Table B.1, col. 2 and Table B.3.

[118] With the major exception of peat.

developing countries, biomass still accounts for about 75% of final energy demand[119].

Firewood is one of the traditional sources of energy in which quantification is subject to the highest degree of uncertainty. Food consumption is normally limited to a fixed degree of variability; wind and water energy consumption is very small when compared with total consumption. Wrong firewood consumption figures, on the other hand, may compromise very easily an otherwise correct figure for total energy consumption. In fact, biomass consumption per capita in early modern Europe could vary from 12.5 to 125 MJ/per capita/day depending on climatic conditions, accounting for 25 to 80% of total primary energy consumption[120]. The risk of seriously under or overestimating energy consumption is of course higher in countries where firewood has a major importance; and among those where most of the consumption is not recorded by the market. Average per capita firewood consumption figures are harder to obtain if most of the fuel is consumed by households, if there are major regional differences in patterns of consumption and if a certain amount of charcoal, dung and crop residuals is also consumed.

Firewood consumption can be estimated by the demand side or the supply side. In Europe, there are well known attempts to estimate firewood consumption from the supply side or demand side, according to the available data. For Sweden, Kander[121] preferred to make an estimate based on the demand side, due to a very good data set on the industrial sector and because household firewood consumption figures were available for a set of benchmark years from the beginning of the twentieth century. For the nineteenth century, the author was able to reconstruct household firewood consumption based on assumptions related to equipment efficiency, number of heated rooms and statistics on urbanization and migration figures that changed the South/North population. For England & Wales, Warde adopted a different method based on recorded and estimated yields of firewood cutting on woodlands, standing trees and hedgerows[122]. Malanima used estimations from economists in different benchmark periods but included some demand benchmarks in the recent years of his series in order to calculate the Italian consumption[123]. The most serious problem with the demand side concerns the availability of disaggregated data, while the most serious problem with the supply method is related to the

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[119] Victor and Victor (2002).
[120] Malanima (2006b).
[121] Kander (2002).
[122] Warde (2007).
[123] Malanima (2006a).

difficulty of knowing precisely the extension of biomass coverage, yields of woodlands and proportions of firewood versus wood cuttings.

For Portugal, adopting land-use areas as a ceiling for the maximum firewood consumption in the country is rejected. First, we have few benchmarks for land use and forest yields[124]. Second, most of the firewood did not come from conventional forests but from the commons or wastelands (in the form of fallen biomass). It is an inglorious task to know precisely the size of the unconventional forest, but it is clear that it was considerable. Table 2.5 indicates some of the few benchmarks for land usage that are available for mainland Portugal.

Table 2.5 Land use in Portugal (mainland), benchmark years, thousand hectares

	1867	**1902**	**1926-1930**	**1951-1956**	**1980**
1.Arable	1 886	3 111	3 283		
2.Pastures, fall and heaths	2 072	1 922	1 560		
3.Agriculture (1+2)	3 958	5 033	4 843	4 833	
4.Forests	1 240	1 957	2 332	2 773	3 047
5.Productive (3+4)	5 198	6 990	7 175		
6.Wastelands	3 329	1 538	1 353	1 094	1 296
7.Social	351	340	340	152	
Total	**8 868**	**8 868**	**8 868**	**8 852**	

Source: Lains and Sousa (1998); Fabião (1987); Marques (1991).

Conventional forest grew to more than twice its value from 1867 to the 1950s, following the increase in population, representing 13% of the territory in 1867 and 31% in the 1950s. However, trees and bushes also grew elsewhere. Arable land also included fruit trees such as vines, olives or hazelnuts which could be partially used to satisfy the needs of the population. On the heaths, *charneca*, covering a large part of the non-arable south of the country, there were cork and holm oaks that supplied most of the charcoal to the capital. In the category of wastelands, considered non-productive territory, and covering 38% of the area of the country in 1867 and 17% in 1902, were included many communal forms of property, from where the rural population, mostly from north-central Portugal, freely collect firewood for their household needs.

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[124] A study performed by INE for the years 1938-1963 indicated annual yields per hectare varying from a minimum of 2.3 m^3/ha in 1938 to a maximum of 2.9 m^3/ha in 1963. See INE (1966).

It is not surprising then, that the few firewood or wood figures extrapolated by agrarian engineers or policymakers at some point of time seem clearly underestimated when contrasted with demand side figures[125]. So the figures that they achieve are closer to the industrial and urban consumption than to the total consumption in the country[126].

In contrast to the supply-oriented approach, richer sources advise the use of a more demand side approach. Total firewood consumption in a given year can be calculated applying the general formula:

$$F_{(t)} = fH_{(t)} + f\,I_{\ (t)} + fTr_{\ (t)} + fEp_{\ (t)}$$

Where:

F Total Firewood consumption
fH Household firewood consumption
fI Industrial firewood consumption
fEp Firewood consumption as a fuel for electricity production
fTr Firewood consumption in the transportation sector
t year

There are various subtypes of wood that can be used as fuel, with different energy contents. I only distinguish charcoal from firewood. Firewood energy content was set in 3 000 kcal/kg[127]. Charcoal is a secondary energy, made from firewood. As the goal is to estimate the primary energy consumption, we measure charcoal consumption as the amount of firewood that was necessary to

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[125] One of the examples is the INE study for calculation of wood extraction (not disaggregated by uses) in the 1938-1963 period. Production varied from 7 million m^3 in 1938 and 9.4 million m^3 in 1963. Firewood and wood consumption in the mainland was about 0.92 m^3 per capita in 1950 and 1 m^3 in 1950, or 1.5-1.7 kg per capita a day. As a ceiling it seems extremely low when compared with my figures from the demand side, which only include firewood. If the same exercise is conducted for 1867, a per capita figure of only 0.67 m^3 per capita will be reached, an implausible value, see INE (1966).

[126] For 1938 and 1947-1950, my demand side estimates of commercial firewood consumption (manufacturing, urban households) represent 27% and 36% of the estimated figures for wood extraction by INE (1966). However, if my rural firewood consumption estimates are included, we see that conventional forests could only in maximum (assuming that 100% of the wood cuttings are for firewood, which is implausible) supply 70 and 80% of the firewood demand.

[127] As indicated in national energy balances. The energy content of firewood is equal to the one applied by Malanima (2006a) to Italy. The energy content of the firewood employed in the electrical utility of Lisbon in World War II was approximately 3 000 kcal/kg (CRGE, *Relatórios da Central Tejo*). Early studies of the average energy content of Portuguese biomass also confirm the chosen firewood energy content (Carvalho, 1964). Early industrialists seemed to be more sceptical, as four firewood tonnes were reported to be needed to substitute one coal ton (MOPCI, *Inquérito Industrial de 1881*), but this could be due to the fact that steam engines were optimized to consume coal.

fabricate it. An experience of charcoal production made in the 1920s with different wood species showed that about 5 tonnes of wood were needed in order to produce one tonne of charcoal[128]. Charcoal production was more efficient in Portugal than in other parts of the globe. In Italy, the firewood needed to produce charcoal is assumed to be 5.5 tonnes for each tonne of charcoal[129]; in Uruguay charcoal production required 7 tonnes of firewood[130].

2.7.1 Household firewood consumption

Household firewood consumption is perhaps the most difficult source of consumption to determine. Today, a major energy issue in developing countries is to determine accurately the level of residential firewood use. For these countries it is crucial to know not only the level of firewood use, but also firewood expenditures, major firewood consumer groups, etc, in order to implement correct energy policies or to test the effect of the same policies. These energy policies can be of different order. Some tend to promote the use of modern and convenient energy carriers, some address indoor pollution problems; others focus on energy efficiency by easing the access to efficient stoves[131]. Some policy makers are worried with biomass stocks and require energy figures in order to implement supply policies. There is also a purely statistical concern in calculating firewood consumption that can result in major revisions of energy use, household income and GDP figures.

Accounting for firewood use is difficult to achieve from the supply side, as most of the firewood is collected from a nearby area by family members. Most of the firewood consumption is extrapolated by a range of surveys. This is also difficult as most of the consumers do not know precisely how much firewood they consume. Firewood figures are normally given as volumes, but metric volume measures are rare. Usually it is given in ox carts, but a different set of traditional measures that nobody knows precisely how to convert to calories or GJ are often used[132]. The inquirer has to deal with the fact that rural consumers have a poor educational background and cannot give accurate answers. However, most of the statistical institutions of these countries are becoming

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[128] Lopes (1929).

[129] Malanima (2006a).

[130] Bertoni and Róman (2006).

[131] Elias and Victor (2005).

[132] Bhatia (1987).

increasingly aware of these problems. As a result, better figures are being produced for a wide range of countries[133].

Firewood consumption figures in developed countries are perhaps even more poorly established. Basically, for a long period of time, firewood was not recorded because it was not relevant for energy policies. It was assumed that firewood use was basically a residual and not worth accounting for. Most of the rough accounts assumed that the market was providing most of the firewood, so firewood consumption is accounted for based on firewood market supplier's reports or expenditures surveys. Some European countries discovered only 10 or 15 years ago that household firewood consumption was clearly underestimated. Portugal was one of these countries. From 1971 to 1989, the series of energy balance sheets assumed a residential firewood consumption of 400 - 600 thousand toe (tonnes of oil equivalent). However, two major energy-specific household inquiries conducted in 1988 and 1995 tripled this figure. A 66% underestimation of firewood consumption was found in 1999 in Italy when the results of a telephone inquiry determined that 22% of Italian families still relied on firewood[134].

Concerning the estimates for Portuguese households' biomass consumption, we have to rely on both qualitative and quantitative evidence.

Until the end of World War II most of the Portuguese population lived in rural areas. From 1864 till 1950 there was no strong change in population distribution. In 1864, 88% of the Portuguese population lived in rural areas; in 1950 the share declined to 77%[135]. Approximately 2/3 of the labour population was engaged in agriculture in 1950, a proportion not substantially different from 1890. Lisbon and Oporto were the two main urban centers, the only ones with more than 100 000 inhabitants in 1940, accounting for approximately 90% of the urban population[136].

Energy consumption patterns varied widely between rural and urban populations. I have decided to consider three major groups of consumers in my estimations: Rural, Lisbon, Oporto and remaining urban areas. Qualitative descriptions and quantitative figures from the rural areas in 1950 give an idea that standards of living were low. Most of the rural population did not have access to electricity, gas, plumbed water or sewage[137]. An open fireplace and a firewood oven were the only equipment of the Portuguese rural house. The

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[133] See Victor and Victor (2002).

[134] Malanima (2006a); ENEA (2001).

[135] Silva (1970).

[136] Silva (1970).

[137] For example in 1950 only 8% of rural population used electricity; none used gas. INE (1954).

houses lacked mortar and glass windows and it was frequent to have fissures in roofs, walls and doors[138]. Those who did not own woods either searched for firewood in wastelands and surrounding hills or “stole” it from neighbouring properties, with the tolerance of their owners. Urban areas of Lisbon and Oporto contrast with rural areas in energy conditions. In Lisbon, in the middle of the 18th century, the houses that were built after the earthquake did not incorporate fireplaces, probably for safety reasons[139]. Charcoal, instead of firewood, was the major fuel in Lisbon in the beginning of the 19th century. Energy transition in those two cities occurred at an earlier date due to several reasons: access to the sea, this is, foreign coal and kerosene; considerable distance from firewood suppliers; earlier adoption of town gas and electricity (potential firewood substitutes). The remaining urban areas can be considered a third distinct group in firewood consumption patterns. Although gas and electricity usage in cooking or heating was an exception in the 1950s, it is presumed that urban dwellers were likely to use less firewood than rural dwellers. The better insulation of urban dwellings, the use of more efficient equipment, and the need to acquire the fuel in the market are some of the reasons for this assumption.

The way I calculate residential firewood consumption until the year of 1950 is expressed by the following formula:

$$fH_{(t)} = Lx_{res.\ cons.\ pc\ (t)} \times Lx\ Pop._{(t)} + Op_{res.\ cons.\ pc\ (t)} \times Op\ Pop._{(t)} + \\ Rural_{res.\ cons.\ pc\ (t)} \times Rural\ Pop\ (t) + OUA_{res.\ cons.\ pc\ (t)} \times OUA\ Pop._{(t)}$$

Where:

fH	household firewood consumption
Pop	population
res.	residential
cons.	consumption
pc	*per capita*
t	year
Lx	Lisbon
Op	Oporto
OUA	other urban areas

We can follow the sources for each region in the following pages.

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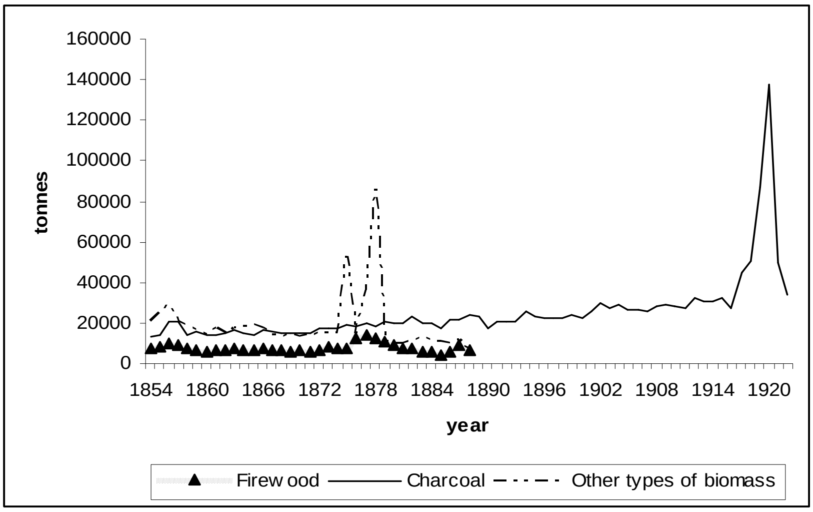
[138] Basto (1943); Barros (1947); Oliveira and Galhano (2003); Vasconcellos (1983).

[139] Couto (2000). On the first of November 1755 a major earthquake, followed by a tsunami, destroyed the downtown Lisbon and claimed several thousand victims. This earthquake was followed by a major fire, which caused the majority of the injuries.

2.7.1.1 Lisbon

Until 1922 the city of Lisbon was subjected to a consumption tax that included, among other products, charcoal, coke, vegetable oils and firewood. Charcoal is the only energy carrier that is covered in all of this period. For 1854 until 1888 there are records of different subtypes of firewood, but taxation of these products came to an end in June of 1888. This tax should represent accurately what was consumed in the city, as the city did not have any relevant forests. Most of the charcoal and firewood would enter into the river ports or train stations where strategic polls were located, so no serious under registration happened[140]. Figure 2.1 presents the raw results of this tax for the years 1854-1922, expressed in tonnes[141].

Figure 2.1 Firewood and charcoal consumption in Lisbon (1854-1922)



Source: *Mapa Estatístico...*(1854/1855 till 1865-1866); *Estatística da Alfândega...* for 1866-1867 to 1888-1889. Ministério da Fazenda,..., *Consumo em Lisboa: estatística dos géneros sujeitos à pauta dos direitos de consumo: anos de 1891 a 1907*, Lisboa: Imprensa Nacional. Ministério da Fazenda,.., *Consumo e real de água: Lisboa e Porto* (for 1908-1922). Conversion measures (until 1884-1887): charcoal bag 98.5 kg[142]; “talha de pinho”, 307 kg, “faxina de lenha” 19 kg, “talha de carqueja” 232.5 kg; “talha de tojo” 120 kg (*Pauta de 30/06/1867*, *Estatística da Alfândega Municipal no ano económico de 1867*)[143].

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[140] The city had also terrestrial polls where compliance could be worse. This was the case with some foodstuff products such as olive oil.

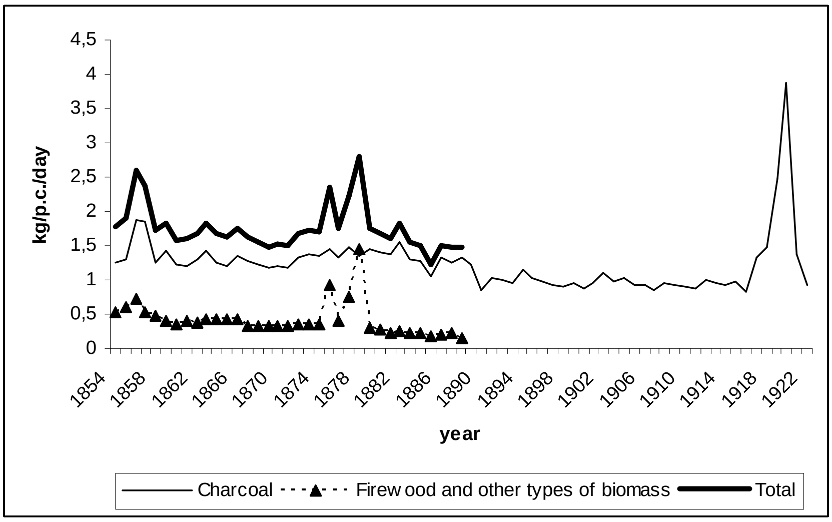
[141] Here, I have not done an energy conversion.

[142] Simply the average of the values indicated for the conversion of a charcoal (cork tree) bag (dimensions 1.15 m height and 0.76 m large or 1.32 m height and 1.10 m large) in kg, on 30/06/1867 (*Estatística da Alfândega Municipal no ano económico de 1867*). There are some doubts as to whether the true value of the bags changed according to the epoch. Gonçalves (1922) reports 90 kg.

[143] The bulk of the sources related with this tax can be found in the archives of INE, in Lisbon.

Not all the Lisbon inhabitants were covered by the consumption tax when the Lisbon area was enlarged in 1886[144]. I took this fact into account when calculating the population subjected to this tax[145]. Figure 2.2 shows the per capita values of both charcoal and firewood. This time, charcoal figures are converted into primary figures, to account for the amount of firewood that it took to produce.

Fig 2.2 Firewood consumption per capita and per day, Lisbon, (Primary energy)



The figure shows a steady decline of firewood consumption from the 1870s[146] and charcoal consumption from the 1890s. During WW I (and immediately after) charcoal consumption rose to a record of 3.8 kg/p.c/day reflecting a serious supply crisis of fossil fuels. Firewood and other types of biomass represented 20-30% of total consumption in the 1860s and 10-15% in the 1880s.

It is possible to compare the firewood requirements of Lisbon city with the ones registered in other pre-industrial European cities. From 1854 to 1888 firewood consumption in Lisbon was about 1.8 kg/p.c./day. In Madrid, in the end of the XVIII century consumption was about 2.15 kg/p.c./day[147]. Lisbon

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[144] *Relatório apresentado à Administração Geral das Alfândegas pelo Director da Alfândega do Consumo, António de Sousa Pinto de Magalhães, àcerca dos serviços da mesma casa fiscal* (1886).

[145] It took some years to finalize the construction of the new polls. We distributed the sudden gain of population in 1886 for the forthcoming decade in order not to bias the levels of charcoal consumption. Therefore, our population figures represent 90% of Lisbon urban population by 1890.

[146] With the exception of some years, when "carqueja" (a plant used to ignite fire) is causing a strong increase in biomass figures.

[147] Warde (2006).

also compared well with the results obtained to the 18th century in Italy: from 2.3 kg in Piedmont to 1 kg in Sicily[148].

To build a per capita series of household consumption of firewood for Lisbon in the period 1856-1922, I have used a strong assumption. Firewood and other types of biomass have not been considered since they are only covered for the period of 1856-1888 and they are believed to be an expression of industrial consumption. On the other hand, charcoal is assumed to be consumed only by the household sector. This is of course a simplification, as some households could consume firewood and some industries could consume charcoal. There are some reasons to assume this division that go beyond the mere convenience of the available data set. There are no complete industrial inquiries for those dates that can definitely resolve this question. However, none of the 75 factories of various branches visited by an Industrial Inquiry Commission in 1881 reported the use of charcoal[149]. While in other countries, like in Sweden, charcoal was widely used in iron works, Portuguese industries that worked with iron reported the use of coal and coke, but not charcoal in that 1881 Inquiry. Tailors were known consumers of charcoal but there was no potential benefit for other industries to use this fuel, as it was more expensive than both firewood and coal per energy unit. On the other hand, some of the ceramic and glassworks reported the use of firewood. Bakeries may also be appointed as a major consumer group, although they are not reported in this survey. A majority of Lisbon dwellings, as already stated, did not have fireplaces. Contrary to industry, there was a health and hygienic benefit from the use of charcoal, as charcoal is less smoky than both firewood and coal.

We have ways of connecting the 1854-1922 series with other sources. An inquiry was conducted in 1938-1939 by INE on the household expenses to a sample of one thousand families[150]. The goal of this inquiry was to update prices per weight at a regional level. Several energy products are included in the final report: coal (both mineral and vegetable)[151], gas, electricity and kerosene. As the report does not distinguish between mineral coal and charcoal, some rough calculations have to be made. We know from other studies that most of the

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[148] Malanima (2006a).

[149] MOPCI, *Inquérito Industrial*, 1881.

[150] INE (1942).

[151] It is confusing when we are referring to charcoal or coal in Portuguese. Charcoal means “carvão vegetal” and coal means “carvão mineral”. If we use the word *carvão* in Portuguese (literally translated: coal) this can be both charcoal and coal. This means we have to be careful with the wording in the inquiries. In this case the word *carvão* is used. The author of these inquiries – INE – uses charcoal (from cork oak) prices in order to calculate expenses with “carvão”, but is stressed that there are other coal/charcoal qualities.

mineral coal consumed in Lisbon came from gas works[152]. Based on the coke production figures of the Lisbon gas factory, it is assumed that 25% of the total coal (charcoal and mineral) reported by the inquiry was of mineral origin[153]. For 1922 (0.97 kg/p.c./day) to 1938 (1 kg/p.c./day), I have taken into consideration the variation in the charcoal quantities transported by railways by the railway lines that supplied Lisbon[154]. Lisbon's consumption represented an important share (about 60%) in total shipments of this train route[155].

During the season 1948 - 1949[156], INE conducted another inquiry with the same goals as the 1938 one. Charcoal consumption had dropped from 1 kg/p.c./day in 1938 to 0.43 kg/p.c/day, a result of an increase in gas and kerosene consumption. The data concerning the years 1938 and 1948 is connected by linear interpolation. The same *per capita* consumption *of 1948 - 1949* is assumed for 1950.

2.7.1.2 Oporto

Per capita consumption is assumed to be the same as in Lisbon for 1856-1938, since there is no data available for Oporto, the only other large city in Portugal. The 1856-1938 series is connected to a household expenses' 1950 inquiry conducted by INE in Oporto. Charcoal consumption in 1950 (1.1 kg/p.c./day) was higher than in 1948-1949 (0.43 kg/p.c./day)[157]. It is assumed that this divergence appeared after 1938, as a result of a more rapid energy transition in the capital[158].

2.7.1.3 Other urban areas

Three surveys were conducted by INE in the mid 1950's for the cities of Évora, Viseu and Coimbra[159]. Families bought on average 900 – 1200 kg of firewood a year (expressed in primary energy). As we are already in the midst of

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[152] Teives (2006).

[153] We can attest that charcoal continued to be the main solid fuel of the Lisbon population for two reasons: 1) Magnitude of charcoal quantities dispatched to Lisbon by railways; 2) Existence of price indexes for charcoal, non-existence of coal price indexes and intermittence in coke price indexes.

[154] Quantities are given in Companhia dos Caminhos de Ferro Portugueses, *Estatísticas dos Caminhos de Ferro.*

[155] Share which was obtained comparing the charcoal quantities transported during the years of 1913 and 1914 in the two railway lines (48 thousand tonnes) with the charcoal quantities subjected to taxation in those years: 31 thousand tonnes.

[156] INE (1953).

[157] INE (1955).

[158] For the history of energy transition during the WW II see Teives e Bussola (2005), and Teives (2006).

[159] INE (1958); INE (1960b), INE (1963).

the energy transition that occurred after WW II, I just taken these values as a reference for modelling the period 1856-1950[160]. Firewood consumption was assumed to be 430 kg/p.c./year (1.17 kg/p.c/day) until 1925, decreasing linearly from 1925-1938 to account for some kerosene substitution until it reached 410 kg/p.c./year (1.12 kg/p.c./day) in 1938, remaining constant afterwards until 1950.The per capita figures are almost similar to the Oporto ones in the 1950-1951 period.

2.7.1.4 Rural areas

In the 1930s, 1940s and 1950s, some monographic inquiries on rural households were conducted by agronomists in the rural areas of Portugal[161]. Among other questions, families were also asked on how much firewood they consumed[162]. Those figures were normally given in oxen carts. I have converted them into kilograms; one cart being equivalent to 500 kg of firewood[163]. This leads to an average of 857 per capita/year, or 2.4 kg/p.c/day. The same value is assumed for the rural population during the entire period since, even in the 1950s, firewood was the only fuel used for cooking and heating. This constant number relies on the assumption that there were no major changes in the efficiency of equipment. This is likely as the description of a rural house interior in 1950 confirms the use of open fireplaces.

Residential energy transition to modern fuels was particularly impressive in the post-war years. In Lisbon there was an increase of gas consumption leading to the quick disappearance of charcoal, the major fuel. In Oporto and Centre-North urban centers there was a major fuel switch from firewood, kerosene and charcoal to electricity. In the rural areas, there was a slow but persistent change to butane.

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[160] Transition was very quick in the city of Faro, reporting only 60 kg p.c./year in firewood equivalents in 1960, see INE (1970).

[161] Basto (1943); Barros (1947); Sousa (1946); Silva (1989); Suspiro (1951); Garcia (1959); George (1940); Silva (1947); Barbosa (1940). These and other similar works can be found in the archives of the Agronomy Faculty, Technical University of Lisbon.

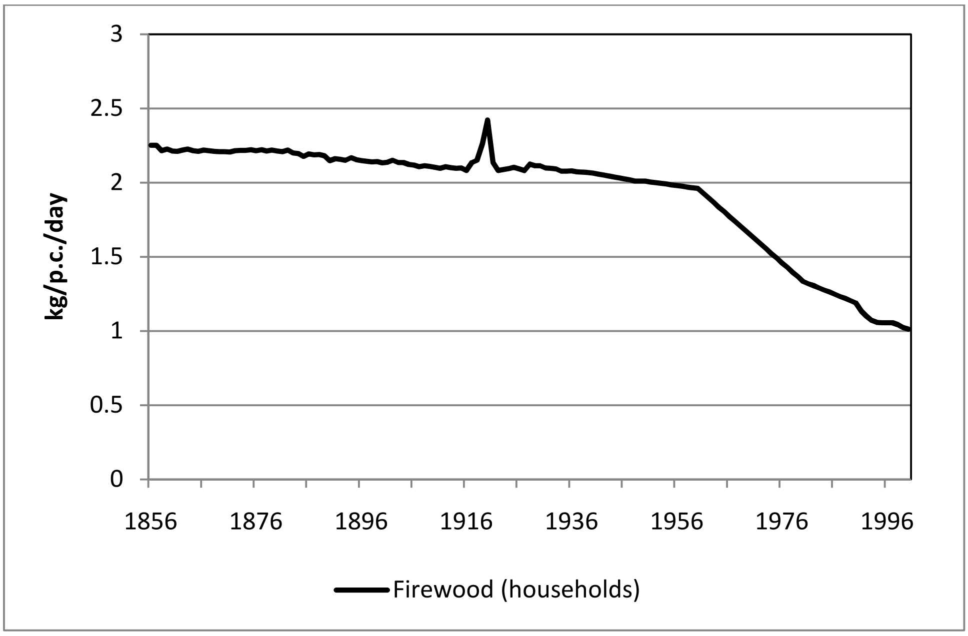
[162] While there is much information on household expenses with heating and lighting there is little information on energy quantities. I managed to compile 65 monographs that had references to energy quantities. The bulk of quantitative responses on firewood consumption can be found in Basto (1943) and Barros (1947). The information was complemented with the studies of Suspiro (1951) and Garcia (1959). The families included in the estimation are from the Northern and Central rural areas of Portugal, where the vast majority of population lived.

[163] It is important to stress that oxen-cart-weight figures are subject to uncertainty. I have used a figure that is similar to the oxen cart in the Oporto region. Higher estimates may be produced with a greater and also plausible weight (800 kg). We prefer to risk underestimation of firewood consumption than overestimation, as both figures give high shares of firewood consumption.

Two major studies on household energy consumption were directed by the national energy agency (DGE) in 1988 and 1996[164]. These studies form the basis for recent estimates of firewood quantities. In the past, household firewood consumption had been estimated by reports from the production sector according to firewood sales figures. The DGE reports were far more accurate than the previous estimates, which were proven outdated and underestimated. Their inquiry in 1988 showed that sales were a poor indicator of firewood consumption: 45% of the population used firewood but only 30% of the firewood quantities were bought. Among users, consumption was rather high, at the level of 3 661 tonnes per family and 3 kg p.c./day. These values make me believe that figures for firewood consumption in rural areas before 1950 are not overestimated despite the fact that conventional forest statistics do not agree with these estimates.

The DGE gives the average of about 1.19 kg/ p.c./day in 1990 and of 1.01 kg/day in 2000 on their balance sheets[165]. These series are connected to the 1950 figures (2 kg/p.c./day), on the basis of decade variation of butane sales, 1950-1960, 1960-1970, 1970-1980 and 1980-1990[166].

Figure 2.3 Firewood consumption per capita 1856-2000, kg/p.c./day



Sources: see text

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[164] DGE (1989), DGE (1996).

[165] The figures of DGE are somewhat lower than the ones in the surveys. For example, the 1988 survey indicates 1.38 kg/p.c./day.

[166] CIDLA, *Relatório e Contas*...; Sain (1959); Ayash (1970) and DGE, *Balanços Energéticos*. Butane has been reported as the main substitute for firewood consumption after 1950. See Teives (2006).

Figure 2.3 presents the evolution on firewood per capita consumption during the 19th and the 20th centuries. Firewood consumption per capita declined by more than one half in relation to 1950. The importance of firewood within the Portuguese households at present is very high. From all the countries in the EU-15 (at the time), Portuguese families were the ones with a higher share of firewood consumption in final residential energy (42%), followed by Austria (21%), Finland (18%) and Spain (17%)[167].

2.7.2 Industrial firewood consumption

Energy balance sheets provide information on firewood consumption by main industrial branches from 1971 to 2006. The main industrial consumers in 1971 were the glass and ceramic industries and food industries, accounting for more than ¾ of industrial consumption. Textiles, paper, wood and cork are the other major consumers[168]. For 1943 to 1970, energy consumption of main fuels (including firewood) is reported by branch in Industrial Statistics[169]. Data from 1943 to 1970 cannot be used without corrections, as total industrial production is poorly covered. Adjustments for industrial production have been made in GDP historical reconstructions by growth accounting economists such as Batista *et al.* (1997). However, due to the fact that coverage of GDP may be different to coverage of intermediate consumption, I adjust the statistics by comparing branch by branch the figures for electricity consumption given in Industrial Statistics with the ones of industrial electricity consumption in Electrical Utilities Statistics, which are considered to be very complete. This is done for a set of benchmark years: 1943, 1948, 1953, 1958, 1963 and 1968. In the case of a homogenous industrial branch it is possible to assume that electricity coverage is approximately equal to firewood coverage. Below, I present the results for each branch, as sometimes I take into consideration other factors in the correction.

2.7.2.1. Ceramics and glass

Coverage in electricity consumption is checked in the glass industries and ceramics and cements against a set of benchmark years. The coverage of Industrial statistics is good. Nevertheless, I have corrected the raw data in order to take into account small differences (see Table 2.6).

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[167] Griffin and Fawcett (2000).

[168] DGE (1986).

[169] INE, *Estatísticas Industriais*.

Table 2.6 Firewood consumption in Clay and Glass Industry

	Coverage electricity consumption in Industrial Statistics (%)					
	1943	**1948**	**1953**	**1958**	**1963**	**1968**
Glass	83	87	99	97	97	96
Ceramics, cement	89	89	92	93	95	88
	Firewood consumption (1000 tonnes)					
	1943	**1948**	**1953**	**1958**	**1963**	**1968**
Raw	309	296	249	307	369	554
Corrected	359	333	265	328	388	625

Sources: see text

2.7.2.2 Textiles

In the first years of industrial statistics, the textile industry is clearly underestimated in terms of electricity consumption. However, in this case the underestimation of firewood consumption is lower than that of electricity consumption because an important branch, the cotton industry, is missing until 1950. Electricity shares of the cotton branch in the textile industry are much higher than its firewood shares. The chosen option is to change the firewood consumption in the cotton branch in the same manner as the rest of the sector for the 1943-1949 period. After this procedure, I still adjust for firewood consumption in 1943-1953 to account for energy coverage (85%). In 1958, coverage of electricity consumption was 99%.

Table 2.7 Firewood consumption textiles

	Firewood consumption (1000 tonnes)					
Textiles	**1943**	**1948**	**1953**	**1958**	**1963**	**1968**
Raw data	49	58	87	88	102	167
Corrected data	83	119	101	89	102	167

Sources: see text

2.7.2.3 Cork and wood

For 1949 to 1970, coverage of firewood consumption is assumed to be 60%. Cork was not represented before 1948, so I have made a correction to include cork firewood consumption, based on cork production figures.

2.7.2.4 Paper

I have applied a coverage coefficient of 90% for the whole period, equivalent to the electricity consumption coverage in this industry.

Table 2.8 Firewood consumption: Cork and wood industries

	Firewood consumption (1000 tonnes)					
Cork and wood	**1943**	**1948**	**1953**	**1958**	**1963**	**1968**
Raw data	11	17	33	38	71	43
Corrected data	50	54	50	63	118	72

Sources: see text

Table 2.9 Firewood consumption: Paper industry

	Firewood consumption (1000 tonnes)					
Paper	**1943**	**1948**	**1953**	**1958**	**1963**	**1968**
Raw data	59	33	22	28	30	56
Corrected data	65	37	24	31	50	61

Sources: see text

2.7.2.5 Food industries

The food industries are clearly underestimated. In 1953 there is a strong increase in the number of branches covered[170]. From 1953 to 1958, the branches included in 1943-1948 accounted for only 40% of firewood consumption in the sector. I assume that the branches entered in 1953 already existed but were not reported in the Industrial Statistics. I have made a first correction in order to incorporate those branches, assuming that the share of firewood consumption in the 1943-1952 periods was equal to the one in 1953-1958. Still, for 1958 the electricity coverage is only 70%. The report on bakeries' consumption appears in 1971. This industry is responsible for 77% of firewood consumption in the food sector, but for only 7% of electricity consumption. I adjust the coverage to be 77% for 1943-1958 and 81% from 1963 to 1970, and apply this ratio to rectify food consumption (excluding bakeries). Bakeries' energy consumption is

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[170] Branches included by date: rice husking/peeling(1943), grain milling (1943), sugar refining (1944), canned fish (1944), beer (1943), milk (1944), chocolate (1948), cigarettes (1943), sausages (1955), mineral water (1953), cookies (1953), sweets (1953), roasting (1953), pasta (1954), powders and yeasts (1954), spirits (1953), spirits oil (1954), olive oil refining (1953), animal food (1953), table waters (1953), bakeries (1971).

calculated from 1943 to 1970 by and index of flour consumption[171]. The following table shows the raw and the corrected data for benchmark years.

Table 2.10 Firewood consumption food industries

Food industries	Firewood consumption (1000 tonnes)						
	1943	**1948**	**1953**	**1958**	**1963**	**1968**	**1971**
Raw data	77	31	89	87	59	66	69
Corrected data	457	101	117	113	69	82	69

Bakeries	Firewood consumption (1000 tonnes)						
	1943	**1948**	**1953**	**1958**	**1963**	**1968**	**1971**
Raw data	n.a.	n.a.	n.a	n.a	n.a	n.a	235
Corrected data	178	180	192	193	207	222	235

Sources: see text

2.7.2.6 Other industries & charcoal

Firewood consumption in other industries has been compiled but is not corrected. Its proportion varies between 1 and 7% of total firewood consumption. A small series for charcoal consumption by industrial manufactures exists for the years 1943–1952 but is not included due to methodological difficulties[172].

There are no industrial surveys that can help us in the estimation of industrial firewood consumption before 1943. Qualitative evidence indicates that firewood was employed in steam machines in rural areas where transportation costs would have made coal a very expensive fuel[173]. Industrial firewood consumption represented only 12% of household energy consumption in 1950. The evolution of industrial indexes in the period 1850-1950 suggests

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[171] Which can be found in INE, *Estatísticas Industriais*, 1943 to 1970.

[172] Charcoal is included with mineral coal from 1958-1970 and it is not disaggregated or converted into primary energy requirements after 1971. Annual average charcoal consumption (tonnes) 1943-1947: 21 984; 1948-1957: 13 745.7 tonnes; INE , *Estatísticas Industriais*, several years.

[173] MOPCI, *Inquérito Industrial de 1881*. Motor reports from the South of the country (Algarve and Alentejo) indicate that in 1905 36% of the motors consumed firewood and 20% consumed firewood and coal. In 1913 the percentage of motors that used both coal and firewood had declined to 42%. A national steam generator inquiry showed that 17.1% used coal, 34% firewood; 3% residuals, 6% both coal and firewood, 39% unknown fuel in 1927, see Santos (2000).

that this proportion was even lower in the past. I have applied a rough measure to estimate firewood industrial consumption for the period before 1943. For 1910-1942, I have varied firewood consumption according to the GDP of each industry[174] and as a proportion of total industrial GDP[175] for the period prior to 1910. This method assumes the same firewood intensities for each branch during 1910 and 1942; and the same global firewood industrial intensity for the period 1856-1909. The results give only 76 thousand tonnes in 1856. Lisbon firewood consumption in that year was reported to be 30 thousand tonnes.

2.7.3 Transportation

Only during World War II did the railways use firewood due to shortage of mineral coal. The total tonnage consumed by the railway sector is reported by INE[176]. Firewood consumption was registered from 1942 to 1952, being expressive until 1947. In 1943, one of the worst years for foreign supply, firewood represented ¾ of fuel consumption on railways. Reports of charcoal production for use by wood gas generators in internal combustion engines are also included for 1943-1947[177].

2.7.4 Firewood as a fuel for electricity and gas production and cogeneration

Firewood was not a main fuel for power production but shortages of coal lead to a heavy consumption during the First World War. The daily reports from the Lisbon electric plant (1914-1918) and the annual reports of Oporto (1917-1918) electric plant on firewood consumption are used to estimate firewood used for electricity production during those years[178]. Thus the amount of firewood used for electricity production in the two cities was multiplied by the inverse of their share in total production[179] (1/0.5) to reach a figure of total firewood consumption used in Portugal during First World War. Firewood was also distilled during the years 1918-1920 in order to produce town gas in Oporto

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[174] Batista *et al.* (1997).

[175] Lains (1990).

[176] INE, *Anuário Estatístico,* several years.

[177] INE, *Anuário Estatístico,* several years.

[178] CRGE, *Relatórios Diários da Central Tejo* (1914-1918); SMGEP, *Relatório Anual* (1917-1918).

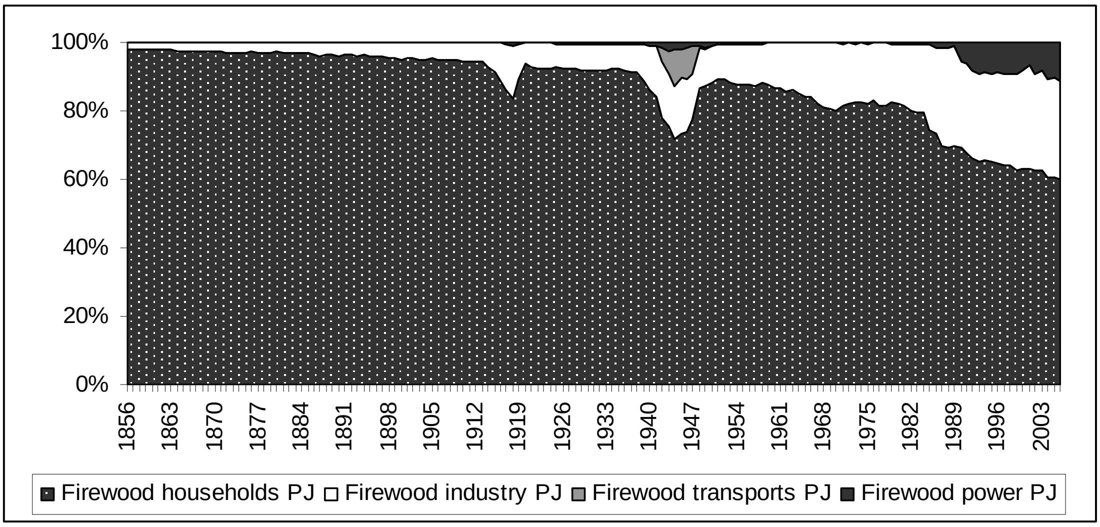
[179] Thermo production is estimated for the years 1918-1930. See Appendix B, Table B.8.

city. Consumption figures have been taken from annual reports of Oporto electricity and gas services[180].

Data on firewood consumption for power production is lacking from the end of the World War I until 1931, when official electrical statistics begin[181]. Firewood consumption for the years 1919-1930 has been obtained from 1931 data, which means assuming that electricity production using firewood accounted for 2.2% of total electricity production, and that each kWh was produced with 7.5 kg of firewood.

For 1971 onwards I connected Electrical Statistics series for 1931-1970 with the values for firewood and other solids (rice peels, olive seeds, etc) reported in Energy Balance Sheets for power uses. After 1990, firewood to cogeneration is included in this rubric.

Fig 2.4 Firewood consumption by major groups, Portugal 1856-2006



Sources: see text

The Figure 2.4 reproduces the shares for firewood consumption during the period studied here. Household figures make the bulk of consumption. Only in the last quarter of the century did manufacturing figures approach household figures.

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[180] SMGEP, *Relatórios Anuais* (1918-1920). No adjustments are made to cover firewood use for gas production in other parts of the territory as 1) The Lisbon coal gas factory was closed from 1917 until 1922 as a result of a government agreement to save coal. 2) Other gas plants had very small dimensions and there is only sparse information on their production values.

[181] DGSE, *Estatística das Instalações Eléctricas* (1929-1970).

2.8 Animals[182]

Animals have been domesticated by humans since the onset of the Neolithic Revolution and were an important source of power in agriculture, industry and transportation. In order to quantify for their contribution, some historical studies calculate the direct energy expense of the animal while working, i.e., the work output of the animal. However, as we are interested in energy inputs we must regard an animal as a living organism that converts chemical energy from fodder into mechanical energy. Like humans, only a portion of the fodder consumption of the animal is used in order to perform work. Most of the fodder ration is given to keep the animal alive. However, all fodder must be taken into account in our calculations, since it is impossible for an animal to survive and thus work without a minimal survival ration. Not all domesticated animal are of interest, since most of them are bred in order to provide for meat and dairy products. To calculate primary energy consumption from an animal we need to know the number of working animals. The feed ration depends on the type of animal, its weight and the type of work it perform, so stratified data on cows, oxen, donkeys and mules must be produced as well as some assumptions of animal weight and intensity of work.

In order to estimate primary energy consumption from the fodder intake by working animals, we benefit from the work of Kander and Warde. The authors suggest a standard conversion of cows, donkeys and mules into oxen or horses, a table of diary fodder requirements according to the size of the oxen and horses, and an assumption of average work intensity. According to the authors, a working cow must be converted into 1/3 of an ox, as their work is only a complement of other activities (dairy production, breeding)[183]. It is assumed that donkeys and mules have an energy requirement of ¾ of a horse and the same as a horse of identical size, respectively.[184] Assuming that working animals worked on average all year round we reproduce here the daily fodder units of digestible energy (1 f.u. = 3 000 kcal) that the authors suggest (Table 2.11).

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[182] Appendix B, Table B1, col. 2, and Table B.2.

[183] Kander and Warde (2011).This would assume that only energy requirements for work would be accounted for in the case of cows. We should notice however that a working or lactating pregnant cow intake could be superior to the one of an ox. Power depends exclusively on the size of the animal so a value of 2/3 of an ox should be taken when referring to power units. The use of cows instead of oxen can be considered an energy saving practice as it allows keeping less animals in a farm.

[184] The fact that donkeys consume about 75% of an animal of the same size is confirmed in the literature, see Aganga *et al*. (2002).

Table 2.11.Fodder units day in relation to animal size

Weight (kg)	Oxen	Cows	Horse/Mules*	Donkey**
300	4.2	1.4	4.7	3.5
400	5.6	1.9	6.2	4.7
500	7	2.3	7.8	5.9
600	-	-	9	6.8

Source: Kander and Warde (2011)

In order to obtain primary energy consumption from fodder intake all we need to know is the number and size of working animals.

For 1852 to 2000 there are about ten national censuses which allow us to determine the number of horses, donkeys, mules, oxen and cows at the time[185]. Since only working animals are of interest for our purposes, 15% of the absolute value of donkeys, mules and horses are deducted, so that foals are not accounted for. Calves up to two years old and non-working cows are eliminated from the total. At the end of the nineteenth century oxen were the most important source of draught power in the country. For some European regions an important improvement in agriculture was the substitution of horses for oxen. Although a horse was more expensive to maintain, it was faster and could endure longer working hours. However, the equines were never important in agriculture, but more reserved for the transportation and leisure of wealthier individuals[186]. More necessary were the cows: in 1870, 66% of adult cows worked; in 1955, that figure decreased to 44%[187]. However, the proportion of cows in the working animals herd increased from 19% to 30% in the same period. This was probably one of the higher percentages in Occidental Europe, which is also connected with the almost vegetarian diet of the Portuguese population. Besides, the use of cows could be an optimal solution as it allowed for a saving of feed resources as fewer animals could sustain both the milk and working needs of a farm[188].

Concerning the size of the animal I have assumed 400 kg for horses and mules and 350 kg for donkeys as proposed by Kander and Warde for Mediterranean countries[189]. The value of 400 kg per horse/mule assumes lighter horses than in Northern Europe. Donkeys were common in the South of the

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[185] MOPCI (1873); *Recenseamento Geral dos Gados…* Justino (1986); INE, *Estatísticas Agrícolas*, several years. Adjustments to include the islands are made for some benchmark periods.

[186] In 1870, only 13% of the working horses worked in agriculture.

[187] For 2000 it is assumed that the number of working cows was zero.

[188] Zerbini and Gemeda (1994)

[189] The value of 350 kg per donkey is considered large by Smil (1994) who gives a common range of 200-300 kg per donkey.

country and assumed to be similar to the Andalusia breed which has an average weight of 370 kg for females and 400 kg for males. The only recognized Portuguese breed comes from the North of Portugal, Miranda. The breed is related to the Spanish Zamorano-Leones with an average weight of 350 kg[190]. The choice of the weight of the bovine cattle is influenced by the weight records of bovines at the slaughterhouses in the two main Portuguese cities. Both slaughterhouses show an increase of bovine weight until WW I. For the period, I have assumed 370 kg per bovine head in 1856 and a linear rise until 450 kg in 1910[191]. In summary, energy consumption from fodder intake can be calculated by the following formula:

$$E = aD\times f.u.d_{(x)} +(bO+1/3\ eC)\times f.u.o_{(y)}+(cH+dM)\times f.u.h_{(z)}$$

D	number of donkeys
O	number of oxen
C	number of cows
H	number of horses
$f.u.d_{(x)}$	average yearly unit intake of a donkey with weight x
$f.u.o_{(y)}$	average yearly unit fodder intake of an ox with weight y
$f.u.h_{(z)}$	average yearly unit fodder intake of a horse with weight z
a	proportion of working donkeys
b	proportion of working oxen
c	proportion of working horses
d	proportion of working mules
e	proportion of working cows

Working animal numbers increased from 1852 to around 1900, stabilized until the 1960s and decreased thereafter with the introduction of tractors and decline of traditional agriculture (Table 2.12).

It is not possible to obtain census data for animals after 2000. The same percentage decrease in feed consumption (58%) of the precedent decade (1989-1999) is projected for 2010. Annual figures for the years 2001-2006 are obtained by linear interpolation between the 2000 figures and the projected 2010 values.

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[190] Data on Spanish breed characteristics is given in the Domestic Animal Diversity Information System from FAO, available in http://lprdad.fao.org.

[191] Justino (1986). In 1849 the average weight of adult bovine cattle was 366 kg. After 1913, statistics at Lisbon slaughterhouse show a strong decline. I assume this was due to World War I – poor breeding, import restrictions and also an increase in the number of cow's proportion. Statistics recovered after the beginning of the 1920s to reach pre-war levels in 1935.

Table 2.12 Draught animal numbers (thousands) for Census years

Year	Donkeys	Mules	Cows	Oxen	Horses	Horse equivalents
1852	112	35	128	282	61	440
1870	123	52	123	285	70	493
1906	129	50	180	285	77	558
1925	209	77	214	204	72	564
1934	234	104	220	156	77	566
1940	209	104	240	156	72	552
1955	201	108	240	176	63	562
1972	103	75	147	94	30	318
1979	101	54	109	77	25	261
1989	63	34	54	93	31	221
1999	33	18	0	22	31	94

Sources: See text

2.9 Wind and water; solar and geothermal heat[192]

Wind and water were the only important sources of energy, apart from firewood and muscular energy, used before the advent of coal. The main consumers of these energy carriers were mills and sailing ships. In most of the cases, wind and water energy represents only a tiny portion of the total energy consumed by the country at a given time, and a per capita consumption in the range of 0.4–2.9 MJ /pc/day[193]. It is very hard to calculate wind and water energy on an annual basis, as it is not possible to know with exactitude the number, power, efficiency and intensity of use of the converting machines. Due to the small amounts of energy involved and the poor quality of the benchmarks, I have decided for reasons of convenience to treat water and wind in the same section, distinguishing them by type of driver (mills and sailing).

2.9.1 Sailing ships

Portuguese history from the 15th and 16th centuries showed that the country was one of the few to benefit from the knowledge of navigation techniques in acquiring an empire overseas. However, our series begins in the 1850s and at that time the Portuguese fleet was unable to compete with the foreign constructors. Statistics on the number and tonnage of sailing ships are available

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[192] Appendix B, Table B.1, col. 4 and Table B.4.

[193] Malanima (2006a).

from 1864 onwards[194]. In that year there were only 582 vessels. Due to the advantages of steam and internal combustion motors, the fleet decreased to 315 vessels in 1899, although tonnage peaked in that year, to 200 vessels just before the WW II and to 3 vessels in 1969.

One way to estimate the power of those vessels is to follow the calculations from Malanima[195]. The author made an estimate, for Italy during the period 1862-1975, of merchant Italian sailing ships' power with basis in Barberis' assumption that, for the same net tonnage, a sailing ship would have 1/3 of the power of a steamship. The ratio of steamship net tonnage to its power was reported to be 2.8. To obtain the power of sailing ships he divided the tonnage of sailboats per 3 × 2.8=8.4. Then he multiplied the power of those sailing ships by their intensity of use assuming that a ships power was fully exploited 10 hours a day for 365 days a year. One of the problems with this method is that it assumes that energy can be transmitted from the sails to motion in a perfectly efficient way.

Lindmark has proposed an alternative method to calculate energy consumption by making an estimation of wind energy hitting the rig and accounting for 50% energy losses in the sails. Lindmark calculates that primary energy from wind is approximately 0.6 kW per tonne[196]. I have applied this coefficient in terms of gross tonnage, and assumed a coefficient of use of 3 650 hours year for merchant sailing ships in line with the previous booklets in this series.

Wind could also be used by smaller boats in coastal navigation and by fishery boats. There are no reliable statistics for the first type of boats, but statistics record the tonnage of registered fishery boats that employed wind as their source of energy[197]. Fishery boats tonnage was 65% of vessel tonnage in 1860. Tonnage reached a peak of 48 000 in 1912. In terms of numbers, fishery boats continued to grow until 1961, when they numbered 15 600 units but tonnage was decreasing due to competition with internal combustion motors. There were still 11 000 in 1986 but decreased quickly to 2 330 due to the rules of the Common European Fishery Policies that financially supported the removal of small and obsolete units. In order to calculate primary energy, I employ the same method used to estimate vessel energy. I assume a coefficient of use of 2 000 hours a year. This also reflects the fact that an unknown proportion of boats was not in use.

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[194] INE, *Anuário Estatístico* and DGM, *Lista dos Navios...* .

[195] Malanima (2006a).

[196] Lindmark (2007).

[197] INE, *Anuário Estatístico*; INE, *Estatística Industrial*; INE, *Estatística das Pescas.*

2.9.2 Mills

The first written reference about a windmill dates from 1182 and there were only 46 watermills inventoried in 1258.[198].

Data on the number and power of windmills is very scarce along the period of 1856-2006. Due to the low quality of the information available, the option is to produce an acceptable benchmark figure for the only year which enough information is given (1890) and to depart from this year to derive long-run estimates for the remaining years.

2.9.2.1 Mills, benchmark estimates 1890

It is easiest to begin the calculations with the most reliable survey, the industrial census of 1890. This inquiry is the only one that reports the number and power of both industrial and cereal mills. The crude information is far from optimal, but Santos improved the reliability of the inquiry by making an estimate of the mean power of watermills and windmills based on the incomplete information of that inquiry[199]. The census records 2 394 windmills and 7 894 watermills in operation. About ¾ of the installed power in industrial and non-industrial premises came from water and wind. Cereal grinding was the most important activity of windmills (97%) and watermills (90%). (Table 2.13)

Table 2.13 Number, power and mean power of windmills and watermills per industry, 1890

	Windmills			Watermills		
Industry	Number	hp	average power (hp)	Number	hp	average power (hp)
Cereals	2 313	9 479	4.1	7 221	18 237	2.5
Wood	16	137	8.6	227	2 649	11.7
Textiles	28	192	24.0	347	4 282	12.3
Metals	34	146.2	4.3	3	21.8	7.3
Paper	1	1.8	1.8	56	712.3	12.7
Chemicals	1	2.3	2.3	16	72.5	4.5
Printing	1	1.8	1.8	1	1	1,0
Chemicals	0	0	0.0	16	72.5	4.5
Total	**2 394**	**9 960**	**4.2**	**7 894**	**26 093**	**3.3**

Source: Santos (2000).

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[198] Marques (1987).

[199] Santos (2000).

The calculation by Santos is of course only a first step. In order to estimate energy consumption from power we have to know how long the mills actually worked in a year. Statistics record only the power of the mills, that is, the capacity to produce work per unit of time. As we are interested in inputs, that is, the water falling on the wheel or captured by the blades, we must add the energy which was lost in the process of transmission.

It is not possible to obtain census data for animals after 2000. The same percentage decrease in feed consumption (58%) of the precedent decade (1989-1999) is projected for 2010. Annual figures for the years 2001-2006 are obtained by linear interpolation between the 2000 figures and the projected 2010 values.

Thus, the calculation of the primary energy of water and wind can be given by the following formula:

$$E = P \cdot h \cdot \frac{1}{i}$$

Where:

E energy consumption;
P power
h hours of use per year
i efficiency

I have decided to estimate the intensity of use of cereal watermills and windmills based on the figures for the cereals ground in water and windmills. I calculate the apparent consumption of grain in water- and windmills adding to the 1890 production figures of wheat, rye and corn[200] the quantities of wheat imports[201], and subtracting one tenth of this gross value to account for animal intake[202] and the grain consumption in steam-mills[203]. Knowing that each hp installed in a traditional mill grounds 14 kg/cereal hour[204], we obtain a use coefficient of 1 997 hours/year[205]. This value is clearly compatible with the 2 000 hours/year that Reis suggested for agricultural work in this period of time[206].

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[200] Lains and Sousa (1998).

[201] INE, *Comércio Externo*, 1890.

[202] Serrão (2005), p.170.

[203] The Industrial Census of 1890 has information on grain consumption of the most important steam mills, see MOPCI, *Inquérito Industrial de 1890*.

[204] Malanima (2006a).

[205] Grain consumption water and windmills= Grain imports+ grain production– animal consumption – steam consumption= 87 971+828 525 − 91 650 − 50 000=774 846 tonnes. Intensity of use= Water- and windmill grain consumption: Power: technical coefficient per hour = 774 846: 27 715.7:0.014 =1 997 hours.

[206] Reis (2005).

The next step is to calculate the intensity of use of industrial mills. According to Reis (2005), industrial workers worked for 293 days a year, 10 hours a day at the end of the 19th century. However, windmills and watermills did not always operated during industrial work. Summer droughts could substantially decrease the use of watermills as the need of water for agriculture works increased. Windmills could be even less reliable, sometimes merely used as a poor substitute for water power. Probably, the power indicated by Santos was not reached throughout the year. To address these constraints, we assume that watermills only worked at full power in 9 months of the year. In the remaining three months, power was reduced to half[207]. This means that we assume that a watermill was working at full power for 2 200 hours a year and 730 hours at half the power. In the case of industrial windmills we use an intensity of use coefficient of 2 000 hours/year at full power, reflecting a lower usage of windmills in relation to watermills.

After calculating the energy consumed it is also necessary to understand the efficiency of both windmills and watermills. Some authors use a very high estimate of 70% efficiency for windmills but this is an exaggeration. In 1919 a German physicist proved that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy to turn a rotor[208]. This law, called today the *Betz´s limit* has to do with the nature of wind turbines that extract energy by slowing down the wind. Thus, for a wind turbine to be perfectly efficient it would need to stop the wind, but then the rotor would not turn. The actual motors have 30 to 45% efficiency and the old windmills did not reach more than 10-15%. In the case of watermills the efficiency was dependent not only on the materials and design of the wheel and transmission equipment but also on the manner in which the water ran into the wheel. A theoretical maximum of 15% of efficiency for undershot water wheels was established in the early 18th century, but in 1759 Smeaton showed that yields could be increased to more than 50% with resource to overshot wheels[209]. In the 1830s water technology was improved with the invention of Fourneyron turbines, which could be easily adapted to different torrents and could achieve 70-80% of useful energy. Despite all these improvements, it was not the best technology that was in use in Portugal. In 1881, it seems that the majority of industrial watermills were still driven by mixed wheels (wood and iron). It is not

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[207] The time of use is estimated on the upward side . Chapter 4 provides some examples that time of use could be even lower.

[208] http://en.wikipedia.org/wiki/Albert_Betz

[209] Cardwell (1996). The wheel is designed as undershot when the water ran at the bottom of the wheel and overshot when the movement is given by the falling water.

possible to know the proportion of overshot and undershot wheels, but it seems the two systems co-existed for a long time in precarious conditions. The number of turbines is mentioned in the 1890 Industrial Census. They were only 418, a tiny proportion of the 7 894 watermills. Power is assumed to be 3 655 hp[210], 14% of total watermill power. An efficiency of 15% for windmills, 30% for watermills driven by wheels and 80% for watermills driven by turbines is used. I assume that turbines were employed in the industrial sector, where a higher intensity of use coefficient is used. In the aggregate, this gives a global efficiency of 25%. In 1890, windmills and watermills consumed 221.1 GWh. It is worth nothing that despite windmills representing only 28% of the installed power, in terms of primary energy consumption they spent almost as much energy as watermills (44%). Adding the wind used in transportation to the energy spent by mills, we reach the conclusion that water and wind accounted only for 1% of total consumption in 1890.

2.9.2.2 Mills, remaining years

Only rough figures on the use of windmills and watermills can be inferred for the rest of the period. In relation to industrial mills, there is scarce information available on their number before our benchmark year, 1890. Therefore, we just assume the same amount of energy use in industrial mills for the period 1856-1890[211].The industrial survey of 1917 records the number and power of industrial watermills[212]. It says nothing about windmills so I just assume that their industrial activity disappeared at the end of World War I. Excluding hydro- electricity industries[213] and cereal grinding industries,[214] watermills had an installed power capacity of 6 822 hp, 87% of the 1890 power for the same industries. Turbines provided 67% of the installed power, more than the 49% of 1890. We can only obtain other benchmarks four decades later, with the publication of industrial statistics. It seems that absolute water power may have grown after 1917. By 1950 the statistics report 10 223 hp; by 1958 11 330 hp.[215] By 1965, waterpower had begun to diminish: 9 612 hp, 80% from

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[210] Cordeiro (1993) table does not show the total turbines power, as power for some districts is missing. I calculate the average power for the districts where power information was given and assume the same average power for turbines with unknown power information. His figures show a total power of 1 294 hp, less than half of what I roughly estimated.

[211] The census of 1881 could be used to estimate water-power, but not wind-power. See Chapter 4.

[212] MOPCI (1926), Estatística Industrial do ano de 1917, *Boletim do Trabalho Industrial*.

[213] Production of primary electricity is represented in section 2.13.

[214] Poorly represented in the 1917 survey as this census only accounted for major units.

[215] INE, *Estatísticas Industriais*.

turbines. Efficiency around that period had grown with the substitution of turbines for wheels but intensity of use had probably dropped. At the early 1930s the length of a working week in industrial premises had dropped to 48 hours/week due to labour legislation. Furthermore, water was used more and more as a complement to steam.

It is even harder to calculate the energy spent in cereal grinding. While apparent consumption of grain can be used to calculate primary energy in the early part of the series 1856-1890, things get complicated after 1890. The statistics report the number of watermills and windmills subjected to the industrial tax until 1918. The absolute number of watermills may have increased from 8 000 in 1890 to 11 000 in 1918 while windmill numbers remained constant. However, in terms of hp, steam already had the capacity to grind all the grain consumption of the country around the 1920s[216]. The situation of the sector in 1960 was elucidative of its overcapacity. At that time the industrial statistics reported the existence of 3 441 factories[217], 2 953 windmills (2 687 with no extra motor) and 32 047 watermills (31 274 with no extra motor) on the mainland. From this number, and for public consumption, there were 1 819 factories, 1 707 windmills and 10 440 watermills operating. An extra 946 factories, 180 windmills and 14 798 watermills produced in regime of own consumption. In terms of power all factories and motorized mills had a power of 56 583 hp[218]. If the average power of a cereal windmill and watermill was the same in 1960 as in 1890, water and wind power in use accounted for 2.5 times the 1890 values. As we do not know the quantities of grain grinded by the motorized units, it is inglorious to attempt any calculation for 1960. I assume then, that despite the overcapacity of the industry, water and wind energy use were related to the number of people employed in the agricultural sector. With this assumption, primary energy use from wind and water cereal mills varies little from 1856 to 1965: 0.5 PJ in 1856; 0.7 PJ in 1890 and again 0.5 PJ in 1965.

Below is a summary of the results of our calculations (Table 2.14). In the period the most important use of water and wind energy was cereal grinding. Water and wind energy represented along the period a very tiny proportion of total energy consumption.

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[216] Steam-mills accounted for 20 164 hp installed in 1917 and 24184 hp in 1927. Applying the same production rates as in 1890, capacity clearly exceeded production.

[217] The statistics regard premises with motors as factories. Windmills and watermills were not considered factories if their production was lower than 10 tonnes of flour per month.

[218] INE, *Estatísticas Industriais*, 1960.

Table 2.14 Summary of wind and water energy calculations

	Wind, sailing ships %	Wind, fishery boats %	Wind & Water: cereal mills %	Wind & Water: Industrial mills %	Wind &Water PJ	Wind &Water % of the Total
1856	19	7	59	15	0.907	1.2
1890	20	8	59	13	1.105	1.1
1917	20	8	61	13	1.080	0.9
1965	0	13	73	13	0.690	0.3

Source: see text

2.9.3 Solar and geothermal heat

Solar and geothermal energy for heating purposes has been reported by DGE since 1998. It is included under this heading in the Appendix.

2.10 Coal[219]

Coal was already used by the Chinese in pre-industrial times but it was in England that its usage reached major importance, accounting for more than half of English & Welsh energy consumption by 1600[220] and being strongly associated with the Industrial Revolution.

2.10.1 Domestic coal production

In Portugal the first coal mines started to be explored at the end of the 18th century. Coal reserves were very limited and the mean calorific content of Portuguese coal was only 50-60% of British coal. In the 19th century the low quality of the coal never attracted the industrial consumers and production reached only a few thousand tonnes. During WW I, coal extraction increased to 100-200 thousand tonnes as a result of a shortage of foreign coal. Domestic coal was mixed with foreign coal in the interwar period to improve its quality; after the Second World War its usage was almost mandatory in thermoelectric utilities. Since the end of the 1980s there has been no coal extraction in the country. In times of peace, domestic coal never amounted to more than 10% of the total coal consumption.

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[219] Appendix B, Table B.1, col 5 and Table B.5.

[220] See Warde (2007) on this subject.

Coal extraction figures from 1890-1970 are taken from Madureira and Teives[221], which are based on official sources[222]. Coal extraction from 1882 till 1889 is taken from Valério, who also uses official sources[223]. From 1856 to 1881, I aggregate data from a variety of sources and studies that give partial information about specific mines[224].

2.10.2 Coal imports

The first registers of coal imports cover the period of 1796- 1831[225] but less than 20 000 tonnes a year were imported during that period. Our series begins in 1856, and from that year until 1970 coal imports are taken from the yearly books of International Trade from INE[226]. For the periods 1857-1860 and 1862-1864, official statistics are missing. In the first period (1857-1860), data for the two most important Customs Offices (Lisboa and Oporto) was used as representative of total consumption in the country[227]. For the second period (1862-1864), data is interpolated from 1861 and 1865 official figures[228]. Data for 1875 is changed due to an error in reporting[229]. Although Mitchell reports coal imports for Portugal from 1875 using Portuguese sources, this series is an improvement of Mitchell data as for some years not all coal imports are registered in his series[230]. Furthermore, I assumed different coefficients for coke, coal, brown coal, turf and peat (Table 2.15). After 1971, Energy Balances from DGE are used. Imports are not always homogenous series as they can include (or not) bunker fuel[231].

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[221] Madureira and Teives (2005). I did not apply a 3- year moving average of the series (as the authors) and extraction figures are given as reported by official statistics.

[222] INE, *Anuário Estatístico*, 1890-1900, 1911-1914 and 1940-1946, 1935-1982; DGOPM, *Boletim de Minas*, 1901-1910, 1915-1939, 1968-1970; INE, *Estatísticas Industriais* 1947-1967.

[223] Valério (2001).

[224] MOPCI, *Inquérito industrial* (1890), Matos (2002) and Guedes (2000).

[225] Madureira (1997).

[226] INE, *Comércio Externo*. Also referred as *Commercio e Navegação* in earlier periods. Data for 1890-1970 was earlier recorded by Madureira and Teives (2005), using the same methods as here.

[227] *Mappas Estatísticos do Rendimento da Alfândega Grande de Lisboa* (1857-1860), *Mappas Estatísticos da Alfândega do Porto* (1856-1859). There is no major problem in not including the Customs of Madeira and Azores as most of the imported fuel would be re-exported to bunkers.

[228] Although British statistics could be used for missing years they would include bunkers, so corrections would have to be performed anyway.

[229] Reported coal imports by Portuguese statistics are 426 thousand tonnes have been corrected to 226 thousand tonnes after comparison with UK trade statistics.

[230] Mitchell (1980), for example, does not account for coke consumption for earlier periods; in some years only coal imports from England are given. For 1937-1960 Mitchell does not include imports to the Portuguese navy, included in a special table.

[231] See correction of imports in bunkers section.

Table 2.15 Conversion coefficients – toe/ton

Coal	toe/ton
Imported coal (Anthracite/bituminous)	0.7
Lignite	0.27
Turf	0.23
Agglomerates	0.68
Coke	0.67
Domestic coal	0.41

Source: DGE (values indicated for 1971-1982). 1 toe = 41.868 GJ

2.10.3 Coal bunkers

Portuguese coal was not exported so the majority of corrections that we have to make to imports, refers to supplies to international navigation. International organizations such as IEA do not account for fuel consumption consumed by international marine bunkers (fuel delivered to sea-going ships) when reporting the primary energy of a country. If one intends to account for bunkers using the same method as IEA one should include the domestic travel between domestic ports and airports, but not the international ones, in primary energy consumption. Bunkers are a tricky issue in energy accounting and not all the countries report them in the same manner. For example, they are considered part of domestic consumption by most Middle East countries but treated as exports in the majority of Latin countries[232]. Even amongst IEA countries, definitions are not entirely consistent. The main problems with bunker reporting is the lack of distinction between deliveries for international and domestic purposes, overestimation of bunkers in order not to have to hold stocks or inclusion of fishing fuel consumption, which is due to the fact that data is obtained by suppliers who do not know precisely the ultimate use of their sales[233]. The issue of bunkers has become more relevant nowadays due to the introduction of greenhouse gas inventories. In order to ascertain responsibility for bunker emissions for each emitting country, detailed information on a country by country basis on the fuels sold domestically and abroad to planes[234] and ships should be available. This is a concern, as the way statistics are made today, at least part of the bunker emissions are lost, with no owner. While the Kyoto Protocol article recommends that Annex I parties pursue the limitation of

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[232] Karbuz (2006)

[233] Det Norske Veritas (1999)

[234] United Nations energy statistics are different from IEA ones, in the way that they subtract also aviation bunker figures.

bunker fuel emissions, bunker fuel emissions are not subjected to emission targets[235].

Portuguese modern statistics do not account for bunkers in the same way as international organizations. Instead, they adopt a territorial concept, accounting for the fuel that is consumed by national aviation and marine ships and excluding the fuel that is consumed by foreign carriers[236]. From an historical point of view it is more interesting to adopt the Portuguese accounting method as it gives more information on the uses of energy by all the sectors in the economy. Besides, wind energy consumed by vessels is also part of our calculations, so it would be inconsistent to treat coal consumed by steam ships in a different way. With this methodology only the fuel acquired by national companies on international territory would not be accounted for.

The choice of the Portuguese method will not imply a major problem when comparing with other European countries, as the proportion of the fuel used by national navigation and air carrier companies on international travel was or is undoubtedly small.

In the case of coal, considering only imports would significantly overestimate Portuguese coal consumption in earlier periods. As in any coastal country, an important proportion of coal imports was destined to supply foreign ships, being only remotely associated with the level of industrialization of the country. There were some important ports used by foreign ships, especially British ones, on international routes to Africa, the Americas and India since the mid 1850's: Lisbon, the port of Funchal on the Island of Madeira and the ports of Ponta Delgada and Horta on the Islands of Azores[237].

In order to correct for supplies to foreign navigation, it is necessary to understand clearly how Portuguese trade statistics were generally presented and also their modifications, errors and inconsistencies. There were three main categories in Portuguese trade statistics: imports for consumption; national and nationalized exports and re-exports. Imports for consumption included as a general principle only the commodities that would be consumed within the country, that is, they would be net of re-exports. However, a proportion of the commodities that entered the country ports under the regime of imports for

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[235] Technical workshop on emissions from aviation and maritime transports, 4-5 October 2007, www.eionet.europa.eu/training/bunkerfuelemissions.

[236] DGE, *Balanço Energético 1987-1991.*

[237] Miranda (1991). The importance of coal trade in the ports of Atlantic (Madeira, Azores, Canary Islands and Cape Vert) is discussed by Bosa (2008).

consumption was afterwards sold to foreign territories[238]. Thus, they would then figure in export figures as nationalized exports. Re-exports comprised the imported goods that were not subjected to a consumption dispatch and that were sold to foreign territories. This generalized principle was followed by Madureira and Teives in their estimate of coal and oil consumption in the country[239]. However, as we will see, Portuguese official statistics do not always follow their definition of imports for consumption, export or re-exports in the case of coal for navigation purposes and some errors and inconsistencies need to be corrected[240].

2.10.3.1 1856-1922

Prior to 1923, the coal consumption to foreign ships is difficult to track. From 1889 to 1916, almost all supplies to both national and foreign steam ships were given in re-exports. As mentioned earlier, re-exports should not be included in imports for consumption, but a detailed analysis shows that some errors in reporting occurred. In that period imports, exports and re-exports are also disaggregated by main ports so it is easy to see that only fuel ship supplies in the islands were accounted as re-exports. However, the re-exports figures of the ports of Madeira and Azores are almost equal to their “imports for consumption” figures. Those islands had almost no industrial development, therefore accounting for imports would mean attributing them the higher per capita figures of coal consumption in the country, which would be impossible. Re-exports must then be subtracted of imports for consumption[241]. We do not have Portuguese registers of each port for periods prior to 1889 but UK trade statistics have separate figures for coal exports to mainland Portugal, Madeira and Azores going back in time. As the UK was the almost exclusive supplier of coal to Portugal, we can get some additional information from those statistics. Comparing UK coal exports for Azores and Madeira and coal exports and re-exports figures in the Portuguese trade statistics, all fuel in exports from 1856 to 1874 and in re-exports from 1875 to 1888 was for the islands of Azores and

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[238] Due to a maximum time that companies were allowed to keep the merchandise in deposit, unanticipated exports or to an improvement of the merchandise.

[239] Madureira and Teives (2005).

[240] The main reason for these inconsistencies was the decentralized nature of customs statistical information methods in the earlier part of the period and differentiated tax regimes.

[241] I double checked the import data for Madeira and Azores with UK trade statistics for the same Islands (which always include future re-exports from Portugal to other countries) and they matched quite well, which gives support to the argument.

Madeira[242]. From 1916 to 1920 fuel supply was also reported as re-exports to the Island of Madeira and in Ponta Delgada (Azores), but Horta (Azores) changes the report of fuels to exports, which is nothing more than the adoption of a new statistical procedure. In order to achieve a figure of coal consumption net of foreign bunkers for the islands in the period 1856-1922, one still needs to distinguish between exports and re-exports that were destined for national or foreign ships. Until 1875 exports distinguish if coal is going to foreign or domestic ships, and the proportion of national marine coal consumption in the islands was approximately zero. I assume that 0% of the coal re-exported went to national ships prior to 1880, 5% between 1880 and 1889, 10% between 1890 and 1913 and 15% from 1914 to 1922.

As for other ports in the country, Lisbon customs reports only a small fraction of its bunker consumption to exports[243]. Only after 1916 did Lisbon start to account for coal supplies to both national and foreign ships as exports[244]. There is a strong possibility that import for consumption before 1916 was given net of bunkers even if they were not registered in export or re-export as an exit. Isolated statistics for the commercial movement of the port of Lisbon in 1883 indicates 67 013 tons of coal supplied to steam vessels are clearly stated as being outside the imports, exports and re-exports figures.[245] I have not performed any correction in order to account for coal supplies to domestic steam ships in Lisbon port before 1916 due to the scarcity of data involved[246].

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[242] SOCED, *Annual Statement of the trade of the United Kingdom...*, several years. . Coal for navigation in the islands was also included in imports in an earlier period. For 1856, by reasons of late report, the customs of Funchal (Madeira) is treated separately from the ones in Mainland and Azores and we can see an importation figure almost identical to the re-exports figures.

[243] Most of the exports of Lisbon in the period 1889-1915 are actually re-exports to Spain or colonies .

[244] Figures for Lisbon in 1916 indicate a total bunker consumption (destined for foreign and national steam ships) of 80 000 tons.

[245] Included in the *Diário da Câmara dos Senhores Deputados*, sessão 04/25/1884, p.1243, table 17. I searched for additional information in the few Lisbon customs statistics that I could find and no records for the totality of navigation coal supply is given. For the period of 1875-1880 about four thousand tons of coals are reported in exports as consumption for bunkers but this did not represent all consumption by ships. The exception is the period 1859-1860 for which a figure of 3 694 loading of coal to 6 foreign ships is given outside the importation or exportation maps as an addition. *Mappas Estatísticos do rendimento da Alfândega Grande de Lisboa no ano económico de 1859-1860* (1860).

[246] I compared the UK coal exports to mainland Portugal and Azores and Madeira with Portuguese coal imports for the XIX century and the first are higher than the second in almost all periods of the series. The difference is about 30 000 tonnes per year but it is lower in the decade of 1890s (about 15 000 tonnes per year). As it is not possible to find stronger evidence of bunker consumption in the Port of Lisbon we leave the statistics like they are. Contrary to the Islands, the majority of ships that entered and cleared the Lisbon port were not supplied with coal. Due to the existence of numerous nearby ports, bunker consumption depended mainly on the price of fuel and route of ships.

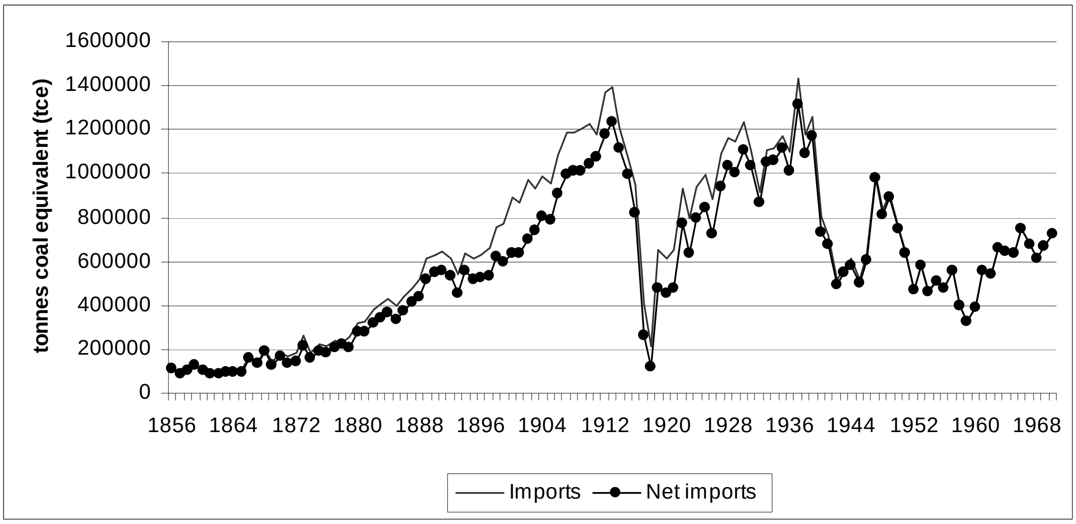
2.10.3.2 1923-1936

For 1923 to 1936, coal supplies to foreign and national ships are included in exports. Exports distinguish the coal for foreign consumption within the mainland but not the islands where an aggregate figure for coal supplies to national and foreign ships is given. I assumed that 15% of the bunker fuel exported from the islands between 1923 and 1936 was to domestic ships, consistent with the proportion of Portuguese ships (measured in tonnage) that cleared from islands ports in that period.

2.10.3.3 1937- present

It is straightforward to correct for fuel to foreign ships and aviation after 1937. From that year onwards, part of this kind of consumption is reported in exports, so subtracting this value from coal imports would give an accurate measure of coal consumption within the country[247]. The figure below (Fig 2.5) presents both general imports and net imports.

Fig 2.5 Coal imports and net imports 1856-1970



Sources: see text. Note: 1 tce = 0.7 toe.

Coal destined for foreign navigation had an important share in coal imports. Considering only imports would overestimate coal figures by about 15%-20% for the period 1880s-1929. However, the correction does not change

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[247] Exports do not include all the bunker fuel sold to foreign ships as some of this fuel would not be included in imports for consumption. United Nations energy statistics for Portugal after 1950 do not reflect this particularity. While their import figures match the Portuguese ones they subtracted the whole total for bunkers (included or not in the import figures) to reach a figure for primary energy consumption.

the overall picture of continuous increase in imports until 1913 and a slow recovery and instability after World War I.

2.11 Oil[248]

The country lacks oil reserves, so all the crude oil has to be imported. The first use of oil was in public and private lighting. Kerosene imports started in 1861 followed by gasoline in the early 20th century and gas-oil and fuel-oil in the 1920s. Non-energy oil derivates such as paraffins[249] or lubricant oils can be found in import trade statistics since the 1890s. Butane imports started in 1938. From the eve of World War II crude oil imports began as the first oil refinery, in Lisbon, opened for production in 1940. In the first fifteen years the refinery had only the technology to produce low octane gasoline, high sulphur gas-oils, kerosene, fuel-oil and lubricants[250]. In January 1955, a major modernization that included the installation of one catalytic cracking unit allowed, besides the production of a higher octane gasoline, the production of LPG (butane and propane), jets, sulphurs and white spirits, among others. However, as the country had lower indexes of motorization at the time, the new refinery process could not be fully optimized and low octane's naphtas remained as production surplus[251]. This fact leads to the emergence of the petrochemical industry. Three units for naphtha gasification for the production of ammonia and urea were installed by 1961. In the early 1960s the refinery started to supply naphthas as a feedstock for the production of ammonia by fertilizer industries. Most of the hydrogen produced by naphtha treatment was used in ammonia production but a small part was returned to the refinery for feedstock. Town gas for the city of Lisbon was produced after 1961 from a mixture of the petrochemical gas, derived from naphtha gasification and ammonia production and refinery gases, propane or butane, replacing the old process of town gas production obtained from coal or coke[252]. This process was maintained until the closing of the refinery in the late 1990s, when town gas was substituted by natural gas. Two other refineries, in Oporto and Sines, started refining crude oil in 1969 and 1979. Besides the production of fuels, the Oporto refinery included, from the beginning, a factory for the production of basic oil, (which has employed

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[248] Appendix B, Table B.1, col. 6; Table B. 6 (energy uses) and Table B.7 (non-energy uses).

[249] Paraffin is here considered non-energy due to its recent applications although, its usage in the late nineteenth century was mostly confined to candle making (not accounted for in this work).

[250] Production of lubricants was discontinued in 1947.

[251] Almeida and Vaz (2002).

[252] Teives (2003).

atmospheric gas-oil as a feedstock since 1984) and an aromatic factory since 1981 for the production of benzene, toluene, naphtha, solvents and aromatics. The Sines refinery was constructed having in mind the external market. A new steam cracker was constructed downstream of the factory in 1981 using naphtha as a feedstock and producing ethylene, hydrogen, propylene, etc. Presently the refinery produces gasolines, petrols, gas-oils, fuel-oils, asphalts and sulphur.

Fundamentally, oil consumption figures are presented in three ways in historical or official publications. International organizations such as the IEA, United Nations and Eurostat include non-energy uses of oil in their primary energy consumption definition, preferring to disaggregate between energy and non-energy uses at the level of final energy consumption. This first method is interesting from a point of view of fossil-fuel resource use dependency[253]. In historical reconstructions, it allows also to study the development of the chemical industry. However, it can be argued that it over-stresses the share of fossil fuels in the energy balances being inconsistent with the treatment given to other energy carriers such as firewood, since energy balances do not include wood for construction purposes, for example. A second method that has been presented in some historical reconstructions is to exclude the primary energy consumption of non-energetic derivates such as lubricants, asphalts, solvents, paraffins or chemical naphtha[254]. It has only the inconvenience of excluding the trade flow of non-energy products (which can be positive or negative), while it includes the production flow. A third method is to exclude not only the non-energy derivates of oil, but also the proportion of crude oil that is employed by the country´s refineries in order to produce non-energy derivates. This method has been employed in historical reconstructions for Sweden[255], England & Wales[256] and the Netherlands[257], among others – and it is also the chosen method in this work. It has the visible advantage of expressing the real consumption of energy. The disadvantages are methodological. First, there are intensive data requirements that can almost never be entirely fulfilled in historical reconstructions like this one. For disaggregating between non-energy and energy uses of crude oil one needs to have access to refinery production figures, which are not easily available for earlier periods. On the other hand, petrochemical

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[253] A more complete way of calculating the resource dependency on fossil fuels is to account for the embodied energy content of all consumption goods.

[254] Due to the fact that naphtha can be used in energy uses (in raising heat or town gas production) it is often considered as an energy vector.

[255] Kander (2002).

[256] Warde (2007).

[257] Gales *et al.* (2007).

processes are closely interconnected with oil refinery ones, which makes separation difficult. A classical example is naphtha which can have energy and non-energy uses. Although non-energy uses of naphtha are reported in energy balances as a feedstock to the chemical industry, some of this naphtha is returned to the refinery in form of refinery feed stocks such as hydrogen, for example. To convert those refinery feed stocks derived from naphtha in terms of primary crude oil, since naphtha production is excluded, is practically impossible as we lack disaggregate information on feedstock and intermediate products refinery use[258]. Finally, it is impossible to determine the efficiencies of individual derivates produced by the refinery with the scarce information given in the statistics. Even though most of the methodological problems can be only partially solved, this method will provide figures closer to what we seek to determine, this is, the primary oil used for energy purposes.

Data concerning oil derivates is taken from the yearly books of International Trade from INE until 1970 and Energy Balances after that date. Crude oil figures are taken from reports of treated oil by the refinery company from 1940 to 1958; from Industrial Statistics from 1959-1970 and from Energy Balances thereafter[259].

In order to exclude non-energy uses of crude oil, I simply deduct from the primary crude oil the refineries production figures for lubes, paraffin, solvents, asphalts and propylene. Non-energy use of fuel oil in the chemical industry has been reported since 1985 and is deducted from the crude oil figures. Naphtha production figures are also subtracted, except for the energy uses reported. Before 1971 there are no Energy Balances but production from refineries is reported in other publications[260]. Naphtha production is only reported after 1963, a 2-3 year difference from its industrial use so a short time omission occurs.

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[258] Refinery feedstock's primary energy consumption (net trade and stock variation) and use in refineries (includes production of intermediary products) have been presented in energy balances since 1971. It is not possible to collect this information for previous years due to the diversity of products considered, although some of them might be incorporated in fuel trade. According to information given by DGEG – Direcção Geral de Energia e Geologia, refinery feedstocks are obtained directly from the refineries and include naphtha SR, components used in fuel production (gasoline, gas-oils, basic oils, etc) and also other intermediary products such as fuel gas, MTBE, hydrogen, etc., The agency does not supply disaggregation of those products at a lower level, so sophisticated measures were not employed.

[259] *SACOR (1940-1958)*; INE, *Estatísticas Industriais (1958-1970). DGE*, *Balanço Energético* 1971-2006. Although the company reports have data on the treated crude oil for most of the period, I could not find data on treated crude oil for the years 1945, 1949, 1953-1956 and 1958. For the period 1954-1956 I have used imports of crude oil from the company reports. For the remaining years Trade Statistics are used (INE, *Comércio Externo*).

[260] INE, *Anuário Estatístico* for 1957-1958 (only production figures); INE, *Estatísticas Industriais* for 1959-1970 (materials, energy consumption and production figures).

Uses of naphtha for town gas production are only reported after 1971. In the first three years of energy balances the ratio of on naphtha/gas production measured in energy units was approximately 3 to 1. Energy uses from naphtha in the period 1963-1970 are interpolated from gas production figures,[261] assuming the same relationship. Before 1956 non-energy usages are not deducted due to scarce information[262]. From 1971 till 1989 energy uses of naphtha are reported in town gas production and refinery losses. After 1990, heat is included in energy balances so naphtha used in order to raise heat in the petrochemical industry and in cogeneration utilities was considered as an energy use. The uses of naphtha for heat purposes represented only 3% of naphtha production so I abstain myself from correcting for previous years. Data was collected at the disaggregated level and the following coefficients were applied (Table 2.16).

Table 2.16 Conversion coefficients –Oil

Products	toe/ton
Crude Oil	1.007
Fuel-Oil	0.969
Gas-oil	1.045
Gasoline	1.073
Kerosene	1.045
LPG	1.140
Naphtha	1.073
Petrol Coke	1.070
Non-energy oil derivates	0.960

Source: DGE (values indicated for 1971-1982). 1 toe = 41.868 GJ

Contrary to coal, bunker correction is not a problem as oil supplies to foreign ships started when statistics already corrected for it. Figures for energetic crude oil and its derivates are presented in the Appendix . In order to ensure comparability with other methods primary consumption of non-energy uses and non-energy crude oil are also presented[263]. The figure bellow (Fig. 2.6) shows the difference between four methods of accounting oil: excluding non-

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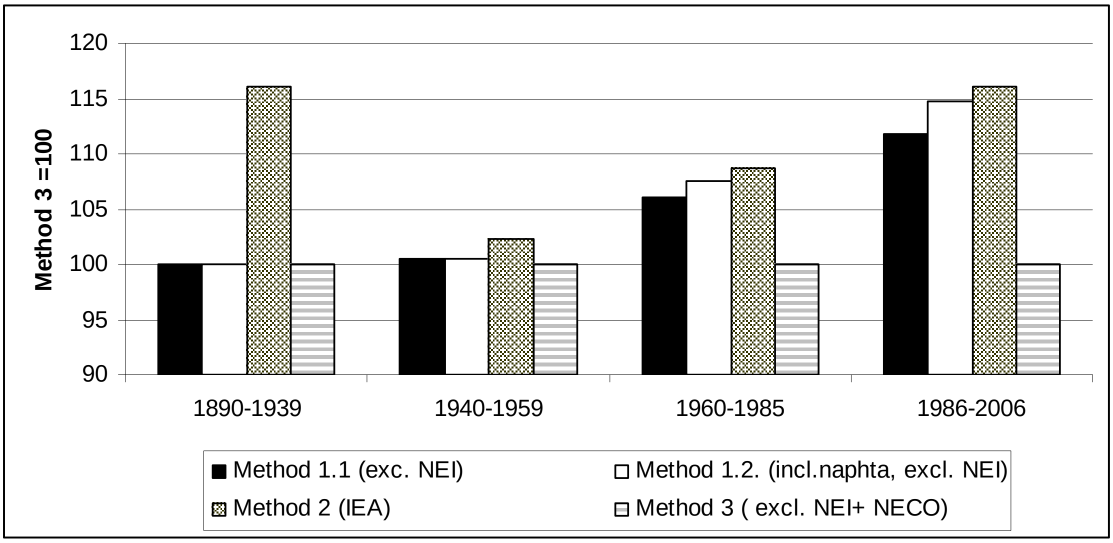
[261] INE, *Estatísticas Industriais* for 1965-1970 figures. The proportions of gas from petrochemical and gas from coal are graphically presented in Matos *et al.* (2005) for the transition period of 1963-1965. About 85% and 60% of town gas in 1963-1965 was produced using naphtha.

[262] There are discontinuous reports from the oil company in the period pre-1957 but they do not provide complete information. The only non-energy product that appears on sales is lubricants for the years 1940-1944, but I opt not to deduct once since a part of those sales could derive from imports. After 1944 lubricant production finished as a result of an agreement between the government and SACOR, in order to allow an increase of the fuel-oil production.

[263] Net imports of non-energy products of oil include asphalts, oil waxes, paraffin, lubricants, solvents (after 1971) and propylene (after 1990). Natural asphalts are not considered.

energy imports (method 1.1.); excluding non-energy imports, but considering naphtha an energy vector (method 1.2.); International Energy Agency method (method 2); excluding non-energy imports and crude oil for non –energy uses (method 3).

Fig 2.6 Comparison of four oil accounting methods (1890-1936)



In the period that precedes the installation of the oil business in the country, there is a difference of more than 15% between methods 1.1-1.2-3 and method 2, which accounts for non-energy imports. In the first 20 years of refining, the differences between IEA method and the others are lower, due to the fact that fuel consumption grew at an accelerated rate, diminishing the weight of non-energy derivates. After the 1960s the difference between our default method (3) and the others grew again to 6-9%. Nowadays, the crude oil that is refined for non-energy products lowers method 3 in relation to method 1.1, 1.2 and 2 by 11-16%. Most of the imports of products not considered in method 3 are from naphtha, which makes methods 1.2 and 2 very similar.

2.12 Natural Gas[264]

Although it is known that the Chinese had already used natural gas before 1000 BC for lighting, heating and cooking[265], the low density of the fuel made transportation and storage a difficult task, so it was normally treated as an

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[264] Appendix B, Table B.1, col 7.

[265] Ray (1979).

undesirable residual. It was discovered in England in 1659, but due to the developments in manufacturing gas, was not used until 1958[266]. In the USA, after the late 1920s innovations in pipeline design, natural gas ceased to be confined to local use and began to be economically viable to transport as far as 1 000 miles in the mid 1930s[267]. After WW II there was a steady growth in the consumption of natural gas but it was only after the 1970s oil crisis that industrialized countries started to use it as an alternative to oil and coal. Natural Gas consumption has a very recent history in Portugal as the country lacks reserves. It was introduced in 1997 and consumption had grown to 12% of all energy consumption by 2004. As the country does not have a tradition in the use of manufactured gas, significant investments in infrastructure have to be made. Nowadays 60% of the natural gas is used to produce electricity and 30% in manufacturing, especially in the ceramic industry. Substitution of natural gas for fossil fuels has been one of the main goals of Portuguese energy policy, especially in electricity production. This is because natural gas is, from all fossil fuels, the one that emits less CO_2 per energy unit. Natural gas consumption figures are taken from national energy balances[268].

2.13 Primary electricity[269]

Electricity is always a secondary form of energy, even if it is produced by water, wind or geo power. However, national statistics make a distinction between secondary or thermo-electricity (produced by coal, oil, natural gas, firewood and wastes) and primary electricity (wind, hydro, solar, geo, wave and tidals). In this way, the hydro and wind power are not included under the sections “water” and “wind” although they could easily be so; we include them in this section for the sake of comparison with national sources. Primary electricity is simply computed as:

$$E = (H + G + W + P)/i + Imp - Exp$$

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[266] Warde (2007).

[267] Schurr and Netschert (1960).

[268] DGE, *Balanços Energéticos*, www.dgge.pt

[269] Appendix B, Table B1, col. 8, and Table B.8.

where: E primary electricity
H hydropower
G geo-power
W wind-power
P photovoltaic
i efficiency
Imp electricity imports
Exp electricity exports

Portugal has never had nuclear energy. Geo, wind and photovoltaic electricity are all new ways of producing electricity so hydro-electricity is the only source where estimates are needed.

Until the end of the 1880s electricity use was confined to telegraphs, telephones, medical applications, lighthouses and private space lighting. The main streets of Lisbon started to be lit in 1889 by thermo-electricity. Regarding hydro-electricity, the first place to have public lighting from a water-power central (88 KW) was the small city of Vila Real in 1894. Before that year, we lack knowledge whether an auto-production central was built.

Detailed information about hydro-electricity production on the mainland is only possible in 1927[270]. In that year there were 59 hydro utilities that produced 54.7 GWh, representing 29% of total electricity production (Table 2.17).

Table 2.17 Selected indicators, electricity, 1927

	Hydroelectricity			Thermoelectricity		Total
	n.º	kW	GWh	n.º	kW	GWh
Public Service	36	27 815	45	104	66 901	91.1
Auto-Production	23	5 515	9.7	151	33 925	41.2
Total	**59**	**33 330**	**54.7**	**255**	**100 826**	**132.3**

Source: DGSE, *Estatística das Instalações eléctricas*, 1927.

Before 1927 we only have partial information about the electricity sector. For 1918 Apolinário[271] compiled information on both the power of hydro and thermo utilities but did not include the factories that employed electricity for their own use. Apolinário records 18 hydro-electricity utilities on the mainland with 2 335 kW, 8% of the 1927 values for public service. In 1923, a magazine published information on the denomination, localization and power of electric

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[270] DGSE, *Estatísticas das Instalações eléctricas*, 1927 to 1970.

[271] Apolinário (1918).

distribution companies, without reference to their energy input[272]. Comparing this information with the official statistics of 1929 we are able to distinguish which ones produce hydro-electricity and which ones produce thermoelectricity. Hydro-electric power in that year amounted to 12 835 kW. Madureira and Baptista have compiled information on the initial power of the most important utilities (both public and private service)[273]. The reconstructions of hydro-electric power for 1923-1927 and 1894-1923, for the public service, and for 1894-1927 for the private service can be performed taking this information into account. As authors only report the main hydroelectric power plants only part of the increases in power is covered. I distribute the power difference in benchmark years assuming a constant growth rate. In order to calculate production, we need to know for how long the utilities were working. This not only depends on the consumer demand but also on the quantity of precipitation in each year. Apolinário estimates a use of 20 hours a day during 365 days a year to calculate the 1918 production, but this could not be further from truth. I assume an average of 1 700 hours/year consistent with the late 1920's statistics[274]. Since 1927 there have been official reports on hydro-electricity production[275] but until 1969 only mainland Portugal was included. Madeira has only had hydropower since 1953 and statistics on production until 1961 can be found elsewhere[276]. I have connected the two benchmark production data years 1961 and 1970 for that island assuming a constant growth rate. Azores´ hydropower production until 1970 has to be reconstructed with based on power registers that can be found in Simões and online[277]. The power of Azores´ plants is multiplied by the time of use in mainland hydraulic plants. As the intensity of use of Azores´ power plants is systematically lower than mainland power plants during the 1970s, the

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[272] *Revista de Obras Públicas e Minas*, p. 71, 1923.

[273] Madureira and Baptista (2002), pp. 12-14. If power is expressed in kVA conversion to kW follows such that 1 kVA= 0.8 kW.

[274] In the year of 1927 intensity of use was 1 700 hours; in 1928 2 022; in 1929, 2 038 hours. I took the 1927 value as the early twenties were particularly dry years, see Marques (1991). In order to check my assumptions on power (Island and Mainland) just divide estimate hydro-electricity production 1894-1926 (Appendix) by 1700.

[275] DGSE, *Estatísticas das Instalações eléctricas*, several years. For 1971-2006, I used the Energy Balances from DGE.

[276] MOP (1962). Only approximate values are given as they were taken from a graph: 1953 – 4.9 GWh; 1954 – 10.5 GWh; 1955- 12.7 GWh; 1956 – 14.5 GWh; 1957 -16.2 GWh, 1958 – 17. 8 GWh, 1959 – 19.8 GWh, 1960 – 21 GWh, 1961 – 21 GWh.

[277] Simões (1997) and www.arena.com.pt/hidrica.html. Power for 1923-1926 – 680 kW, 1927-1928 – 2 104 kW, 1929-1934 – 2 899 kW; 1935 – 1950 – 3 371 kW, 1951-1953 – 4 779, 1954-1965– 6 531.2; 1966-1970 – 7 675 kW. Accumulated power since 1894 was 8 011 kW in 1966 but was reduced to 7 675 kW in order to match DGSE statistics for 1970. Conversion of 1 kVA =0.8 kW which can produce small differences between sources.

estimated production is reduced by 20% for the years 1951-1969[278]. Net imports of electricity are added after 1927[279]. Other sources of electricity are only present after 1980.

There are various ways that one can calculate the primary content of electricity. One is to apply the thermal substitution method, which does not make much sense for countries that rely only in hydropower. The IEA method considers the heat generated in the reactors of nuclear power stations and in geo-thermal plants, applying conventions of 10% efficiency for geo-thermal and 33% for nuclear power. Electricity for hydro, wind, tide/wave/ocean and photovoltaic is considered by its heat content, the level where multiple energy uses are practical. A third choice is to use the heat content of electricity produced for all these renewable and non-conventional sources.

In order to be consistent with the wind and water series, one should assume different efficiencies to account for the potential energy of water and wind lost at the turbines or for the heat released in the production process. This however complicate things as evolution of efficiencies of different processes are difficult to determine. We could assume 75-90% efficiencies for hydropower turbines, 20-40% of efficiency for wind production[280] and an efficiency of 10-20% for photovoltaic and geothermal electricity with basis in some values suggested by the literature[281]. I do not apply this range of efficiencies in the next chapter due to compatibility issues with international data and some uncertainty of the estimates[282]. Instead, I apply the heat content method as chosen by Gales *et al.* (2007), Bartolleto and Rubio (2008) and Kander (2002). It has the advantage of making international comparisons easier to understand, as the growth trend and the shares of the different primary electricity forms are equal to the final electricity growth trends and shares. The appendix includes however a calculation of the two methods. For most of the time period, considering various efficiencies will have small implications in the total due to the predominance of hydropower which have very high efficiencies. It could change however our interpretation in the last part of the series, where other forms of electricity are

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[278] 1970 Azores hydro production was 22.3 GWh. Applying the intensity of use in mainland Portugal (3 723 hours) to the installed power, the production of that islands would be 28.5 GWh. Correction is only applied to the years 1951-1970, when intensity of use varied from 2 500-4 000 hours.

[279] Net imports 1927-1970 and 1971-2006 from Figueira (2003) and from DGE (1971-2006).

[280] This is probably a maximum of efficiency at optimal conditions.

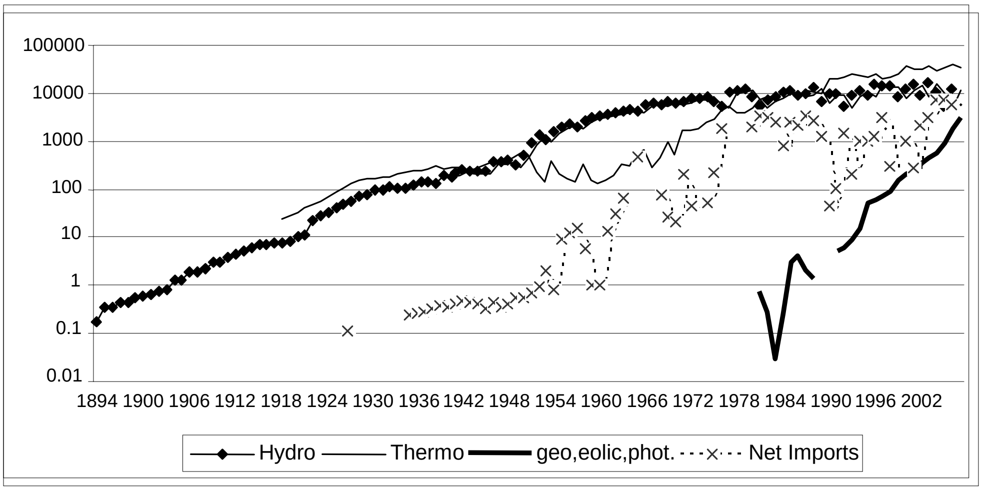
[281] Wind-power and photovoltaic electricity, values suggested by Roth (2005), Hydropower by Malanima (2006a).

[282] See Warr *et al.* (2011), for example. The authors consider lower efficiencies of only 15% for wind-power, 7% for photovoltaic, while considering higher efficiencies for geo-thermal and hydropower in relation to the ones suggested.

present. For countries that have a large share of nuclear power, the level of consumption will be 1/3 lower with this method.

Figure 2.7 shows production of both thermo and primary-electricity. There are three phases in hydroelectricity growth. Until the Second World War, hydroelectricity shares were 30-40% of total electrical production.

Fig 2.7. Thermo, hydro, geo, aeolic, photovoltaic electricity production and imports (1894-2006), logarithmic scale



Sources: See text and appendix. Negative values of net imports (1964, 1966-67, 1973, 1977-79 and 1999) are not shown in the graph.

The 1950s and 1960s were the golden years of hydropower, with strong governmental investment. At the end of the sixties there occurred a shift in investments, and large fuel plants were considered to be a better option. Thermo-electricity has been growing in importance ever since. In the last decade, drought years have contributed to irregularity of hydropower production, which has to be supplemented by imports. There has been an increasing investment in renewable electricity other than hydro power. In 2005, wind accounted for more than 1/3 of hydroelectricity production. Other sources are still in an experimental period. Portugal inaugurated its first wave power plant in September 2008, which when completed will supply 15 000 families. One of the largest PV solar plant in the world was inaugurated in 2008, with a total power of 45 MW and the capacity to supply 30 000 homes.

2.14 Others[283]

This heading includes energy use of sulphite liquors and bleaches (residuals from the paper industry), solid urban wastes and biogas. These energy sources are entirely consumed by the electricity and cogeneration power plants. Registers from solid urban wastes and biogas can be found in Energy Balances after 1998[284]. Sulphite liquor and dark bleach records came from Electrical Installations Statistics after 1954[285] and from Energy Balances after 1971[286].

2.15 International database[287]

This thesis contains a strong comparative perspective and relies on databases which were constructed and provided by many authors. In the next chapter we make use of those databases to compare energy transitions in Portugal in a wider context. The international database includes the following countries: Canada, France, England & Wales, Italy, Germany, the Netherlands, Spain, Sweden, the US. The main original sources used for each country are presented bellow and a discussion follows in the end for the methods employed in order to reach a minimum compatibility.

Canada – Steward, F. R. (1978), (Wood, Coal, Water power, Oil and Natural gas. 1870-1970; Mitchell, B.R. (2007) for muscle power and IEA (1960-2008). GDP figures from Maddison, A. (2008).

France – Gales, B. and Warde, P. (unpublished) – 1800-1960, and IEA (1960-2006). GDP figures from Maddison, A. (2008).

Italy – Malanima, P. (2006), 1861-2000 and IEA (1960-2006). GDP figures from Malanima, P. (2006).

Spain – Rubio, M. (2005), revised wood series[288]; IEA (1960-2006); Odyssee (1980-2006). GDP figures from Maddison, A. (2008).

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[283] Appendix B, Table B.1, col.9 and App. II, 8.

[284] DGE, *Balanços energéticos 1990-2006*.

[285] DGSE, *Estatísticas das Instalações Eléctricas*, 1954-1970.

[286] After 1990, the inclusion of heat in energy balances led to a series break, resulting in an increase in sulphite liquor energy consumption.

[287] Benchmarks figures for the various countries are presented in Appendix E.

[288] This revised series can be found in Gales et al. (2007).

England & Wales – Warde, P. (2007), revised oil figures[289], and IEA (1960-2006). GDP figures from Maddison, A. (2008).

Germany –Gales, B., Kander, A. and Warde, P. (unpublished) 1815-2000 and IEA (1960-2006). GDP figures from Maddison (2008).

Netherlands – Database from Ben Gales. Gales, B. et al. (2007), and IEA (2000-2008).

Sweden – Kander, A. (2002) 1800-2000 and IEA (2000-2008). GDP figures from Krantz and Schön (2007), adapted to $1990 PPP.

US – EIA (2009), Schurr and Nestchert (1960), IEA (1960-2008). Mitchell, B.R. (2007) and US Department of Commerce (1975), *Historical Statistics of the United States* were used in order to account for animal power. GDP figures from Maddison (2008).

Scarcity of data or different individual decisions of the various researchers cannot be totally solved but a minimum of compatibility is desirable. Primary electricity is recalculated by its heat content whenever was the case (US, Canada, England &Wales – only for nuclear). Feedstocks need to be treated consistently in the various databases. For the purposes of comparison in Chapter 3, non-energy uses of oil and natural gas are excluded from the totals. This is done for all the series from 1960 onwards with the exception of the Netherlands, Sweden and England and Wales, which already account for this. The series CRW (Combustibles, Renewables and Wastes) of International Energy Agency was used in many cases. For Spain I use the data from Odyssee on residential firewood use (1980-2006) which gives higher figures than Rubio.

2.16. Concluding discussion

This chapter presents the main calculations and assumptions necessary for the construction of an historical index of primary energy. In my opinion, this index is very useful for achieving a degree of understanding of the level and mix

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[289] The revised oil figures can be found online in http://www-histecon.kings.cam.ac.uk/history-sust/energyconsumption/.

of Portuguese historical energy resource use. As in reconstructions of national accounts, this work presents point estimations instead of confidence intervals. Some of the difficulties in estimating reliable data are directly related with the fact that energy use occurs in every dimension of human life. Energy consumption occurs in both the productive and informal sectors. Estimating food consumption or firewood use is almost like estimating the size of the informal sector in historical national account reconstructions.

A historical work like this one always relies on many methodological decisions. Unfortunately, is not possible to apply a perfect guideline for what is considered good practice today by international organizations. Even important organizations such as National Energy Agencies, International Energy Agency (IEA), United Nations or IPCC change methodology frequently in such cases such as which calorific content to employ, how to treat bunker fuel, non-energy uses, methods of reporting emissions, how to consider new energy carriers and how to treat non-thermal electricity. This is because energy transitions are permanently occurring making some methods outdated. One hundred and fifty years of energy history can never reach a methodological perfection and I am aware of this fact. Some of the methodological decisions are almost a matter of taste and it is not clear that different decisions will not be valid.

I have decided to omit non-energy uses and feedstocks of oil and natural gas in the international comparison in Chapter 3, although I provide the data for non-energy uses in the Appendix and as a separate heading in some discussions. This makes the level of primary energy use in some countries relatively lower in relation to other countries. This is the case of the Netherlands, for example, a country that has a well developed petro-chemical industry. It makes it easier, however, to estimate apparent CO_2 emissions from fossil fuel combustion.

I have decided to consider as primary energy the kinetic and potential energy of the wind and water that is lost at the turbines, but employ the heat content method for primary electricity (nuclear, hydro, aeolic, photovoltaic and geothermal electricity) . The choice of the heat content method has implications for the interpretation of energy use, and it will make countries with large shares of primary electricity look more efficient than ones with large shares of fossil fuels. France and Sweden have relatively lower levels of primary energy consumption for the later part of the series, *vis-à-vis* the IEA accounting method, due to a relatively high share of nuclear power in primary electricity.

As we understand, the most important assumptions relate to traditional energy carriers. The estimates of firewood, wind, water and food consumption until 1950 should be always carefully interpreted. Given the scarcity of some of the data involved, the author is relatively satisfied with the magnitudes obtained.

Below, a short discussion follows about whether or not different assumptions could substantially change the results.

Firewood: The most relevant part of the wood results for the totals relates to the level of rural households' residential wood consumption. Inquiries used during 1938-1950 were extrapolated backwards to 1856, using the lower range of firewood quantities. So, of course, if we used a higher range in 1938-1950 rural per capita values would be higher in the first part of the series and would decline quicker in the second part of the series. But this would make pre-industrial levels of firewood consumption much higher than in other Mediterranean countries. Although a different per capita value could change the percentages of wood consumption in the total figures, it would not change the idea of the importance of household wood consumption in the total level of consumption. Could 1856 levels of wood consumption per capita be significantly higher than 1938-1950 levels? For this to happen, it would be necessary some kind of improvement in household's equipments, rural incomes and some kind of energy transition in the rural areas. It is well established that nothing like this happened to a large degree. A less relevant issue for the totals, but more important to independent comparisons is the size of industrial firewood consumption before 1943. This figure could probably be improved in the future.

Animals: Figures for animals are based on national census; sizes are established by the weight at the slaughterhouse, by looking into the breeding characteristics and by employing the Kander and Warde[290] method.

Food: Food intake before 1938 is estimated based on the height/weight assumptions of Portuguese population and its distributional activity. The average *kcal* intake varies little and cannot be much higher or lower than estimated by given other intermediate inquiries, opinions of experts and food production + imports figures. However, this method does not take into account the variation in agriculture production and it may hide malnutrition in certain periods such as world wars. Future research can account for this. Still, food is a small and falling share of total energy.

Water and wind, and hydropower (1894-1927): Estimations are based on the power of the devices and assumptions are made on the time of use and efficiency of the devices. There are some uncertainties regarding the efficiency

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[290] Kander and Warde (2011).

of power devices and capacity use (wind and water). These have no influence in the final results.

Coal: There is still a little uncertainty about whether the data until 1913 incorporates coal for foreign boats in Lisbon harbour or not.

Oil and Natural Gas: No uncertainty.

In the following chapter, I analyze the energy transition in Portugal by establishing a comparison with other industrialized countries and focusing on the consumption of traditional and non-renewable energy resources.

Chapter 3

Long-run energy transitions and CO_2 emissions: Portugal in comparative perspective

3.1 Introduction

Past energy transitions are associated with an increase in the quantities of energy and a shift from traditional sources of energy towards fossil fuels and electricity. Nowadays, energy transition in developed societies means a shift from fossil fuels towards renewable sources of energy and more sustainable patterns of energy production and consumption that allow mitigation of the problems of global warming or the foreseen exhaustion of affordable fossil fuel reserves. However, even if it is well established that major energy shifts have happened at some point in time in all of the post-industrialized societies, there is still a lot of uncertainty regarding the magnitude, nature and pace of the transitions across time and space, and the impact that those energy shifts have brought to the environment.

This chapter uses the database described in Chapter 2 to provide a characterization of the long-run Portuguese energy transition from organic sources towards fossil fuels and its associated environmental consequences, and compares the energy shifts with seven European countries and two New World Countries.

The first aim of the chapter is to assess the main changes in the energy systems of our set of countries, and to what extent Portuguese energy transitions are similar to the experiences of early-comers. I present the long-run levels of per capita energy consumption across countries and compare how the transition from organic sources towards fossil fuels proceeded, by analyzing the composition of the energy baskets and major energy shifts. Was the shift towards high-energy quantities a universal phenomenon? Or were there drastic differences in the magnitude of the shift across countries? Did different energy eras have more or less the same impact on our set of countries? Or can we find significant differences among countries, which could be explained by a different stock of natural resources? How quickly were traditional energy carriers displaced by fossil fuels?

A second aim is to compare the levels and the shape of long-run evolution of energy intensity in Portugal and in our set of countries, and to identify some possible reasons for both common and divergent patterns.

A third aim is to quantify the importance of the factors behind the changes in long-run energy consumption and CO_2 emissions in the various countries. Long-run growth of incomes per capita and population caused an increased demand for energy. However, changes in the relation between energy and economic growth also occurred, either in the direction of saving energy, or spending more energy per unit of economic growth. In addition, the evolution of fossil fuel carbon dioxide emissions depended not only on changes in energy demand but also on changes in the composition of the energy basket. By employing well-known decomposition techniques we will contrast the past and the present contributions of energy intensity and fuel switching to slow down energy consumption and carbon dioxide emissions. Are the present, energy policies of developed countries, which are aimed at mitigating climate change and improving energy efficiency more effective in decoupling energy and emissions from growth than in the past? Is there any important difference between the drivers of pressure in Portugal relative to other countries?

Last, this chapter will investigate how convergence and divergence in Portuguese economic growth were related to convergence or divergence in energy use and pollution.

3.2 Income per capita, climate, population and natural resources

The long-run evolution of energy consumption patterns depends on a variety of factors such as population characteristics, climate or income per capita. Natural resources endowments can be important for an understanding of the different energy intensity modes of development. This section presents some comparisons of the economic and geographic indicators, which are potential determinants of the intensity and pace of transition.

3.2.1 Income per capita

The countries in our set have had different development paths. In the early nineteenth century, with the exception of England & Wales and Netherlands, incomes per capita were rather similar across Europe. Portugal was one of the most backward countries, along with Sweden, and its income still represents about 3/4 of the average of our sample. Around 1870, countries were already much more divergent in income per capita, and Portuguese income per capita fell to about ½ of the average. By 1913, the income per head was only 32% of the average of the other countries. Portugal was the biggest loser in the first wave of industrialization which spread in the 1820s from England to Europe and North America. In fact, in addition to its already backward position in 1870, it was the country which grew least until World War I, in deep contrast to Sweden or Canada. After World War I, the US took over leadership of the world from England. In 1950, Portugal was joined in the category of underdeveloped European countries by Spain, in part due to the negative impacts of the Spanish civil war and World War II. Portuguese income per capita in 1950 had doubled compared to 1870, but the divergence relative to other countries was maintained.

Table 3.1 Per capita GDP in $1990 PPP

	1820	1870	1913	1950	2006
England & Wales	2 366	4 192	5 941	7 351	23 300
US	1 257	2 445	5 301	9 561	31 049
Canada	904	1 755	4 447	7 291	24 618
Netherlands	1 838	2 648	3 937	5 959	23 751
France	1 172	1 956	3 633	5 270	22 675
Germany	1 077	1 768	3 543	3 881	19 993
Italy	1 117	1 589	2 670	3 639	20 077
Spain	1 008	1 218	2 048	2 196	18 449
Sweden	635	1 092	2 486	5 996	23 362
Portugal	923	997	1 207	1 998	14 219
Portugal/Average (%)	73	48	32	35	62
World	870	1 261	1 524	2 111	7 614

Source: Maddison (2008) for world average.

In the post-war period, incomes per capita increased much more rapidly across the countries of our database and Portugal and Spain grew faster than any of the other countries. It was only in this second half of the 20th century that Portugal forged ahead in terms of the world average per capita income. Hence, Portugal was an underdeveloped country even by world standards in 1950.

Presently the differences between Portugal and the core of industrialized countries are smaller than in 1870, but larger than in 1820. Portuguese per capita GDP nowadays represents about 60% of the corresponding average for our set of countries. Today all these countries are considered post-industrialized societies. Although Portugal is today considered a developed country, its economy is still substantially weaker than most of the top countries in Europe.

3.2.2 Geography and natural resources

Table 3.2 Population characteristics

	Area	Population		Density (inh/km^2)	
	1000 km^2	1870	2006	1870	2006
England & Wales	151	21 696	53 129	143.52	351.44
US	9 827	40 241	298 444	4.10	30.37
Canada	9 985	3 801	33 099	0.38	3.31
Netherlands	42	3 610	16 510	86.93	397.58
France	552	36 870	60 876	66.85	110.38
Italy	301	27 390	58 259	90.90	193.35
Germany	357	40 805	82 422	114.29	230.86
Spain	506	16 060	41 324	31.74	81.66
Sweden	450	4 169	8 975	9.26	19.93
Portugal	92	4 340	10 599	46.97	114.72

Source: Maddison (2008).

In relation to the countries of our database, Portugal belongs to the group of small countries on par with the Netherlands. The size of its domestic demand in 1870 was small, comparable with the Netherlands, Canada and Sweden. As can be seen from table 3.2, population grew by a factor of 2.4 between 1870 and 2006. The growth of population varied by a factor of 2-3 in most of the countries, with the exception of the Netherlands, the US and Canada. The Netherlands quintupled its population between 1870 and 2006. The US and Canada were new world countries that received a massive influx of migrants; population grew by a factor of 7 and 9. Canada, the US and Sweden are the countries with the lowest population densities in our sample, while the Netherlands, Germany, Italy and England have the highest densities. Low population densities require more energy per head of population, as goods and people need to be transported over longer distances. In theory, countries with lower densities can have a relatively wider incentive to adopt capital and resource intensive technologies as population is prone to be relatively scarce in relation to the natural resources of the country. However, high densities can also be advantageous when it comes to successfully spreading energy technologies, especially those that require concentration of population and have increasing returns of adoption, such as in electricity or gas networks. Countries with high population densities are likely to use their resources in a more efficient manner.

Climate can determine, to a large extent, the level of energy consumption across nations. In pre-industrial societies, space heating constituted the most important energy need to be satisfied and it was the most important explanatory factor in energy consumption variations across regions. Nowadays, although to a smaller degree, it can still explain differences in consumption patterns in household and service sectors. In this respect, Portugal has favourable climate conditions. Its climate is characterized by hot and dry summers and humid and mild winters, with an average mean temperature of 18ºC in the South and 13º C in the North. The energy needs for space-heating, measured in heating degree-days, are the lowest of the EU-15 countries, followed by Italy and Spain, and just one fourth of Sweden, the second coldest country in EU-15, after Finland (see Table3.3).

Table 3.3 Heating degree-days, selected countries

	Heating Degree Days (HDD)
EU-15	3 380
France	2 494
Germany	3 358
Italy	2 085
Netherlands	2 905
Portugal	1 302
Spain	1 856
Sweden	5 423

Source: Gikas and Keenan (2006)

Natural resource endowments can be an important factor in explaining the energy mix, speed of energy transitions and the evolution of the energy intensity of the economy. If possibilities of economic growth were biased through the use of resource intensive technologies, countries that were more endowed could have a relative advantage over others. Table 3.4 shows some of the estimates for energy resources endowments at the time they were important in the energy budget of industrialized societies.

Table 3.4 Energy resources, selected years

	Forests	Coal	Oil	Natural Gas
			Reserves	
	ha/p.c	1000 tonnes/p.c	barrels/p.c	m3/p.c
	1900	1913	1950	1970
US	2.89	39 328	172	37 285
Canada	59	*157 191	86	69 491
UK**	0.04	4 146		19
Netherlands	0.04	714	5	186
France	0.25	17 583		5
Italy	0.12	7		6
Germany	0.25	11 187	2	6
Spain	0.35	433		
Sweden	3.89	20		
Portugal	0.36	3		
World		4	38	

Sources: Forest area in Zon (1910) and in Gomes *et al.* (1945) for Portugal. Coal Resources: Dominian (1915); Natural Gas reserves for Western Europe in Vries and Kommandeur (1975), Canada: Quirin (1983), US: Oil reserves: Woytinski and Woytinski (1953).

An extensive analysis of the world's forest resources was made by Raphael Zon for the year 1900[291]. At the turn of the century, the proportion of land covered by forest area in all the countries, except Canada and the US, was smaller than it is today. As a result of population pressures for food resources and industrialization needs and early use of fossil fuel sources such as peat and coal, forests occupied an area of only 5 and 7% in the UK and Netherlands, respectively, with a per capita endowment of only 0.04 ha. The forest area in Spain and Italy was also much diminished, and comprised 13% and 14% of the land area, respectively, although Italy had substantially less forest resources on a per capita basis. France, Portugal and Germany had more favourable forest resources with 21%, 19% and 25% of the land covered by forests[292]. These countries and Spain had a per capita endowment of 0.25-0.36 ha. All countries except Sweden, the US and Canada were wood importers for building purposes, although Spain and Portugal were also exporters of cork. England, for instance, had a dependency of 80% on wood and imported about half of the wood traded in the world markets. By contrast, Sweden, the US and Canada were extremely

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[291] Zon (1910).

[292] Although Zon (1910) characterized Portugal as a deforested country with only 5% of forests, he used partial statistics which do not account for the real size of forest.

well endowed with forest land, even if we consider the larger heating needs, with a per capita endowment of 10 to 200 times that of Portugal in 1900.

Fossil fuel reserves were even less well distributed. As the estimates of fossil fuel resources for coal in 1913, oil in 1950 and Natural Gas in 1970 indicate, Portugal had almost no fossil fuel reserves at the time when each of the fuels gained relevance in the energy system of industrialized societies. In 1913, when the first inventory of coal resources of the world was made, England had already exploited its most economically viable reserves as a result of large consumption and exports to the rest of the world. Its coal endowments were characterized by high quality and concentration in extensive fields with ease of access to the sea and centres of consumption[293]. Canada, the US, Germany and France were the countries with more endowments per capita, although reserves for Canada were highly overestimated and should be interpreted with care[294]. Oil and natural gas were also abundant in Canada and the US. Europe practically lacked oil. The situation was slightly better for natural gas. Most of the reserves of natural gas in Europe were found in the 1960s - 1970s. Nowadays, the United States produces 1/5 of the world's natural gas. Canada occupies fourth position in world production. The Netherlands and the UK are the most important European Union producers.

3.3 Energy consumption and energy per capita

Portuguese energy consumption rose by a factor of 15 in 150 years, with two distinct phases (Fig. 3.1):

1. From the beginning of the period until the end of World War II, i.e., 90 years, total primary Portuguese energy consumption rose by slightly more than 1% a year.
2. After the end of World War II, energy consumption rose at a much higher rate of almost 3% a year.

The differences between the two phases are accentuated when measured in per capita terms, since the population grew at a higher rate (0.8% a year) in the first period than in the second period (0.4%).

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[293] Woytinsky (1953).

[294] Woytinsky and Woytinsky (1953). Estimates in 1913.

Figure 3.1 Energy consumption in Portugal 1856 – 2006 (PJ)

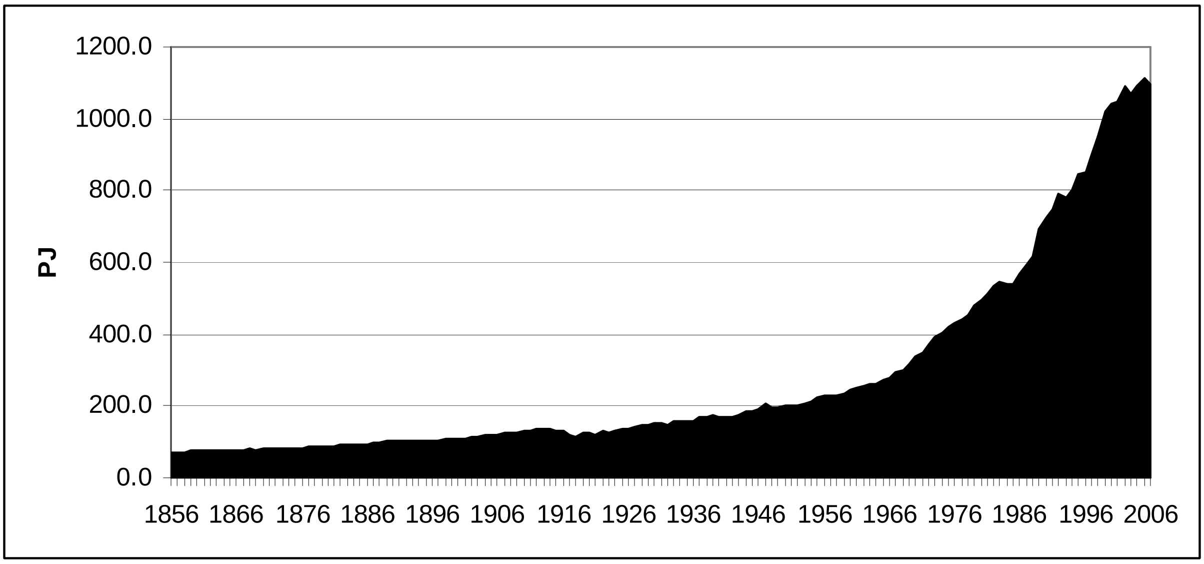
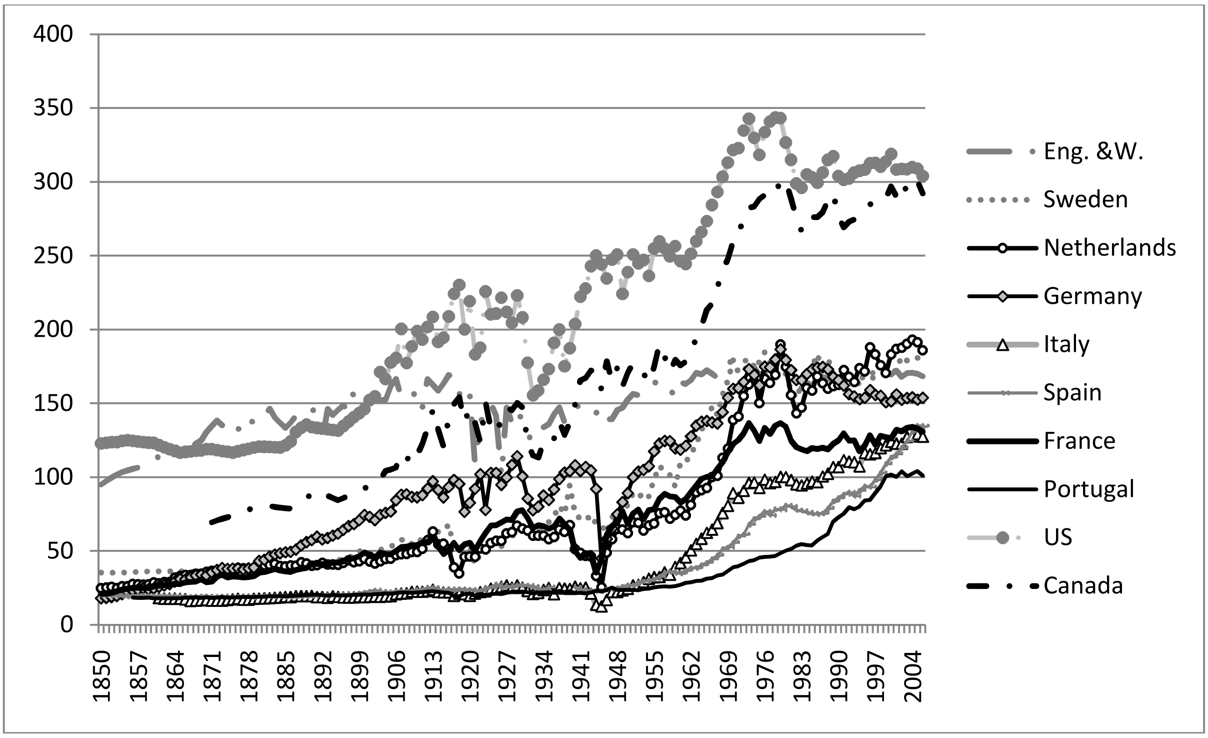


Figure 3.2 Energy per capita in selected countries, GJ



Population growth levelled energy consumption per capita, which in the very long-run grew by a factor of 6. Until the end of World War II annual growth in per capita terms was very small (0.2%) and energy consumption per capita was practically maintained at the level of 20 GJ per capita/year. The vast majority of the increase in per capita energy has therefore taken place in the post-war period and is clearly associated with the beginning of the convergence with the core. Since that time, per capita energy consumption has grown at an annual rate of 2.5%.

Portugal's long-run trend of energy consumption per capita presents a more comprehensive picture if put into a multi-country perspective (see Fig. 3.2). In the long-term view, all the countries exhibited increasing trends in energy use, a well-established feature of industrialization. However, the points of departure, magnitude and pace of that shift were significantly different across countries. Globally we can distinguish three main epochs of energy pathways that have long-term relevance: 1850-1938 (differentiated energy paths); 1950-1973 (extreme growth) and 1973-2006 (stagnation in all high consuming countries).

The first phase is characterized by different points of departure and differences in the level of energy per capita growth. We can distinguish three regional groups of resource use. The first group comprises the pioneers in resource intensity. In 1850, England & Wales and the US were already above all others in the energy consumption per capita indicator. Besides, being already characterized as the two first industrial nations of the world, they were also extremely well endowed with natural resources. In the English case, the abundance of natural resources was due to an extremely highly productive agricultural soil and vast and high quality coal reserves. Additionally, large increases in the level of energy per capita indicator had occurred in the early 1800s. On the other hand, the US and Canada had excellent natural resources: land, coal and oil reserves, hydro-power and vast forests. The US and Canada would surpass Britain around 1913 and 1940, respectively, following a resource-intensive path. The fact that these two countries became the wealthiest in the world fits well with the model in David, where a capital-intensive or resource-intensive path is the most fruitful in terms of technological progress[295]. England and Wales, the US and Canada form a long-term energy path that has no parallel with the rest of Europe – from 1850 to the present day in Canada and the US, and from the eighteenth century to World War I in the case of England.

Clearly below those three countries, the rest of Europe had a level of 18-35 GJ per capita in 1850. A second group, constituted by Germany, Sweden, and France, and accompanied by early-comer the Netherlands, would soon diverge from Southern Europe. They can be labelled the energy followers, attaining 60 GJ-100 GJ per capita in the late 1930s. They were characterized by a different stock of natural resource endowments and departed from very different levels of

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[295] David (1975).

income. Sweden had a GDP per capita of only 40% of the Netherlands in 1870. By 1938, their levels of income were quite similar and the difference in incomes between the poorest and the richest was only 20%.

A third group of countries is constituted by Portugal, Italy and Spain. They can be called the energy laggards. This regional group followed a very low energy per capita path until World War II at levels between 18-25 GJ p/c, less than half the Swedish, Dutch or French consumption. If we consider the fact that the typical energy transition in Europe was characterized by an increase in the availability of energy, then this group had an atypical transition. In fact, these ranges of values are considered by Grübler to be the typical per capita consumption of pre-industrial societies[296].

The second phase (1950-1973) sees most of the countries increasing their levels of energy consumption per capita at a very fast rate, doubling, tripling or even quadrupling pre-World-War II levels. Still, the upswing is much softer in England, which loses the character of resource-intensive country in the early 1970s. The differences between energy per capita in England and the two New World Countries widen, while the gap narrows in relation to the rest of Europe. In the case of Southern Europe, the Portuguese energy per capita growth is lower than in Italy or Spain. This can indicate a different pattern of intensity in the process of industrialization. One hypothesis is that the new energy cluster based on oil had a relative lower importance in the Portuguese society.

The oil crisis is a clear trend reversal for most countries, which might indicate that modifications in energy prices did have an influence on the paths of energy use. After the 1970s, a stabilization of energy availability per person occurred in countries with consumption levels above 150 GJ per capita. Portugal, Spain and, to a lower extent, Italy do not share the same trends. In the case of Portugal and Spain, this can probably be associated with the low levels of per capita energy use in the 1970s.

Concluding, at the level of energy per capita indicator Portugal is characterized by a long-run low energy consumption energy path. It shared this characteristic with Spain and Italy until the eve of World War II. In comparative terms, the doubling of energy consumption per capita until the oil crisis is not particularly impressive. Portugal doubled its energy consumption after the early 1980s from about 50 GJ per capita to 100 GJ per capita, a level similar to England in 1850, to Canada in 1900, and to Northern Europe in 1950-1960.

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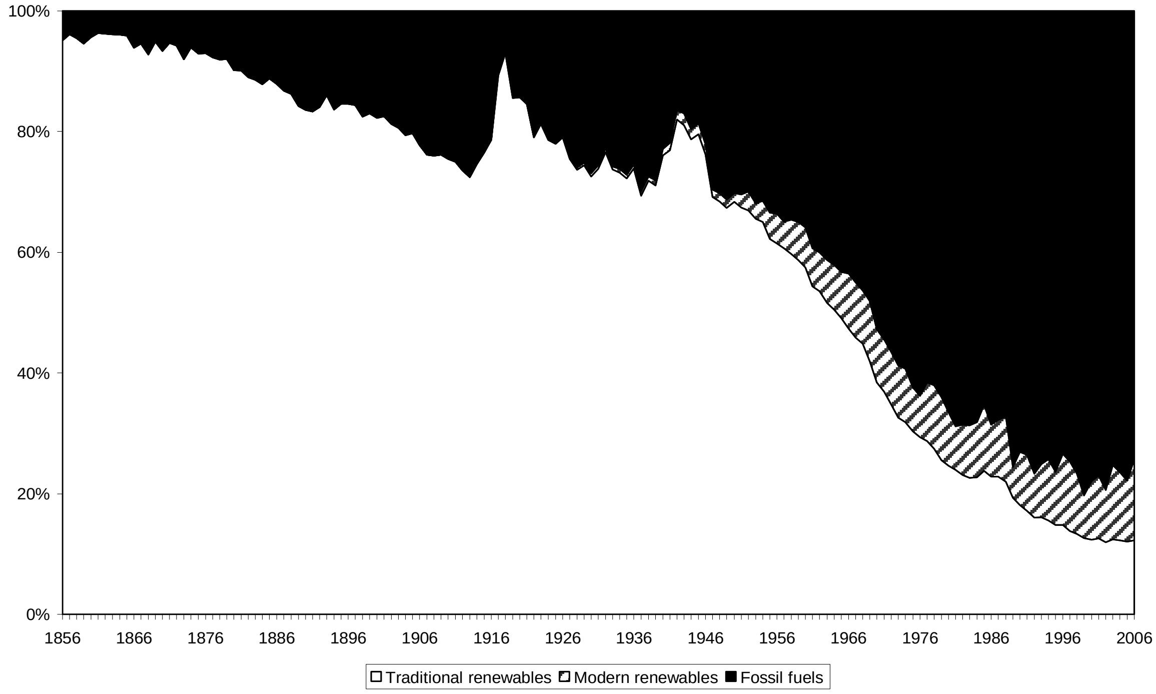
[296] Grübler (2004).

3.4 Energy mix in Portugal

The calculations performed in Chapter 2 allow for a much more accurate picture of the energy system of the Portuguese economy in the period 1856-2006.

In terms of structure, a major long-run transition, from traditional renewable sources towards fossil fuels, took place during the 150 years of the study (see Fig. 3.3).

Figure 3.3 Renewable and fossil-fuel energy, Portugal, 1856-2006



Note: Traditional renewable sources include firewood, muscle, direct water and wind. Modern renewable sources include primary electricity, waste and all the traditional renewable sources used for production of thermal electricity.

The most striking feature is that this transition was remarkably slow. The share of fossil fuels increased from only 5% in 1856 to about 28% on the eve of World War I, but the interwar years were a period of stagnation in energy transition. On the eve of World War II, modern sources still accounted for only 30% of the energy total. After World War II, there was a rapid expansion of fossil fuels and a stagnation of the traditional renewable energy basis. Fossil fuels accounted for about one half of total energy in 1970 and peaked at 80% in 2000. Apparently, another transition from fossil fuels towards “modern renewable sources” has started to take shape in the 21st century. The expansion of modern renewable sources was visible after the 1950s with the investment in hydro-utilities, but stopped at the end of the 1970s. However, the change of energy policy that took place in the late 1990s with the ratification of the Kyoto Protocol has had an impact in recent years on the diversification and growth rate of modern renewable sources of energy.

If we look at the energy structure in more detail (Table 3.5 and Figure 3.4), there were very weak signals of a fossil fuel transition in 1856. Firewood was the major energy carrier with 57%, followed by muscular energy (35%). Coal accounted for only 5% of the total. The first transition to be noticed occurred between 1880 and 1913. Coal expanded its share in the energy basket, becoming the second most important energy carrier. This first expansion of modern energy carriers had less to do with substitution, and was mostly driven by urban industrialization and investments in railways, ports and town gas infrastructures.

Table 3.5 Composition of energy consumption in Portugal (1856-2006) (%)

	1856	1913	1950	1970	1990	2006
Food	19	15	16	12	7	6
Fodder for draught	18	12	8	3	1	0
Firewood & Others	57	45	44	26	14	11
Wind, water, heat	1	1	1	0	0	0
Coal	5	27	15	8	16	13
Oil	0	1	15	46	58	49
Natural Gas	0	0	0	0	0	14
Primary electricity	0	0	1	6	5	7

Despite being the energy carrier that expanded most until 1913, coal was incapable of surpassing the traditional energy basis. Consumption of coal was lower than muscle energy as a whole (feed and food) and much lower than wood. The transition towards coal was severely interrupted by the outbreak of World War I, and at the end of the thirties coal consumption was almost similar to 1913, with firewood still the most dominant fuel.

The second transition occurred only after World War II and coincided with a long period of economic growth and convergence to the European Core. In this period, oil and, to a lower extent, primary electricity expanded to most of the economic sectors of the society. Oil became more important than coal in 1951.

Fig 3.4 Energy consumption in Portugal (1856-2006), per carrier (%)

However, it only surpassed firewood in 1965, which shows the long-run importance of wood in Portuguese society. The dominance of oil as the leading energy carrier prevails to this day. Nonetheless, oil has been losing its share since the early 1980s in relation to other energy carriers; coal for power generation increased in the mid-1980s and natural gas was also introduced in the electricity sector in the late 1990s. There has been an increased interest in the promotion of renewable sources, but the outcomes of these policies had not had a significant impact on the energy system by the end of 2006.

3.5 Energy transitions: a global perspective

The evolution of the Portuguese energy system assumes different relevance if put into a wider perspective. This section characterizes how European and North American energy systems changed from a traditional energy basis towards the fossil-fuel based system of today, and identifies some common and divergent trends in the process of transition across countries.

3.5.1 The traditional energy basis

In pre-industrial societies, biomass was the almost only source of energy. Arable land provided the food for human beings, pastures the feed for animal power and forests provided the wood for heating and industrial needs. Water & wind were the two only non-vegetable sources of energy.

Table 3.6 presents some estimates of the traditional energy basis in early periods of economic growth for some selected countries[297]. Of the biomass sources, wood was the most important. In most of Europe the traditional energy basis was at the level of 15-20 GJ p.c./year, and Portugal was no exception to the trend. Only Sweden significantly surpassed this norm with 47 GJ pc in 1800. Although it had an important charcoal based iron industry in the nineteenth century, only 1/10 of the firewood was used by industry. Climate differences were the most important reason for disparities between Sweden and the rest of Europe. Improvements in household equipment were able to reduce Swedish firewood consumption to a significant degree, from 38 GJ pc/year to 26 GJ pc/year around 1850[298].

Table 3.6 Traditional energy carriers in early periods, selected countries, GJ p.c.

		Food	Feed	Wood	Total
France	1800	4	2	13	19
Germany	1815	4	3	8	15
Sweden	1800-1850	4	5	38-26	47-35
US	1850	4	17	96	117
Spain	1850	4	6	9	20
Portugal	1856	4	3	11	17
Italy	1861	4	3	9	17

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[297] Although coal was already used in all the countries, consumption was low, so we believe that substitution did not occur to any significant degree.

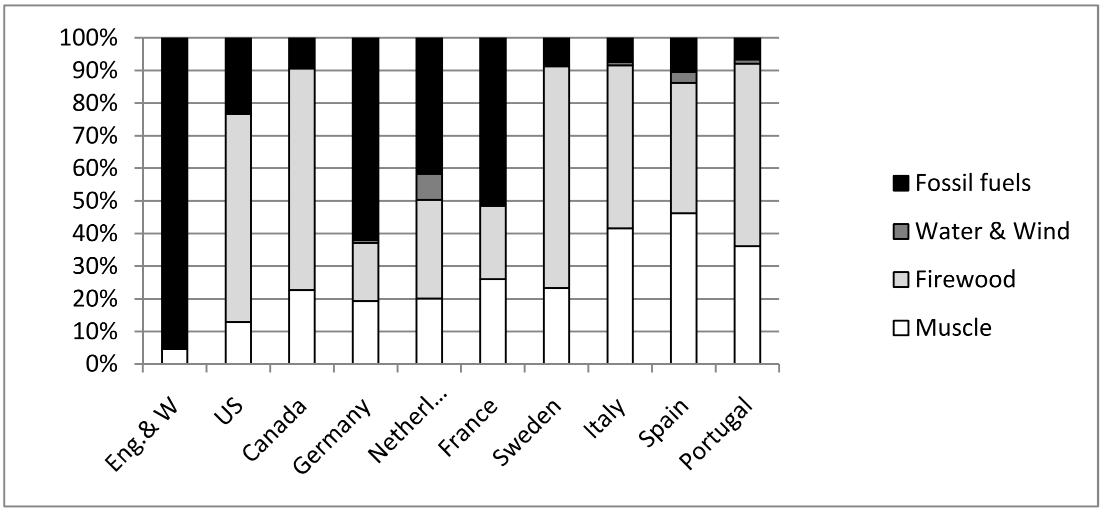
[298] Kander (2002).

If most of the differences in energy use in Europe were related to the climate, the extremely high consumption of wood and animal energy in the US around 1850 tells us a different story. The relative scarcity of population in relation to natural resources moved the US economy early on to a high profile of energy consumption. The estimates suggest that, in 1850, an American consumed 10 times more wood and 4 to 5 times more animal energy than an average European. That kind of shift would most likely have been ecologically impossible to follow in Europe, as population densities were substantially higher. England, a country that had comparable levels of energy per capita, would not have been able to raise its levels of energy consumption with domestic wood. By the early 19th century the whole of the country would have had to be planted with trees in order to replace all the coal consumed in the country; by the early twentieth century a land surface 10 times larger would have been required[299].

3.5.2 The uneven transition towards coal

In the early nineteenth century, the Industrial Revolution started to spread to other regions of the globe. The earliest date for which we are able to compare the full energy mix of Portugal to other countries is 1870, by which time there were already large differences between their energy structures (Fig. 3.5).

Figure 3.5 Composition of primary energy consumption in 1870, selected countries (%)



Sources: See Appendix E. Note: For the Netherlands firewood includes peat.

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[299] Sieferle (2001).

Around 1870, England, the coal-pioneer, differed substantially from most countries in terms of its energy mix, which was almost totally dominated by coal. The transition to coal was already visible in Germany, the Netherlands and France, which had a 40-60% proportion of coal in the energy mix. These three countries seemed to be following in the footsteps of England & Wales. In the Netherlands, the share of fossil fuels was even higher, as peat[300] (included with wood in the figure) had been used as an alternative to wood since the early seventeenth century[301]. In the remaining countries, wood and muscle were the main sources of thermal energy and power. Resource-intensive Canada and the US (to a lesser extent), follower Sweden, and the laggards Italy, Spain and Portugal all had high shares of traditional energy carriers, irrespective of their levels of per capita energy consumption. In the case of Canada, the US and Sweden (to a much lower extent), the high share of wood was also related with vast forests, cold climate and an early wood–intensive-based industrialization[302].

In Portugal, Spain and Italy, the high shares of traditional energy carriers were associated with a low penetration of coal. Until 1913, the widening of the differences in energy consumption between Southern Europe and other countries can be almost solely attributed to the differential adoption of that energy carrier. Figure 3.6 shows the gap of coal consumption in the various nations in 1870 and 1913. From 1870 to 1913, coal had become the most important energy carrier for all the nations, with the exception of Portugal. Its consumption was high in England & Wales, Canada, Germany and in the US (80-140 GJ), and lower in France, Netherlands, and in coal -poor Sweden (30-45 GJ). In Southern Europe, coal consumption was extremely low and did not allow the economies to go beyond their traditional energy basis. This suggests that the first wave of industrialization associated with the coal cluster (coal, steam engines, railways, navigation, iron and gas) had a differentiated impact across countries, being late and less intensive in countries with scarce fossil fuel sources.

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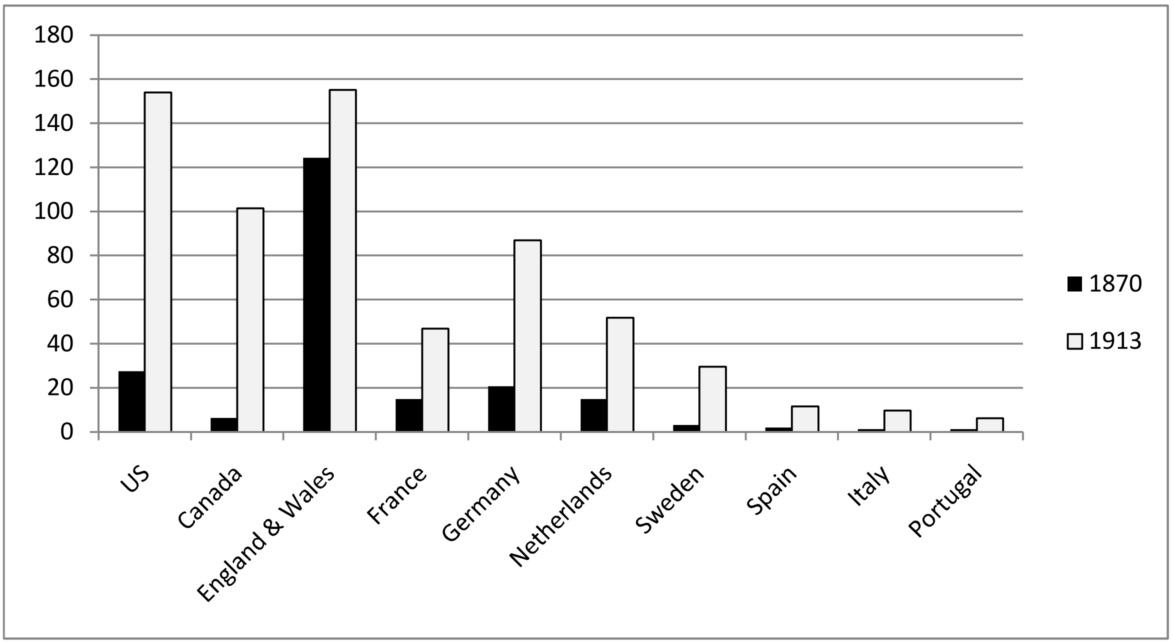
[300] Peat or turf is a partially decomposed form of vegetation which can be found in some areas such as wetland bogs. It is the earliest formation stage of coal, and can be used as a fuel.

[301] For an interesting interpretation of the role of peat in the rise and fall of the Dutch period of prosperity in the seventeenth century, see Zeeuw (1978). According to the author, in a period when the country was already much deforested, the existence of significant exploitable deposits of turf close to the waterways made peat a cheap alternative, as it could be easily transported. The use of peat allowed the Netherlands to double its renewable energy basis, with about 16 GJ pc being supplied by this fuel in periods of the seventeenth century. The increasing difficulty in exploiting peat due to the exhaustion of the resources, which were near the surface, is assumed to have been one of the reasons for the end of the Dutch Golden Age. In the early nineteenth century, peat still supplied about 7 GJ pc.

[302] Wood consumption per capita in 1870: 25 GJ p.c in Sweden, 47 GJ p.c in Canada and 76 GJ p.c in the US. This was not matched by any of the other countries, which had wood consumption levels around 6-10 GJ p.c.

Figure 3.6 Coal consumption per capita 1870 and 1913, GJ



Sources: See Appendix E.

Did coal substitute or supplement traditional energy carriers such as wood or animal energy? The initial transition to coal meant some substitution, at least in per capita terms, for wood. In England, the replacement of wood by coal for household needs had even preceded the Industrial Revolution. In some ways, the country had already been deforested by the early 17th century and the substitution occurred due to an acute timber famine, expressed by the rising prices of wood relative to coal[303]. For Robert Allen, it was the growth of London's population that ignited the rise of fuelwood prices and the use of coal, as it was responsible for a large and concentrated demand for fuel in a limited area[304]. As wood could not be transported over longer distances without a substantial rise in prices, coal was a much cheaper alternative. The transition to coal was not automatic: it required a learning process in how to heat a house with coal with the design of well-constructed chimneys in order to get rid of the unpleasant smell. In the US or Canada, large firewood consumers in the late nineteenth century, the transition to coal also meant a significant decline in wood consumption per capita as a result of substitution in manufacturing and in the household sector. By 1913, wood consumption had been reduced to about 20

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[303] See Nef (1932), Hammersley (1973), Sieferle (2001), Warde (2007), or Thomas (1986) for the debate on the extent of the fuel crisis in the country.

[304] Allen (2009).

GJ pc/year. In the US, the transition was far from abrupt, as wood was plentiful. In the initial phases of industrialization, wood also offered the advantage of clearing land for agriculture and building[305]. Only after innovations in the process of making wrought and cast iron with anthracite in the 1830s, was the coal age born. The availability of cheap and better iron allowed iron-machinery steam-power manufacturing to be located near the major cities and to displace the former wood-machinery and water-power light industry[306]. With an increase of urbanization and the appearance and marketing of iron-cooking stoves, coal spread to household uses[307]. To a smaller extent, wood was also replaced by coal in the urban areas of Europe, with the sole exception of Sweden and Portugal, where wood consumption per capita remained constant (see Table 3.7).

Animal power was more resilient than wood. Although there was some diffusion of steam-power for certain agricultural tasks such as threshing, agriculture largely remained non-mechanized. Table 3.7 shows the annual energy consumed by working draught animals per agricultural hectare[308] in 1870, 1900 and 1913. In Portugal, the use of animal power, already low by European standards, decreased slightly from 1870 to 1900, as animal power did not accompany the rapid increase in agricultural area. In most of the countries the use of animal power per ha increased during the period. Increases in agricultural production at this stage were still predominantly dependent on achievements in the organic economy, although the use of coal allowed to free forest for arable or pasture.

Table 3.7 Traditional energies during the age of coal

	England	France	Netherlands	Germany	Sweden	Italy	Spain	Portugal
				Wood per capita (GJ/pc)				
1870	0	7	11	6	25	8	8	10
1913	0	5	2	3	25	5	5	10
		Energy consumed by draught livestock per agriculture hectare (GJ/ha)						
1870	3.3	3.4	4.3	5.3	4.1	3.5	5.2	3.4
1900	3.9	3.6	4.3	6.2	5.0	6.4	4.7	3.1
1913	3.9	3.1	4.8	6.8	5.5	6.4	4.9	

Sources: Warde and Kander (2011) for energy consumed by draught livestock. For Portugal, own calculations. Agricultural land taken from Gomes *et al.* (1945).

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[305] Melosi (1982).

[306] Melosi (1982), see also Cowan (1987) for a systemic analysis of the delays in the adoption of iron stoves in America.

[307] Melosi (1982).

[308] Includes fallow, arable and pasture.

In conclusion, although there was some substitution, muscle power and wood (in much lesser extent) still retained some importance. The bulk of the difference in coal consumption per capita across countries was especially associated with the intensity of adoption of coal technologies (steam engines, railways, city gas) and the expansion of energy-intensive industries such as mining, iron and steel.

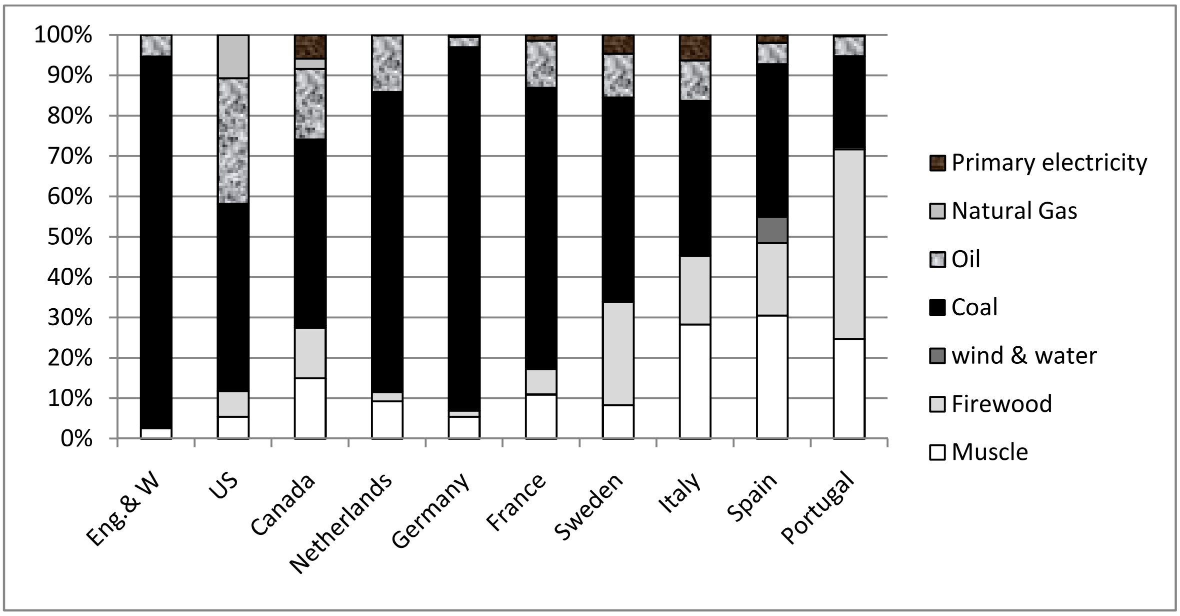
3.5.3. Early diversification of the energy basket: the interwar period

After the war, coal continued to expand its share of the total energy system in most European countries (with the exception of Portugal), but other sources of energy also become important, such as oil and hydro-power.

The late 1930s corresponds to the end of the first phase of differentiated energy pathways and the energy mix of our set of countries is represented in Fig 3.8. Compared to 1870, all countries now had a higher share of modern energy carriers in their energy basket. However, the degree of importance of each energy carrier varied greatly. In England and Germany coal comprised practically the whole energy system. Diversification in the energy basket was more visible in the US and Canada, which had comparable levels of energy per capita consumption in relation to England and Wales. Those two countries had early transitions to oil, natural gas and primary electricity (in the Canadian case). The same happened in Sweden and France in relation to Germany, for example, where primary electricity and oil were relatively more important.

In the countries with a low energy consumption path (Portugal, Italy and Spain), traditional energy carriers still had a very high degree of importance in the energy system. This was especially evident in the Portuguese case, still 70% dependent on firewood and muscle power. The Portuguese energy path until World War II did not differ much from Italy and Spain from a per capita perspective, but differed substantially in the penetration of modern energies. As seen in Fig 3.6, the levels of coal consumption per capita in the late 1930s were almost half of the Italian and Spanish levels. This gap was not compensated by a relatively high importance of hydro-power or oil. Contrary to what happened in Spain, and especially Italy, hydro-power had very little importance in the Portuguese energy basket before the 1950s. Instead, firewood compensated for most of the gap in modern energy consumption.

Figure 3.7 Composition of primary energy consumption in 1938, selected countries (%)



Note: The shares for Spain refer to the year 1935.

Sources: See Appendix E

The difference in wood consumption was not a result of substantial climatic differences, as Italy, Spain and Portugal had comparable levels of wood consumption around 1860. The transition to modern energy carriers in Spain and in Italy involved substitution between thermal sources (coal for wood) and a window of opportunity with an extremely efficient energy carrier: hydro-power.

The low level of Portuguese modern energy consumption can be further assessed by a comparison of the different uses of coal and oil and electricity across some European countries and the US (see Table 3.8).

The gap in coal consumption in Southern Europe in comparison with the economic leaders extended to all categories of use. It was lowest in the railway sector, where there were few alternatives to coal, and highest in household uses where competition with other energy carriers existed. The gap was so large that just for household uses England & Wales, the US, Germany, France and the Netherlands consumed more coal than Italy, Spain or Portugal did for all categories of use.

Figure 3.8 Differences in the Portuguese, Spanish and Italian energy mix (GJ per capita), late 1930s

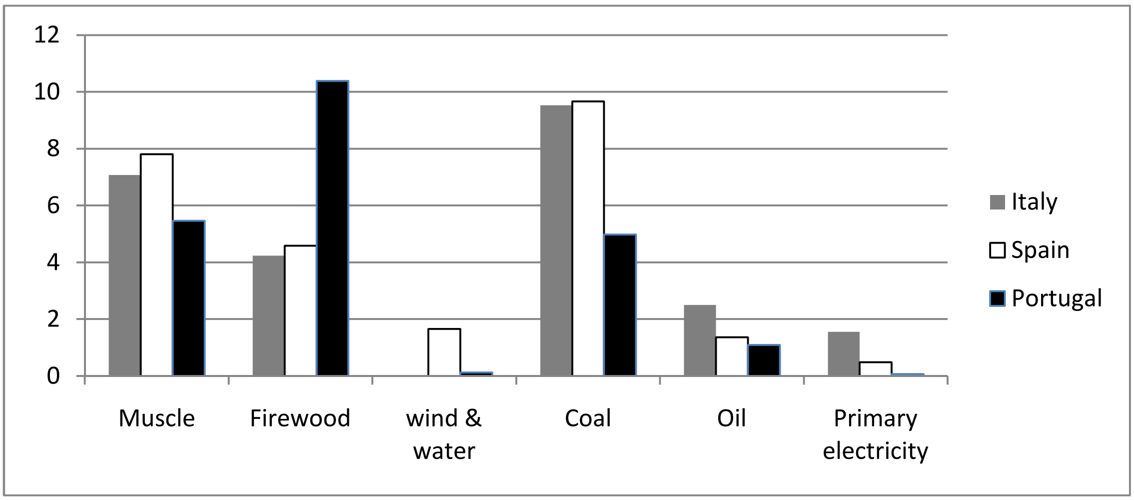


Table 3.8 Modern energy consumption in European countries and the US 1936-1939 (GJ/pc)

	Eng.&Wales.	US[a]	Germany	Neth.	France	Italy	Spain	Portugal
Total Coal	**120**	**89**	**75**	**43**	**44**	**10**	**9**	**4**
Railways	9	19	7	2	7	2.4	2.3	1.1
Steamships	1	0	2	3	1			0.1
Manufacturing	71	44	43	25	22	5.4	6.5	3.0
Domestic Heating	26	24	20	10	11	0.5	0.2	
Gas Works	13	1	3	3	3	1.5	0.3	0.2
Electricity[b]	**2.6**	**3.2**	**2.9**	**1.5**	**1.8**	**1.4**	**0.5**	**0.2**
Total Oil	**7**	**50**	**4**	**7**	**6**	**3**	**1**	**1**
Gasoline	5.8	26.0	2.3	2.8	3.2	0.8	0.7	0.5
Kerosene	0.9	2.8	0.1	1.4	0.2	0.1	0.0	0.3
Fuel-Oil	0.4	21.3	1.7	3.0	2.2	1.7	0.4	0.1

Sources and Notes: [a]Natural Gas consumption excluded from the totals and equal to 19 GJ/pc. [b]Electricity is a final form of energy, therefore coal for electric stations and hydro-power are excluded from the totals to avoid double counting. Coal consumption for Portugal for 1938, own construction from several sources: coal for steamships is included in INE (1938) *Comércio Externo*; coal consumption for railways and gas consumption can be found in INE (1938), *Anuário Estatístico*; Coal for manufacturing is the residual that is left after deducting from the total coal for electric utilities (not shown) from DGSE (1938), *Estatísticas das Instalações Eléctricas*, gas and railways. Shares of coal by uses for other countries, 1936, from Woytinsky and Woytinsky (1953), adapted to levels of consumption of LEG database. Electricity: Portugal: see Appendix B, Table B.8; Italy: Malanima (2006), Spain: Bartolomé (2007), other countries: Mitchell (2003). Oil consumption refers to the year 1939, taken from Woytinski (1953), p.915.

If we compare the production of electricity across countries, the story is different. Large coal consumers were also large electricity consumers, but there were far fewer differences in the level of adoption of technologies associated with electricity, a final form of energy, which could be produced either by fossil fuels or water-power. For example, Italy had almost the same level of consumption as the Netherlands or France. In Portugal, the gap to the leaders continued to be almost as large as for coal, and the differences when compared to Italy were now much wider.

For oil, we only have information on the type of fuel used: gasoline (for cars), kerosene (mostly for lighting, but also for cooking and motors) or fuel-oil (navigation, manufacturing or railroads). The differentiated levels of gasoline consumption indicate the much more intensive motorization of the US in relation to Europe. This leadership had emerged around the first decade of the XX century when the internal combustion motor was recognized as being a superior motor in relation to steam, gas or electric competitors. The availability of cheap gasoline coupled with innovations in the production process of the automobile, such as the assembly line, allowed the automobile to become affordable for American consumers in less than two decades. By 1935 more than half of the American families had an automobile. In Europe, the diffusion of automobiles was much slower and dependent on both the existence of domestic production and disposable incomes; there were 40 to 50 automobiles per 1000 people in England & Wales and France, 16 in the Netherlands and Germany, 10-11 in Italy and Spain and only 6 in Portugal in the mid-1930s[309].

The US also had much larger fuel-oil consumption than Europe. The transition from coal to fuel-oil was first tried in the military navies at the onset of World War I, for strategic reasons (faster reloading)[310]. The uses of fuel-oil were also extended to manufacturing and electric stations in the US during the interwar period. In Europe consumption remained negligible, probably due to high relative prices. Italy was probably the only country with some relevant substitution of oil for coal in the manufacturing sector. The Industrial Census of 1937-1938 indicates that oil already accounted for 20% of the fuel needs[311].

In relation to Europe, Portugal only had comparable levels of oil consumption in the fuels used for lighting, a likely result of poor levels of electrification. Consumption remained low in both fuel-oil and gasoline markets.

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[309] Sudrià (1990a)

[310] Podobnik (1999)

[311] Ristuccia (1997).

In conclusion, on the eve of World War II, the Portuguese energy system was the least modern of all the countries in the database.

3.5.4 The age of oil (1950-1973)

The European energy system was greatly modified in the post-war years. The epoch of 1950-1973 was characterized by a universal expansion of modern energy, especially oil.

With the exception of the US, where the age of oil had started after World War I, the uses of oil were much confined to transportation, in cars and ships before World War II. Even in transportation, there was still a huge market to explore, especially in Europe. A series of events accelerated the transition from coal to oil after World War II. Firstly, refining techniques were greatly improved. Yields of gasoline from crude oil had increased from 11% in the 1910s when most of the oil was wasted to 39% in 1939 with the introduction of the cracking method during World War I. In 1936, the latest development was catalytic cracking, a process which could give the petrochemical industry a large array of useful products and improved yields of gasoline to 60%[312]. Secondly, many of the old European energy and industrial infrastructures needed to be reconstructed due to the effects of the war. As a result, much of the productive structure could be rebuilt from scratch, taking advantage of the new technological frontier of the time. Lastly, a series of discoveries in the Middle East allowed estimated world reserves to jump from 34 billion barrels in 1939 to about 95 by 1951[313], depressing the international oil prices. From the end of the war until the early 1970s the real international price of Arabian light oil fell from 18 dollars a barrel (2009 prices) to almost 10, see Fig 3.9. Developments in transportation, such as increases in the size of the oil tankers, contributed to reducing freight costs. In Portugal, for example, a GJ of crude oil imports paid about the same as a GJ of coal imports by the early 1950s, and substantially less during the 1960s.

The golden age of economic growth became associated with the rise of new industries from the oil cluster, such as production of automobiles, tractors, planes or petrochemical industries, which used oil as a raw material for the production of plastics, fertilizers and other synthetic materials. The emergence of new industries had an important spurring effect on the whole economy, including old coal sectors. The production of transportation vehicles, for example, demanded an array of materials, such as steel and other metals, glass

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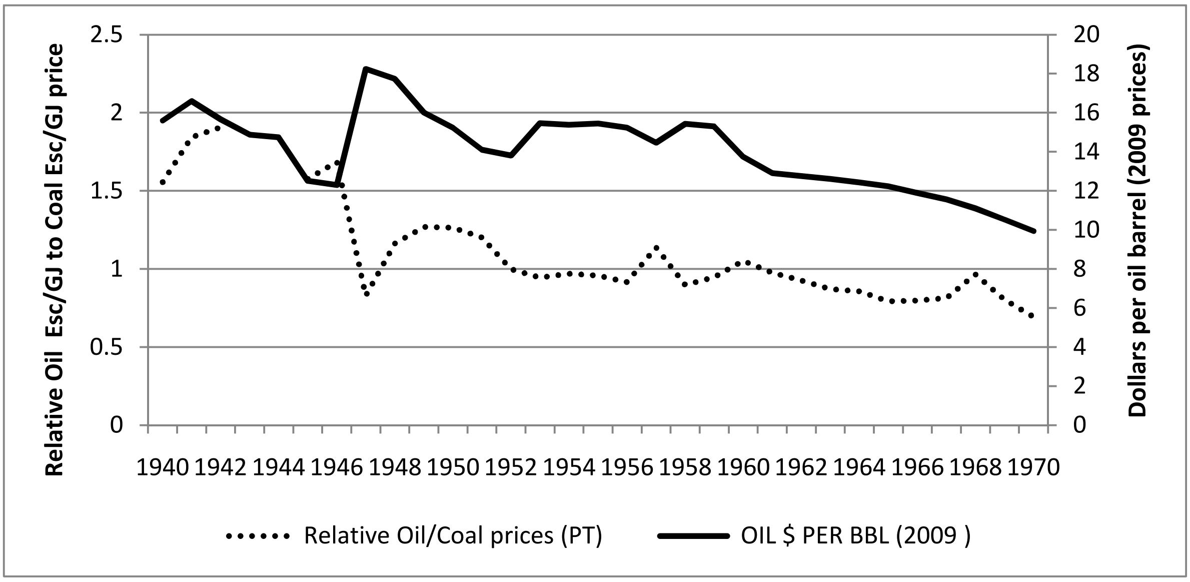
[312] Woytinsky and Woytinsky (1953).

[313] Woytinsky and Woytinsky (1953), p.889.

and rubber, and implied drastic infrastructural changes, e.g. roads, highways, and airports, which also had their own demand for materials[314].

Figure 3.9 Relative import prices oil/coal and real international oil prices USD/bbl, $2009



Source: For relative import prices my own construction INE, *Comércio Externo*. Dollars per oil barrel comes from BP, *Statistical Review of World Energy 2010*.

Oil also contributed to the industrialization of agriculture in developed Europe. The availability of a relatively cheap source of energy for the production of nitrogen fertilizers and the diffusion of tractors in agriculture should not be underestimated. Draught animals were increasingly replaced by tractors. The use of nitrogen fertilizers in developed countries quadrupled from 1960 to 1980, which allowed significantly increasing yields of the main crops[315]. Oil also became attractive as a substitute for coal for heating in manufacturing and household uses as relative oil to coal prices fell. The preference for oil was not always related with lower prices per GJ in relation to coal. Oil had some useful characteristics when compared to coal: higher density, easiness to handle and lower pollution levels.

The timing of the transition from coal to oil differed across countries. Oil surpassed coal as a major energy carrier in the early 1950s in countries with oil reserves (the US, Canada), and in the countries which lacked important reserves

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[314] Freeman and Louçã (2001).

[315] UNIDO and IFDC (1998).

of coal such as Portugal, Italy or Sweden. In other countries oil surpassed coal only from the mid-1960s. In Germany that transition occurred even later, in the 1970s; and in England only in 1992. The apparent delay in the transition from coal to oil in coal-endowed countries points not only to the existence of large sectors of the society where coal was still the fundamental input, such as steel works, but also to differences in relative prices. These differences were exacerbated after the late 1950s by public policies which sought to protect the old coal industry faced with a falling output after the demand for oil soared[316].

To lesser extent, natural gas also had an important development in some European countries. Before the war, the only important known reserves of natural gas were located in the United States, which had a world share of about 90% of both production and consumption in 1950[317]. The concentration of consumption in the country of production was simply justified by technical reasons. Due to its high volatility, natural gas was not easily transported or stored, so a system of pipelines had to be constructed in order to connect the wells to the final consumer. In the US, natural gas was a much more efficient and cheaper alternative to town gas in domestic uses, being also used for the manufacturing of carbon black (for rubber), Portland cement or ammonia production (for fertilizers)[318]. Two events changed the future of Natural Gas in Europe. The first was associated with the development of technology that made natural gas possible to transport by sea, by converting natural gas at the point of production into a liquid form which could be reconverted to its gaseous state at the point of consumption. In the mid-1960s, Algeria exported Liquid Natural Gas (LNG) to England or France. Secondly, there were some discoveries of natural gas in Europe. The first field was discovered in the Po-Valley, in Italy during World War II[319]. In the Netherlands a huge gas field was found in 1959 near Groningen, on the North Sea coast, which allowed the country to specialize in chemical production and become the largest market in Europe in the late 1960s[320]. Other reserves of less importance were found in the North-Sea in the late 1960s and1970s. By 1973, only Sweden and Portugal had not consumed natural gas. Both lacked reserves and the proper infrastructures, as a result of their historically small production of coal gas.

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[316] Chick (2007) describes some measures in the UK in the early 1960s, which included import bans on energy substitutes and coal-burn targets in electricity production. In Germany direct subsidies to the industry (such as social aids or sale aids) became increasingly important from 1958 onwards, see Storchmann (2005).

[317] Woytinsky (1953).

[318] Woytinski (1953).

[319] Victor *et al*. (2006).

[320] Victor *et al*. (2006).

The rise of oil and natural gas was also accompanied by a disproportionate growth in electricity. In this period electricity increased in many of the countries at a higher rate than energy consumption or domestic product per capita, e.g. 10% a year in Spain and Portugal, 9% in Germany, 7% in Sweden and 6% in England & Wales. For developed Europe, the rise of electricity was not only due to economic growth and continuous electrification of manufacturing, but also to the rise of household consumption and extension of the grid to all the citizens. In the post-war years, Western Europeans acquired a diversity of electric appliances such as fridges, washing machines and TVs. Along with the automobile, the electrification of the home represented the age of mass consumption.

It was in electricity generation that the diversity in the use of fuel across countries was more evident, a result of different national energy polices. The doubling of electricity consumption in each decade required large and fast increases of capacity, which altered the structure of electricity production in some countries. In England or Germany, electricity continued to be mainly produced by coal. Sweden maintained a hydro-profile. In Southern Europe, the post-war period result in three distinct paths. Italy ran out of additional hydro-resources and turned from a hydro-power system, which covered 82% of production in 1960, towards a fuel-oil based network in 1973. Spain adopted the most diversified approach: after a hydro period which would last until the early 1960s, it adopted a policy of using national coal, thereafter switching to oil and nuclear power. Portugal followed an autarkic trajectory and became a hydro-power country by the 1950s. However, despite the different profiles of each country, by the late 1960s most of the new capacity was driven by the three energy sources of the period: oil, natural gas and nuclear power (See Table 3.9).

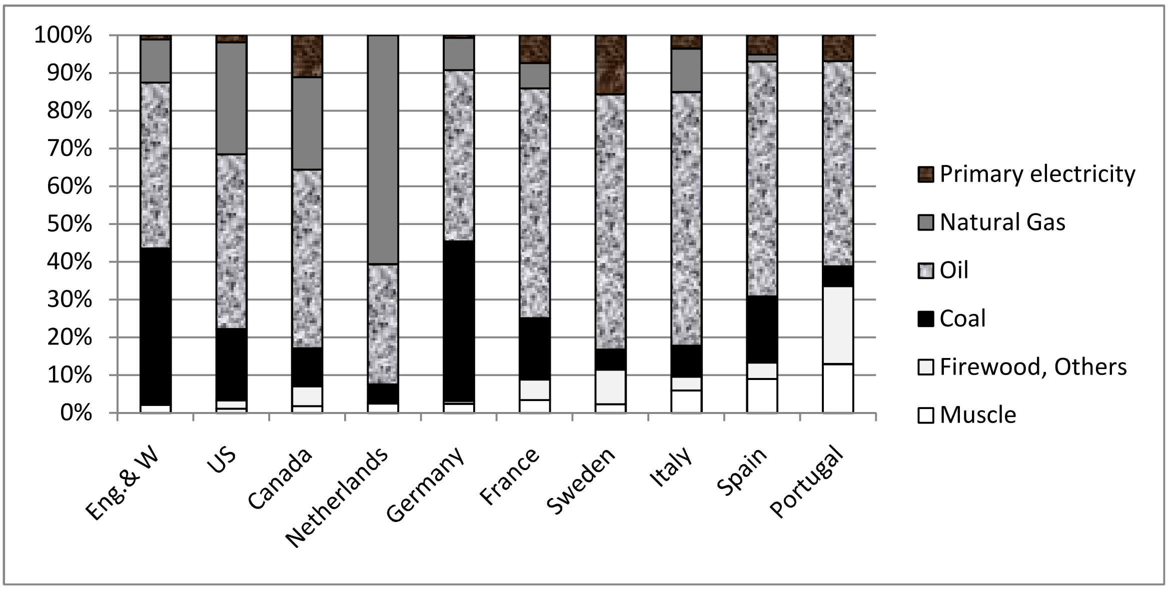
Table 3.9 Electricity production, by source, in 1973

	Coal	Oil	Natural Gas	Nuclear	Hydro	Others
Italy	4	62	3	2	27	3
Germany	69	12	11	3	4	
Spain	19	33	1	9	39	
Portugal	4	18			75	3
Sweden	1	20		3	77	
England & Wales	62	26	1	10	2	

Source: IEA (2010b), *Electricity Information.*

Figure 3.10 shows the effects of the age of oil on the structure of primary energy consumption of our set of countries on the eve of the oil crisis.

Figure 3.10 Composition of primary energy consumption in 1973, selected countries (%)



Sources: See Appendix E.

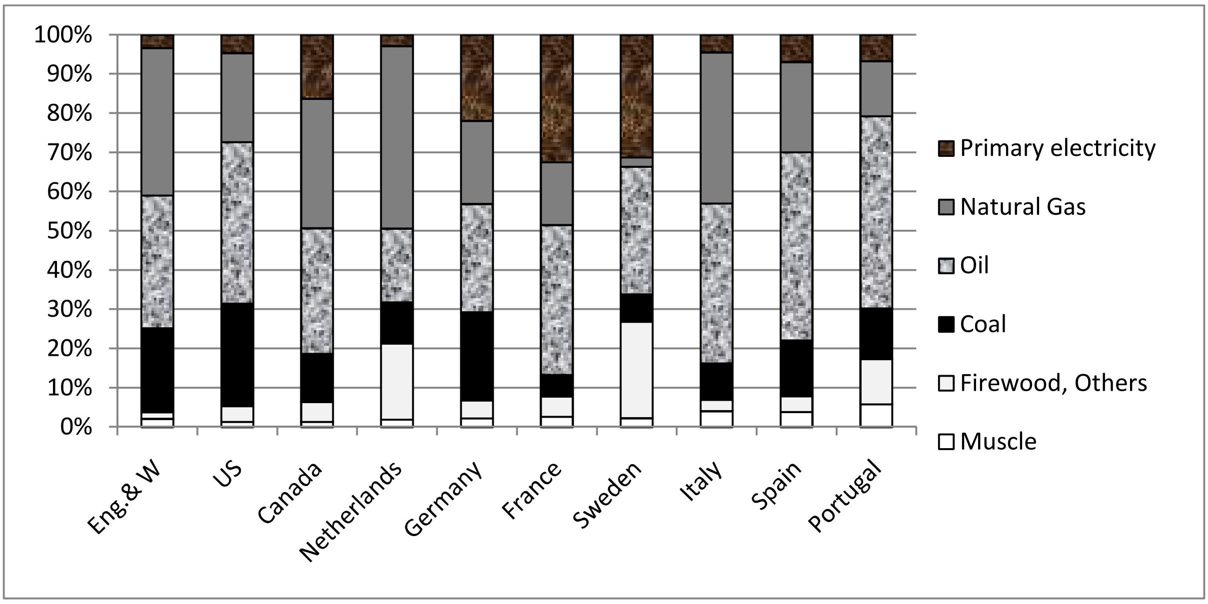
In 1973, the proportion of traditional energy carriers in the energy basket was dramatically reduced in Italy, Spain and Portugal. Oil represented the energy carrier that allowed the Southern European economies to significantly increase their levels of primary energy consumption per capita. The share of fossil fuels in the energy system of the countries was below 80% only in Portugal (60%) and Sweden (72%). Compared to other countries, the remains of a traditional energy system were still visible in Portugal. The high wood consumption was mainly observable in the household sector, the result of a poor urbanization.

3.5.5 Diversification of the energy basket, reduction of oil dependence and continuous electrification (1973-2006)

The 1973 oil crisis marked a shift in the energy structures of developed countries. International oil prices quadrupled during the crisis, changing the prospects of continuous economic growth based in cheap oil. The oil share peaked in most of the countries in the 1970s (with the exception of Portugal and Spain) and countries diversified their energy mix in order to reduce external dependence from oil. Later, environmental concerns also became important.

Nowadays, countries rely much more on a diversified portfolio of energy carriers. (Fig 3.11).

Figure 3.11 Composition of primary energy consumption in 2006, selected countries (%)



Sources: See Appendix E.

Diversification of the energy sources has become partially possible due to a long-run increase of electricity as a share of the final energy consumption (excluding muscle energy)[321]. In 1938, despite all the contributions that electricity had made to industrial growth during the inter-war period, the electricity share of final energy consumption was small, between 1% in Portugal and 8% in Sweden and Italy. In 1973, electricity rose to levels of more than 10%. Nowadays electricity represents a share of final energy consumption of about 20% in most countries and 36% in Sweden, see Table 3.9. The augmented share of electricity since the 1970s has been a phenomenon across all the sectors of the economy, with the possible exception of transport, where electric vehicles are still in the first steps. It has been associated with the emergence of the Third Industrial Revolution: innovations around the microprocessor have put the computer at the centre of daily life. The rise of new industries such as microelectronics and telecommunications, based on knowledge, has produced a

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[321] Final energy consumption differs from Primary Energy Consumption as it excludes losses in the transformation of the energy sector

shift away from heavy industries based on material intensive techniques. But the computer has also influenced the way energy is used as automation of processes & information technologies allow important energy savings in the production process.

Table 3.10 The increasing long-run importance of electricity in energy systems, selected countries

	Sweden	Portugal	Spain	France	Engl. & Wales	Germany	Italy
	Electricity as a share of Final Energy (excludes muscle power)						
1938	8	1	3	3	2		8
1973	17	12	13	9	14	11	11
2006	36	21	22	22	20	18	19
	Fuels to electric power as a % of Primary Energy						
1938	15	4	3	7	11		7
1973	23	14	21	19	31	23	20
2006	31	34	31	26	31	28	24
	Efficiency of electricity						
1973	77	83	45	40	30	35	48
2006	95	58	55	81	45	66	63

Source: Own calculations from IEA (2008a), *Energy Balances of OECD countries* and LEG database.

The increasing share of electricity in final consumption means that about 1/3 of the primary energy is used in order to produce electricity today, giving much wider power to policy makers to affect the global energy mix in the long-run. The different policies followed by the different countries since the 1970s shows that there is no unique energy source that represents an obvious advantage to all. If oil fired plants practically disappeared from the policy options, the choice of fuels would alternate between environmental, economic, health safety or security of supply considerations. In the 1970s and 1980s policies were mostly focused on the economic and security of supply options. France and Sweden chose a clear nuclear power path; while others alternated between coal, natural gas, nuclear and imported electricity, (hydro-power was much dismissed, in part due to the exhaustion of the most profitable sites). Since the late 1990s, European electricity systems have been shifting to low carbon forms of energy in order to mitigate climate change, and natural gas and renewable sources such as wind or solar energy have seen a spurt of investments. The shift is far from easy as climate targets enter into conflict with other objectives. While nuclear power is accepted in France as a triple way of fighting global warming, having competitive electricity prices and assuring energy independence, the expansion of nuclear power is quite unacceptable for other countries. Germany, for example, has had a nuclear phase-out policy since 2002 (due to safety reasons) and a historically high consumption of coal. However, switching from coal and nuclear to natural gas could also imply increasing energy dependence on Russian natural gas or French nuclear power; an undesired effect. As a result of the difficulty in drastically changing past investments and the tension between different goals, the energy mix for fuel generation is still quite different across countries. This has impacts on the levels of primary energy consumption, due to the different efficiencies of the fuels.

Table 3.11 Oil dependence (%), several sectors 1973-2006, selected European countries

1973

	Industry	Households & Services	Transports	Agriculture	Electricity	Primary Energy
France	68	59	97	67	40	64
Germany	37	56	93	53	12	45
Italy	54	62	97	69	62	67
Portugal	61	21	98	63	18	54
Spain	57	50	99	57	33	64
Sweden	70	75	97	85	20	68
UK	51	21	99	80	26	43

2006

	Industry	Households & Services	Transports	Agriculture	Electricity	Primary Energy
France	18	29	96	83	1	41
Germany	7	29	91		0	33
Italy	17	13	97	74	12	41
Portugal	26	25	98	69	6	49
Spain	21	22	98	68	5	50
Sweden	14	5	94	32	0	33
UK	21	7	98	33	1	33

Sources: Oil share for Industry, Household & Services, Transports and Agriculture construction from IEA (2008a), *Energy Balances of OECD Countries*. For 1973, wood values of the household sector are adjusted for Portugal, Italy and Spain. Draught animals are included in agriculture in1973. The oil dependence in the electricity sector represents the share of electricity produced with oil and comes from IEA (2010b), *Electricity Information*.

Some of the convergence in energy uses between Portugal and the rest of the countries can be explained by divergent paths in the energy mix. Portugal was the only country where the efficiency of its electricity system decreased from 1973 to 2006, a result of a reduction of the hydro component, which was not compensated for by nuclear power or renewable electricity.

Increasing electricity use is not the only way in which dependence on oil is reduced; for example, the development of district heating systems fuelled by wastes and biomass (Netherlands, Sweden), or the investment in the natural gas grid, has replaced oil in many thermal processes in the household, services and manufacturing sectors. In agriculture, the oil share has increased in various countries due to a still ongoing process of replacement of draught animals by tractors. In others, such as Sweden or UK, oil dependence has also decreased as a result of the use of both electricity and biofuels, see Table 3.11.

Today, oil is mostly used in sectors where it does not have easy substitutes: in transportation systems and the petrochemical industries (for non-energy uses). The decline in dependence is extraordinary in Sweden, especially if we take into account the fact that, along with Italy, it was the most dependent country in 1973. It is less impressive in Portugal, where one half of the primary energy consumption is still satisfied by oil. This is explained by later energy policies (oil share peaked only in 1982 in Portugal), and the relatively larger share of the transport sector and a less developed network of natural gas.

In conclusion, in comparative terms the energy basket of Portugal shows a clear predominance of traditional energy carriers until World War II. As in Italy and Spain, this high share was a result of low levels of coal consumption *vis à vis* other industrialized countries. However, Portuguese delay in the energy transition was even more extreme than in these two countries, mainly perceived in the comparatively low levels of coal consumption or hydro-power in the late 1930s. Portugal was the only country where coal never dominated the energy system. In the 1950s and 1960s, the share of traditional energy carriers declined to low levels in most of the countries and the energy basket became dominated by oil. Nowadays, the energy portfolio of all the countries is more diversified and the Portuguese energy basket is much more similar to that of other industrialized nations. The only relevant exception, which Portugal shared with Italy at the end of 2006, was the absence of nuclear power in the energy mix.

3.6 Energy intensity in the long-run

A widely used concept to evaluate the relationship between energy and income is the ratio between energy consumption (measured in calorific units) and gross domestic product, GDP, measured in monetary units. Comparing this ratio over time gives us a rough picture of the economic efficiency of energy use. If the ratio increases over time, then the country in question needs more units of energy to produce one unit of GDP; if the ratio decreases, the inverse is true. As already mentioned in our introductory chapter, there are two strands of theory regarding energy intensity. The first view includes only modern energy carriers and associates changes in the ratio with stages of development. It theorizes that energy intensity follows an inverted U-shaped pattern (EKC). Energy intensity will increase in a first stage with industrialization, peak at a determined point and then decrease as a result of technological change and a transition towards lighter economic sectors such as services[322].

According to the second view, which incorporates traditional with modern energy carriers, energy intensities tend to exhibit a long-run decline which is seen as the result of continuous technical change surpassing the effects of structural change (industrialization). The intuition of the argument is strongly related to the transition from traditional energy carriers (less efficient) to modern energy carriers (more efficient), with continuous improvements in the efficiency of energy converters throughout history and with technological change in the broader sense, for example indirect improvements in labour productivity[323]. This section investigates whether Portuguese long-run energy intensities follow the patterns indicated by these views, and suggests some possible reasons for the different shapes of the curves and analyzes Portuguese energy intensities in a comparative framework.

3.6.1 Modern and total energy intensities, Portugal

In the Portuguese case, whether including traditional energy carriers or not, there is no evidence of an Environmental Kuznets Curve (Fig 3.12). In the case where only modern energy carriers are considered, there is a long-run growth in energy intensity with a long lasting depressive break in trend during the interwar period. The growth of commercial energy intensity was high (*ca.* 3% year) until World War I, probably because the levels of diffusion of modern energy were low. The outbreak of World War I represented a GDP shock to the Portuguese economy, but it faced a much stronger energy shock due to strong restrictions in coal supplies. During the interwar period, modern energy intensity exhibited instable behaviour and no distinguishable trend, and was subsequently affected by energy restrictions in World War II. In the post-war period increases in

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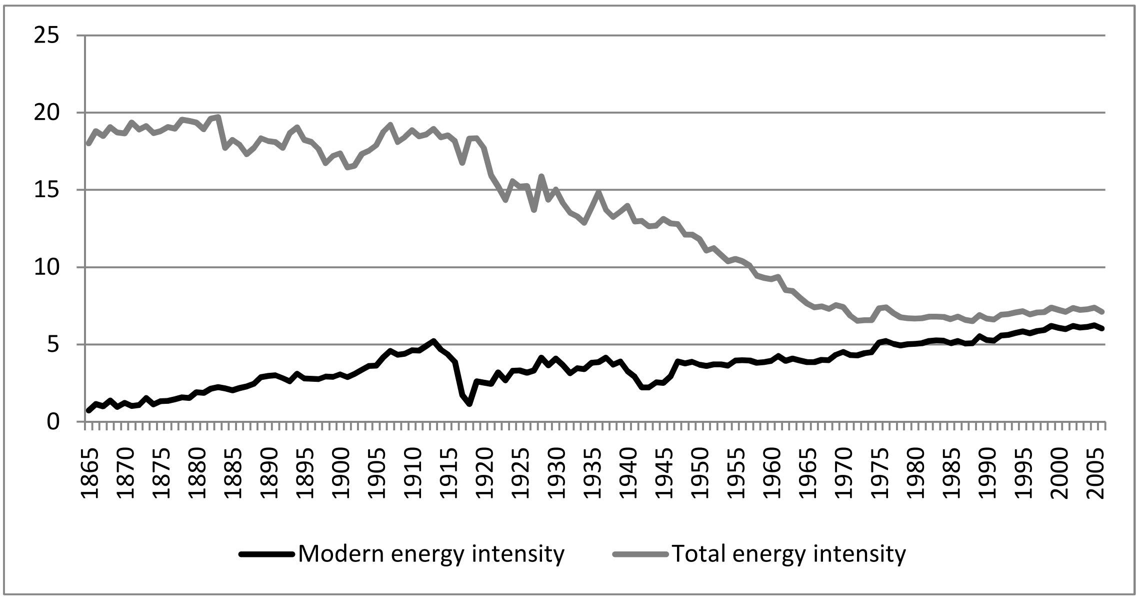
[322] Reddy and Goldemberg (1990)

[323] Gales *et al.* (2007).

energy intensity were of 0.5% a year. Modern energy intensity recovered its 1913 values only in the mid 1970s. Energy intensity grew at a rate of 0.9% a year after the oil shock.

Figure 3.12 Modern energy intensity vs Total energy intensity, Portugal 1865-2006, MJ/$1990



If, on the other hand, we consider modern and traditional energy carriers together, three phases can be observed. The first is the period until the World War I, when energy intensity remained at the level of 18-20 MJ per dollar of GDP; the second is from 1920 to 1973 when energy intensity dropped spectacularly to 6.68 MJ per dollar produced, and a third phase is observed after 1973 with an increase in energy intensity to levels of 8 MJ per dollar.

Energy intensity can be affected by many factors, such as technical efficiency, energy mix and economic structure, and it would require more sophisticated analysis to determine the reasons for the variation of the ratio. Notwithstanding, certain characteristics allow us to distinguish the decreasing trend of total energy intensities from the upward trend of modern energy intensities. A hypothesis that can be formulated is that the size of the informal sector mattered in the Portuguese case known for its historically low energy path. For most of the decreasing period, household energy dominated the energy system. In this agrarian society, most of the energy was consumed within the household sector to satisfy the basic needs of food and shelter. In 1880, household energy had an importance of 71% in the energy system, a position that had only slowly declined in importance in the 1950s to about 60%, when 49% of the population was still employed in the agricultural sector. In this phase, it is very likely that the growth rate of this type of energy is lower than GDP growth, especially if GDP grows at a higher rate than population. Some accounts show that energy per capita at the household level can even decline during the phase of energy transition to modern fuels[324]. Because of the high household share of total energy consumption, the transition from biomass (less efficient) to fossil fuels and electricity (more efficient) in the household sector that took place during most of the 20t^{h} century was certainly very important in determining the declining growth rate of energy intensity.

As a country develops, changes within the formal sectors gain relevance. This suggests that, after major transitions within the informal sector have occurred, a period of structural changes within the formal economy can offset gains in efficiency. However, not all these changes need to occur inside the informal economy; agriculture for example, would be a sector where increases in land productivity or in the composition of agricultural products (movement to high-valued products, low-muscle-use intensive agriculture) could also produce those effects.

3.6.2 Modern and total energy intensities, all countries

We can gain further insights into the evolution of Portuguese energy intensities in a cross-country context. Fig. 3.13 plots the evolution of modern energy intensity of our set of countries.

There seems to be a certain element of time in the shape of the energy intensity curves. Coal-intensive countries followed a clear inverted U-shapped pattern: Germany, England & Wales, Canada and the US. They had spectacular rises in energy intensity peaking more or less at the same time, 1910s-1920s (with the exception of England, which peaked early), precisely when other energy carriers such as electricity and oil were becoming more important.

A second group of countries with intermediate modern energy intensities followed a more mixed pattern during the interwar years, with a wave pattern which could resemble, with some imagination, three EKCs. For France the highest peak was in the 1920s; in Sweden and Netherlands the highest peak was in the early 1970s, which coincided with the oil crisis. Portugal had a historically low modern energy intensity path on the same level as Italy and

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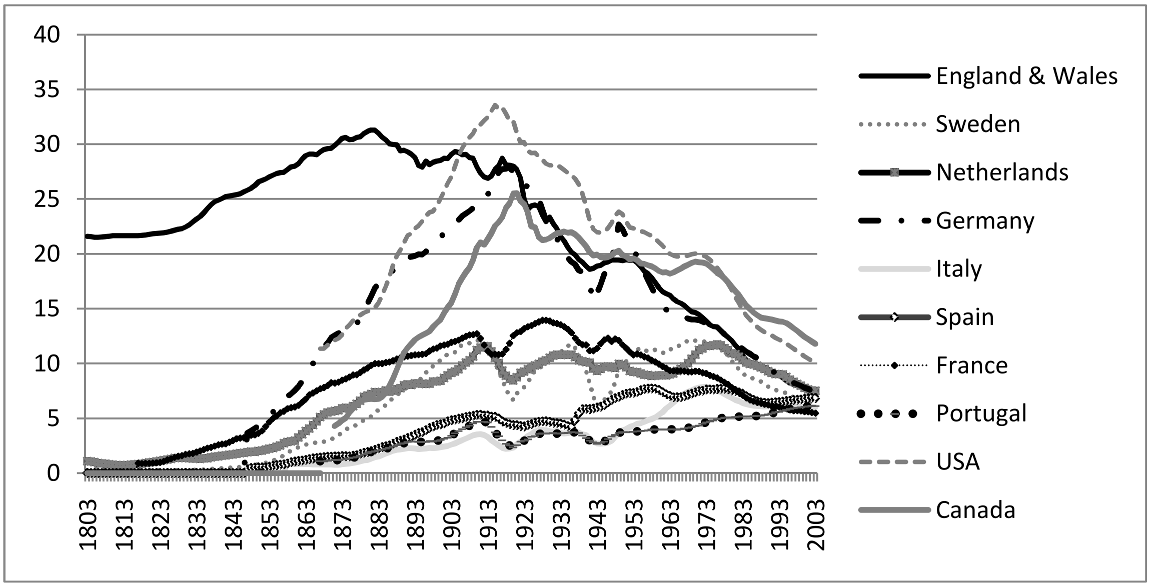
[324] A substantial decline in the energy consumed per person/ household, as a result of a transition from wood to coal, was observed in Morrison (1982) for the US in the period 1910-1930.

Spain and the lowest in the post-war period. These three countries also showed wave patterns during the interwar period. After the war they all increased their energy intensity, but Spain and Italy did so faster that Portugal. Italy and Spain lowered their modern energy intensities following the oil crisis, although Spain reversed the trend again in the early 1990s[325]. After 1973, increasing modern energy intensities in Portugal, coupled with decreasing trends in all the other countries, resulted in a general convergence of energy intensities.

Figure 3.13 Modern energy intensity, selected countries, moving averages (7 years) MJ/$1990



In the long-run, if we do not consider the break in trend during the interwar period, there is no EKC in the Portuguese case. Portugal seems to have been tunelling the EKC of the leaders without really peaking[326]. The fact that Portuguese modern energy intensity did not really peak does not correspond very well with the idea that all countries peak around the same levels of income, as Portugal had already surpassed the income level of early peakers. Nevertheless, it fits the idea that developing countries are able to benefit from a new stock of technology as they develop, and avoid the intensive steps of early comers. However, historically, development and technology should also be seen

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[325] Peaks in 1970 (Italy) and 1976 (Spain). Unfortunately, the Spanish trajectory after the 1970´s is dependent of which GDP data one uses (Geary Khamis or EUKLEMS) and which level of energy consumption (primary or final). Using the EUKLEMS data (as in chapter 5) we obtain an increase on Spanish energy intensities around the period 1971-2005.

[326] The concept of tunnelling the EKC can be found in Munasinghe (1999).

as interlinked with each other. The fact that pioneers in development were also pioneers in modern energy intensity, makes us believe that late-comers were late-comers precisely because of their incapability of adapting to the dominant technology of the time. In this case, natural resources and the price of factors should also be further investigated.

Figure 3.14 Total energy intensity, selected countries, moving averages (7years) MJ/$1990

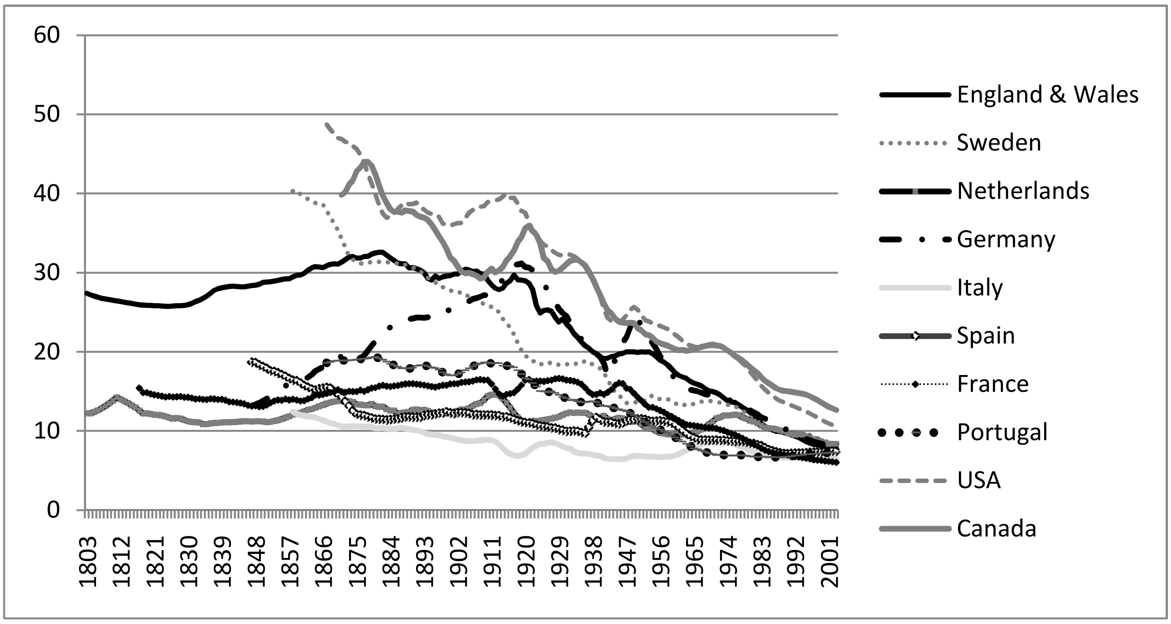

Fig 3.14 presents total energy intensities for our 10 countries. With the probable exception of England, where the transition towards modern fuels was almost complete, the inclusion of traditional energy carriers drastically changes the behaviour of the long-run energy intensities of our countries in various aspects.

In the past, relatively high initial levels of energy intensity seem to have been largely determined by relatively high levels in the consumption of traditional energy carriers resulting from adverse climatic conditions, vast endowments of forest or land and low population densities. Sweden, Canada and the US, countries with at least some of these characteristics, appeared to be the most resource intensive countries with an energy consumption of 40-50 MJ/dollar around the mid-1850s[327]. All the remaining countries (with the exception of England &Wales) had much lower initial energy intensities, at the

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[327] Swedish energy intensity was 80 MJ/dollar around 1800. This was due to a combination of even higher wood consumption and low incomes per capita.

level of 12-20 MJ/dollar. In the case of England & Wales it is necessary to go backwards to the seventeenth century, when the country was still an agrarian economy with scarce use of fossil fuels, to find energy intensities below 20 MJ/dollar.

The figure confirms the tendency of a long-run general decline in the energy intensities curve, as suggested by earlier works[328]. In all countries, energy intensities are lower nowadays than in the mid-nineteenth century, which indicates that developed societies of today are more energy efficient than agrarian societies were in the past. In 1870, energy intensities decreased at an average rate of 0.9 -1.1% a year in the high intensity countries (England and Wales, Sweden, the US and Canada), 0.6-0.7% per year in Spain, France, Portugal and Germany and 0.4% a year in Italy and the Netherlands (the low intensity countries in 1870). As a result of differentiated long-run growth rates, energy intensities are less divergent now than they were in the nineteenth century.

Still, the tendency for decline was not linear and phases of growth or stagnation also occurred. Depending on climate, economic structure, intensity of industrialization at each growth phase, efficiency of the technological stock and composition of the energy mix, there were some variations in the growth trend of each country at different points in time. For example, England & Wales, Germany and France (in much less extent) had energy intensity phases of growth during the coal period of industrialization; the Netherlands and Italy had a period of growth in the late 1960s, during a phase of low oil prices and Portugal and Spain (in a less extent) increased their energy intensities in the late twentieth century.

The most important exception to the long-run decreasing energy intensities was the clear EKC pattern that Germany and England & Wales followed. In these countries, the effect of coal-biased economic growth towards energy intensive industries clearly offset the effect of technical change in the early periods of industrialization. Both increased their energy intensity sharply from less than 20 MJ /dollar in pre-industrial times to 30 MJ/dollar around 1913, joining resource-intensive countries like the US, Sweden and Canada. This group of countries exhibited persistent higher energy intensities than the rest of the countries for most of the period, which indicates technological disparities in the modes of industrialization. For the European countries those differences practically disappeared after the oil crisis, which can be interpreted as a result of convergence of economic structures, consumption patterns and technology. The

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[328] Gales *et al*. (2007), Grübler (2004).

US and Canada, however, still had relatively high energy intensities in relation to Europe. This persistence was connected not only with a more intensive industrial structure, but also with much higher levels of personal energy consumption per capita as a result of past technological choices. Historically low oil prices gave an incentive for the use of larger and less energy efficient cars. Larger houses coupled with low electricity prices also resulted in higher levels of household consumption per capita.

Portugal belonged to the group of countries where energy intensity did not surpass the 20 MJ/dollar in the period. In this group, Portuguese energy intensity remained the highest until World War I. From 1920 to 1970 energy intensity in Portugal decreased faster than in Italy, Spain, France and the Netherlands. However, in contrast with modern energy intensities, Portuguese total energy intensities could only be considered low by international standards in the 1950s-1980s. The fact that energy intensities were relatively high before the war suggests that agrarian economies (like the Portuguese one at that time) can be more intensive than industrial ones, as long as economic growth is not resource biased. The low energy intensities in the period of rapid industrial growth are an indication of a low intensive type of industrialization. However, after the oil crisis, Portuguese energy intensity grew weakly in contrast with other industrialized countries, where energy intensity declined sharply. Spain also showed the same behaviour after 1990, which suggests that the drivers of energy intensity changes were quite different for late-comers, the countries with the lowest energy per capita, energy intensity and income per capita in 1973. Portugal now has higher energy intensity than France, Italy and the UK.

The declining trend after the oil shock in developed economies has been associated with a much wider range of factors than the previous trends: energy efficiency policies, structural changes towards services and from heavy industrial sectors such as mining and steel towards lighter industrial sectors. Portugal and Spain are today also service economies, so what were the reasons for the diverging trends? This will be investigated in Chapter 5.

3.7 Long-term drivers of energy consumption

Now that long-run energy intensities in the various countries have been presented, we are able to assess the impact that energy intensity had in saving energy in the various epochs of growth, when compared with other factors that cause stress in the environment.

The energy consumption of our set of countries grew on average by a factor of 13 after 1870. In order to understand the main forces of this growth, researchers have used decomposition techniques which manage to capture the relevance of three forces: population, income and technology.

The Commoner – Ehrlish formula is a very frequently used equation in ecological economics to decompose the environmental impact of a nation (I) into population size (P), per capita affluence (A) and the impact of the technologies involved in the production of a unit of consumption (T); *i.e.*,

$$I = P \times A \times T^{329}.$$

Translated into energy terms, the T factor can be substituted by energy intensity, the environmental impact by energy consumption, and the per capita affluence by the GDP per capita in the form of the following equation:

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

If we take the derivates, this equation can be simplified in the form of growth rates:

$$e = p + y + \frac{e}{y} \ .$$

Growth in the scale effects (*p+y*) needs to be counterbalanced by improvements in technology (*e/y*) for increases in impact (*e*) to be null. The results can be presented in a multiplicative or additive format. To show the results in a cumulative format, we choose the multiplicative version where Denergy, Dpop, Dy and Dey can be shown in the following way:

$$\frac{X_{t+n}}{X_t} = \frac{X_{t+1}}{Xt} \times \frac{X_{t+2}}{X_{t+1}} \times \ldots \times \frac{X_{t+n}}{X_{t+n-1}} .$$

In the Portuguese case, the cumulative energy consumption has been positively associated with cumulative economic and population growth, and negatively associated with cumulative change in energy intensity. As a positive force, GDP per capita only surpassed population effects around 1940, and energy intensity only started to have negative cumulative effects after World War I. During this period, energy intensity gains were not enough to counterbalance scale effects of economic growth and population (Fig 3.15).

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[329] See Chertow (2001) for a historical background on the use of this equation.

Figure 3.15 Drivers of energy consumption, cumulative, Portuguese energy decomposition

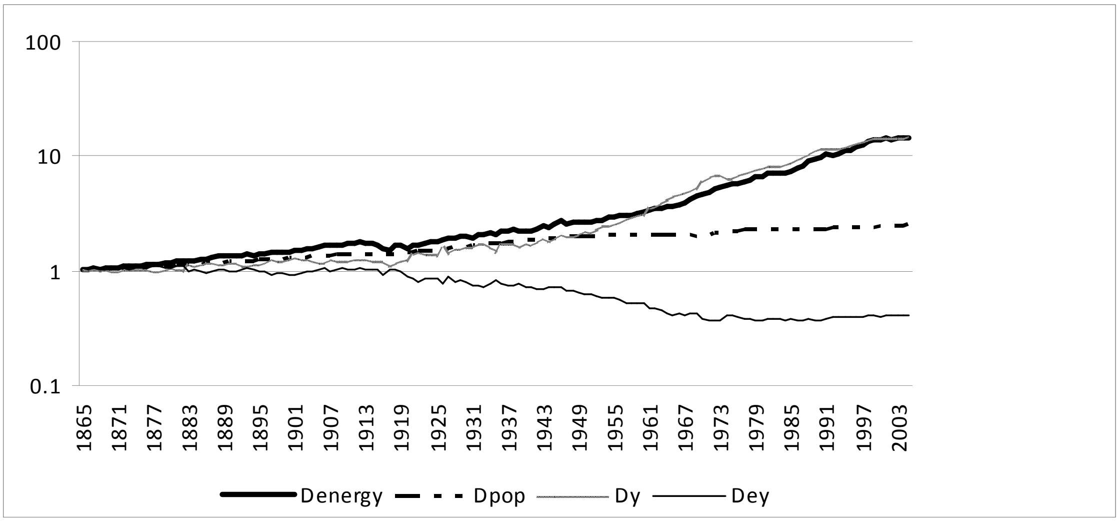

Table 3.12 compares the Portuguese results of the IPAT decomposition with the remaining 9 countries per periods. Long-run IPAT decomposition has been recently performed for the Netherlands, Italy, Sweden and Spain[330]. Three aspects are highlighted. Yearly growth rates of energy consumption increased in those four countries until 1973 and declined thereafter. Scale effects (population plus activity) were more important than efficiency gains in the overall period, and energy intensity had a regular and strong decreasing pattern after 1973.[331]

Does the global picture change when we include a larger set of industrialized countries? I argue that it partially does.

Despite the impressive declines in energy intensity shown in the previous section, as in Gales *et al.*, scale effects (*p*+*y*) were in general more important than energy intensity declines, and, as a result, energy consumption grew consistently in most of the countries.

In general 1870-1913 and 1950-1973 were energy-expanding periods (relatively high increase in the rate of E and relatively low decrease in the rate of Ey), and 1920-1938 and 1973-2006 were energy saving phases (relatively low increase in the rate of E and relatively high decrease in the rate of Ey). In the early phases of industrialization (1800-1913), the energy intensity effect was a

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[330] Gales *et al.* (2007)

[331] We should point that the results that we present here for Spain, Sweden, Italy and the Netherlands differ somewhat; the result of slightly different datasets. See Chapter 2 and Appendix E, for the alterations in the datasets.

minor explanatory factor for changing energy consumption compared with both population and economic growth effects.

Table 3.12 Results of energy decomposition for selected countries, yearly growth rates, per period

	England & Wales				Netherlands			
	E	*P*	*Y*	*Ey*	*E*	*P*	*Y*	*Ey*
1800-1870	2.5	1.2	1.2	0.1	1.5	0.8	0.6	0.2
1870-1913	1.7	1.2	0.8	-0.3	2.6	1.3	0.9	0.4
1920-1938	-0.2	0.5	2.2	-2.9	3.1	1.4	1.2	0.5
1950-1973	1.4	0.5	2.2	-1.4	5.4	1.2	3.4	0.8
1973-2006	-0.1	0.2	2	-2.2	1	0.6	1.8	-1.4
	USA				Sweden			
	E	*P*	*Y*	*Ey*	*E*	*P*	*Y*	*Ey*
1870-1913	3.4	2.1	1.8	-0.5	2	0.7	1.9	-0.6
1920-1938	-0.1	1.1	0.5	-1.8	2.3	0.4	2.6	-0.6
1950-1973	3	1.4	2.4	-0.9	4	0.6	3.5	-0.1
1973-2006	0.7	1	1.9	-2.2	0.2	0.3	1.8	-1.8
	Canada				Italy			
	E	*P*	*Y*	*Ey*	*E*	*P*	*Y*	*Ey*
1871-1913	3.5	1.7	2.2	-0.4	1.5	0.7	1.2	-0.4
1920-1938	0.7	1.5	0.9	-1.6	2.1	0.8	1.4	-0.2
1950-1973	4.3	2.1	2.8	-0.6	6.6	0.6	4.7	1.3
1973-2006	1.3	1.2	1.7	-1.6	1.1	0.2	1.9	-1
	Germany				Spain			
	E	*P*	*Y*	*Ey*	*E*	*P*	*Y*	*Ey*
1870-1913	3.6	1.2	1.6	0.9	1.2	0.5	1.2	-0.6
1920-1938	1.7	0.5	3.4	-2.2	1.4	1	1.1	-0.7
1950-1973	3.5	1.2	4.9	-2	5	1	5.4	-1.4
1973-2006	-0.2	0.9	1.6	-1.9	2.6	0.5	2.7	-0.6
	France				Portugal			
	E	*P*	*Y*	*Ey*	*E*	*P*	*Y*	*Ey*
1820-1870	1.3	0.4	1	-0.1				
1870-1913	1.9	0.2	1.4	0.2	1.2	0.7	0.4	0
1920-1938	1.5	0.5	1.8	-0.7	1.5	1.2	1.9	-1.6
1950-1973	4	1	4	-1	2.9	0.2	5.2	-2.5
1973-2006	0.3	0.5	1.7	-1.8	3.1	0.5	2.3	0.2

I consider 1920-1938 an energy saving phase, despite the fact that energy consumption growth surpassed the growth of the 1870-1913 period in five of the countries. In most of them, this could be explained by a break in trend during World War I. The period 1920-1938 was one of intense technological change in most of the countries. Intensity effects offset scale effects even in the US and the

UK. Declines in energy intensity are consistent with the generalized electrification of manufacturing in the interwar period and with the rapid progress in the efficiency of thermal processes[332]. Economic factors such as the Great depression and the reduction of trade and industrialization in general can also be possible explanations. Svennilson suggests that the UK was running out of cheap coal by that time, which could also explain a downward shift in resource intensity, especially in coal intensive countries (Germany, the US, England & Wales)[333]. As in Gales *et al.*, we do not perceive a generalized increase of energy intensities as a result of low prices in the period 1950-1973. While energy intensity growth rates were significantly higher than in the period 1920-1938, they were still negative. The energy intensity increases in Italy and the Netherlands were exceptions and not the norm. A possible explanation is that the appearance of oil and natural gas allowed a shift in the Italian and Dutch production function, which was not possible during the coal age. The general idea that energy intensity forces were stronger after the oil crisis is confirmed. In half of the countries the reduction of energy intensity was larger than the increase of economic growth; and in two of the countries (England & Wales and Germany) absolute decoupling occurred. This suggests that the nature of economic growth in developed countries changed substantially.

As a late industrializing country, Portugal stands out from the general picture in three important aspects. Firstly, it is the only country where yearly energy consumption growth rates increased systematically across the given period (1.2 in 1870-1913; 1.5 in 1920-1938, 2.9 in 1950-1973 and 3.1 at 1973-2006). Secondly, Portugal is the only country where energy intensity increased after 1973, at much higher levels than in any other period of Portuguese history. Lastly, Portugal shares with Spain the fact that the largest decrease in energy intensity occurred during the period that coincided with its industrialization process, 1950-1973. This suggests that Portuguese and Spanish industrialization must have been accompanied by an intensive technological change which could have been connected with, among other things, the substitution of traditional energy carriers by modern sources of energy.

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[332] This idea was expressed by Sonenblum and Schurr (1990), Rosenberg (1998) or Devine (1983) for the American case.

[333] Svennilson (1954).

3.8 Long-run CO_2 emissions from fossil fuels

The transition from traditional energy to fossil fuel energy has resulted in an increase in CO_2 emissions, the gas in atmosphere that is actually responsible for more than 75% of total anthropogenic emissions. Global warming is nowadays considered the most serious problem, related to the use of energy, that mankind has to solve. The man-based accumulated CO_2 emissions in the atmosphere are considered the main factor that has contributed to an increase of the Earth's temperature since pre-industrial times. The IPCC estimates, that in order to limit the temperature rise in 1.5 C by 2100, global emissions will need to peak around 44 $GTCO_2$ by 2020 and decline fast afterwards[334].

In order to understand the impacts of the historical energy transition on the global environment, we present CO_2 estimates for our set of countries. The CO_2 emissions in this section are only references to fossil fuel combustion, which accounts for the bulk of total CO_2 emissions in industrialized countries today. The combustion of biomass also emits CO_2, and each joule of firewood has a larger emission coefficient than those of fossil fuels. However, traditional energy carriers are different from fossil fuels in the sense that they do not necessarily cause net CO_2 emissions. This is because plants also sequester carbon dioxide as they grow. As long as biomass is sustainably burned, that is, as long as biomass stocks remain constant, there will be no net CO_2 emissions associated with biomass combustion. Therefore, the Intergovernmental Panel of Climate Change *(IPCC*) has considered biomass combustion emissions as carbon neutral in their energy-related CO_2 emissions calculations, as changes in forestland already account for the release or capture of CO_2 from biomass. We do not perform the calculation from CO_2 released or captured from Portuguese forests here, although they could have been relatively important in the past[335]. Nowadays, Portuguese forests function as a sink of $CO_{2,}$ this is, they remove CO_2 from the atmosphere; about 40% of the country is forested. Forests recover about 5% of what the country emits to the atmosphere. However, in dry summer years, fires can make Portuguese forest CO_2 emitters. It is not uncommon to have bad years, due to the type of forest (eucalyptus and marine pine) and due to carelessness in cleaning the woods. So in 2003, for example, when 372 thousands hectares were consumed by forest fires, emissions increased by 9%.

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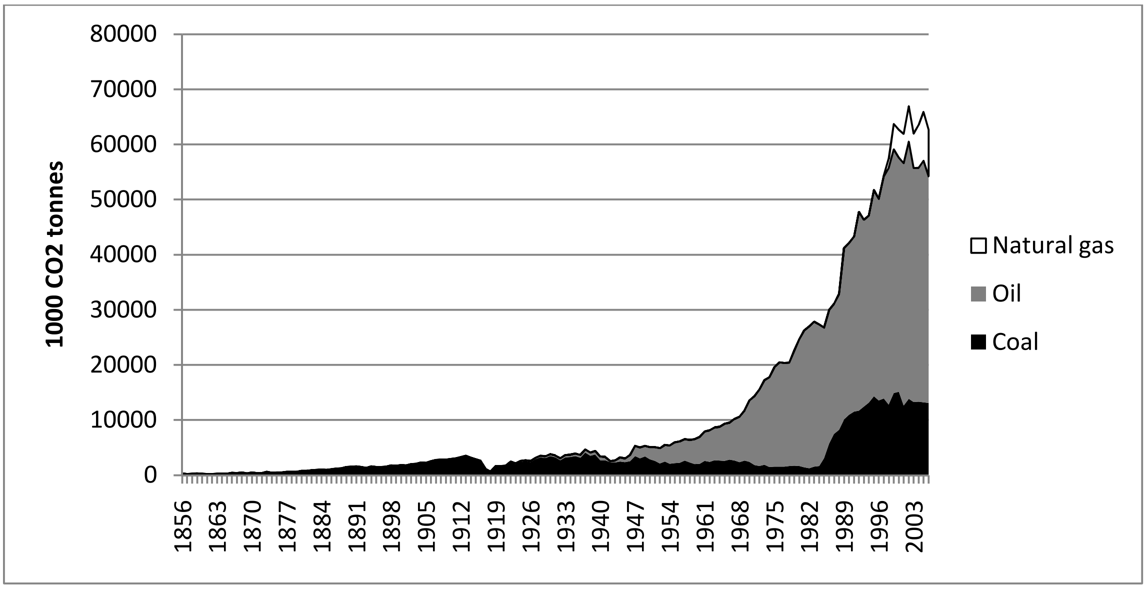
[334] UNEP (2010)

[335] The area of conventional forests increased during the period covered in this study, with the exception of the war years, so it is possible that forest emissions were negative.

Figure 3.16 CO_2 emissions, Portugal 1856-2006



Greenhouse gases and human-induced emissions include, besides fossil fuels and forests, other land use changes, methane from domesticated animals, industrial processes, and fertilizer consumption, among other things. For historical reconstructions taking into account forest and land use changes see, for example, Kander[336], who showed that total emissions in Sweden in the period 1800-2000 resembled an N shape, due to unsustainable practices in forest management and agriculture in the past[337]. Although CDIAC (Carbon Dioxide Information Analysis Center)[338] has produced historical series of CO_2 emissions from gas flaring, cement and fossil fuel combustion for almost every country in the world, we use our own CO_2 series for the 10 countries. This is due to the fact that historical statistics, on which CDIAC has based estimates, are less reliable than our sources, and that we want our energy estimates to be consistent with emission estimates[339]. For all the countries except Portugal, coal, oil and natural gas are converted using the emission estimates of 94.6 kg CO_2/GJ for coal, 73.1 kg CO_2/GJ for oil and 56.1 kg CO_2 /GJ for natural gas[340].

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[336] Kander (2008).

[337] Kander (2008).

[338] See CDIAC, http://cdiac.ornl.gov/.

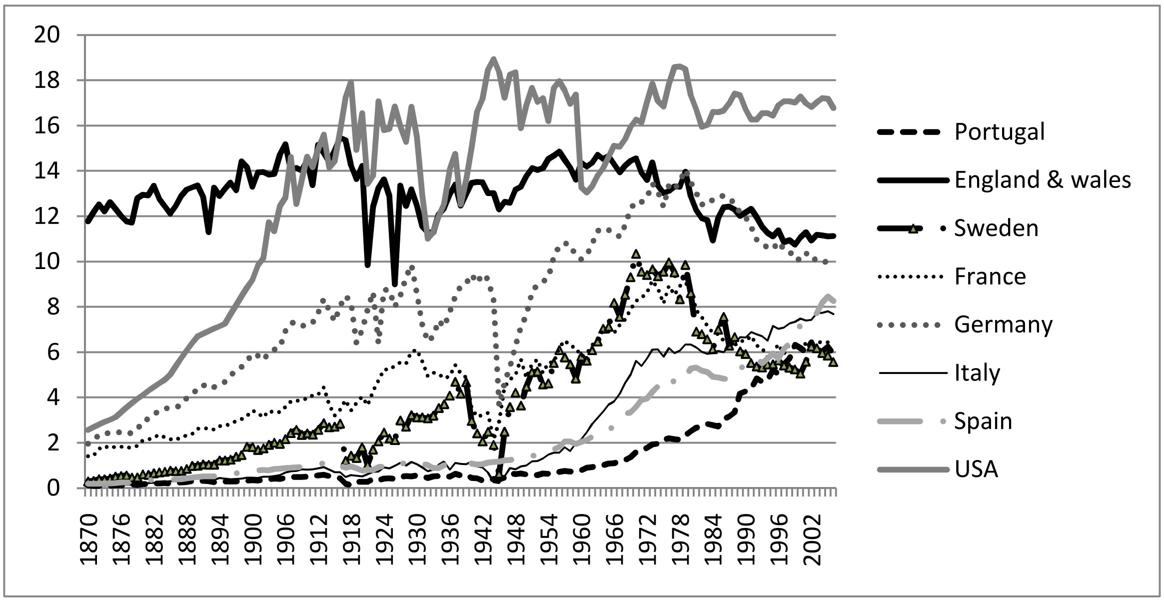
[339] CDIAC uses Mitchell statistics for example.

[340] IPCC (1996). For Portugal a more disaggregated estimate is used with the following coefficients (in kg CO2/GJ): Crude Oil 73.3; Gasoline – 69.3, Jet Kerosene – 71.5; Kerosene 71.9; Gas/Diesel 74.1; Fuel-Oil 77.4; LPG 63.1; Petroleum Coke 100.8, Coal imports 94.6; Domestic Coal 98.6; from the same source.

In the long-run, Portuguese CO_2 emissions show a steeper trend after the 1960s than energy consumption, accelerating after 1980. This is due to the fact that, before 1960, a high percentage of energy consumption was satisfied by traditional sources, which are considered carbon neutral in our analysis. Most of the contribution comes from oil. In accumulated terms, about half of the Portuguese historical emissions occurred after 1990.

Figure 3.17 plots the historical per capita emissions in various countries. In comparative terms, the per capita evolution of Portuguese CO_2 emissions is different from the evolution of energy per capita. First, the differences between Portugal and the remaining countries are larger than in energy per capita in the first phase of the series, until 1950. This difference is also visible for example for Sweden, with a lower pollution intensity path in relation to France or Germany or in the case of the US in comparison with England. Secondly, after 1973, trends become fairly different between industrialized Europe and Portugal. Previously, we have seen that energy per capita stabilized in the wealthiest countries while it increased in Portugal. Here, we can observe that in Germany, England & Wales, Sweden and France emissions per capita actually declined substantially. In the case of Sweden and France the decline was so large that they are now, along with Portugal, the least polluters in per capita terms.

Figure 3.17 CO_2 emissions per capita in selected countries, tonnes p.c.

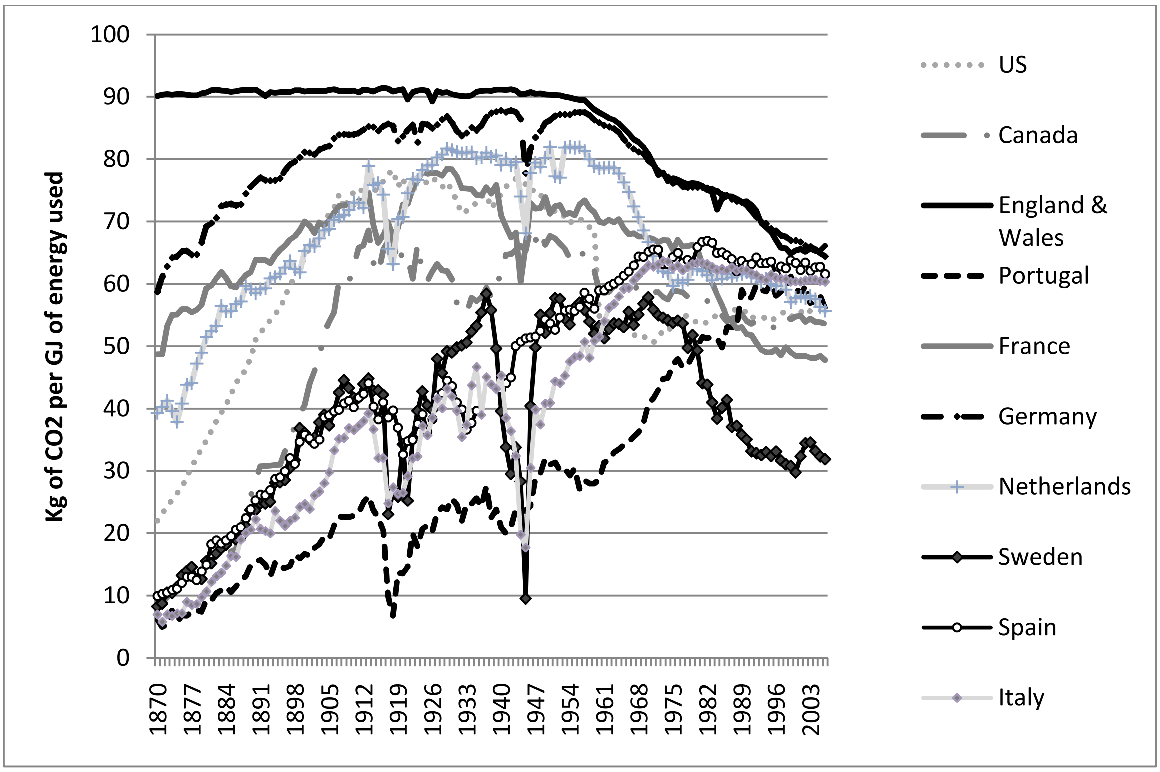


Differences between the level of energy and the level of CO_2 emissions in the various countries are caused by a distinct composition in the energy mix.

Most studies focus only on an analysis of the CO_2 emissions per GJ of fossil fuels. In that case, there is normally a historical decline in the intensity of emissions of each GJ due to a transition from carbon intensive coal to less carbon intensive oil and natural gas. This is usually mentioned as decarbonisation[341].

In the long-run it is more interesting to include the CO_2 intensity of all energy carriers. Even if traditional fuels do not cause CO_2 emissions[342], the transition from biomass towards fossil fuels was a historical process that had influence in the increasing of CO_2 emissions. In the same way, the transition towards wind or nuclear power or biofuels is expected to have a declining impact on CO_2 emissions. In comparative terms a very different dynamic emerges from calculating the emission intensity of all energy carriers (Fig. 3.18).

Figure 3.18 CO_2 intensity of all forms of energy (kg CO_2/GJ)



The figure shows that all countries increased their pollution intensity as a result of the transition towards fossil fuels and peaked at a certain point with the exception of England, which was already a sole coal economy in the late

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[341] Grubler and Nakicenovic (1996).

[342] If sustainably burned.

nineteenth century. They did so at different points in time and different levels of pollution intensity. Countries that attained an early large share of coal in their energy basket peaked at 75-90 kg CO_2/GJ. In these countries pollution intensity started to decline either in the inter-war period (the US, France) or after World War II as a result of switching to oil or natural gas. In countries that missed the early coal-intensive patterns (Italy, Spain, Portugal or Sweden), the shift occurred later in time and at lower levels than their predecessors; that is, around 55-65 kg CO_2. In Portugal the peak was reached only in 1995 at 60 kg CO_2 just some years before the introduction of natural gas.

After reaching the peak, the decarbonisation trend is substantially different across countries. This can also be interpreted as a result of different energy policies or natural resource endowments. It is very steep in Sweden and in France, which reach levels of 30 and 50 kg CO_2/GJ, a probable result of a high share of primary electricity (especially nuclear) in the energy basket. It is practically flatter for Italy, Spain or Portugal. As a result of steeper decreasing trends in high polluting countries and later peaks and flatter decarbonisation trends in late-comers, pollution intensities across countries are much more equal nowadays than in the late nineteenth century (with the exception of Sweden). While late-comers avoided the high pollution intensities of their predecessors, their opportunity for fuel switching to comply with environmental targets was probably more limited than most other countries. In order to gain further insights into the magnitude of fuel switching *vis-à-vis* energy consumption factors in the changes of historical CO_2 emissions, the next section employs a decomposition technique that separates the various forces which affect CO_2 emissions.

3.9 Drivers of CO_2 emissions changes

CO_2 emissions from the energy sector are a function of both energy consumption and pollution intensity composition of the energy basket. The Kaya decomposition is an extension of the IPAT and allows decomposing of CO_2 emissions in the factors that influence energy consumption (scale and technology) and pollution intensity, in the following way[343]:

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{Y} \times \frac{Y}{P} \times P$$

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[343] Kaya (1990).

The first term of the right hand side of the equation, CO_2/E, is the pollution intensity of energy. The other terms are energy intensity, per capita GDP and population, the drivers of energy consumption.

In order to understand how the energy basket influenced CO_2 emissions, we use a decomposition technique, applied by Ma and Stern to Chinese data, that extends the Kaya decomposition in order to separate fuel switching into three effects: (1) the effect of the transition from biomass to fossil fuels as a driver of changes in CO_2 emissions, (2) the effect of changes in the pollution intensity of the fossil fuel energy basket, (3) the effect of the penetration of carbon-free energy in the energy basket[344]. The equation below shows the decomposition terms employed by the authors to decompose emissions.

$$CO_2 = \frac{CO_2}{FF}\times\frac{FF}{CF}\times\frac{CF}{E}\times\frac{E}{Y}\times\frac{Y}{P}\times P = C_{ff}S_1S_2IyP$$

Where:

CO_2	Carbon emission from fossil fuels combustion
FF	Fossil fuels consumption (coal+oil+natural gas)
CF	Carbon-based fossil fuel consumption (fossil fuels+biomass (feed, fodder, firewood & biofuels)
E	Total energy consumption
Y	Gross domestic product
P	population
C_{ff}	Carbon emissions coefficients from fossil fuels
S_1	Share of fossil fuels in carbon-based fuels
S_2	Share of carbon based fuels in total fuels
I	energy intensity of economic output
y	per capita GDP

This identity can be applied to the method of index decomposition analysis, specifically the multiplicative logarithmic divisia decomposition (LMDI I), which has the advantages of path independency and no residual, among other properties. Like Ma and Stern, we apply here the multiplicative decomposition method, which has the advantage of showing the changes in relative terms. If we take the logarithms of the extended Kaya identity and then use the first

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[344] Ma and Stern (2008).

derivative in order of time, we yield a multiplicative form of decomposition that can be expressed as:

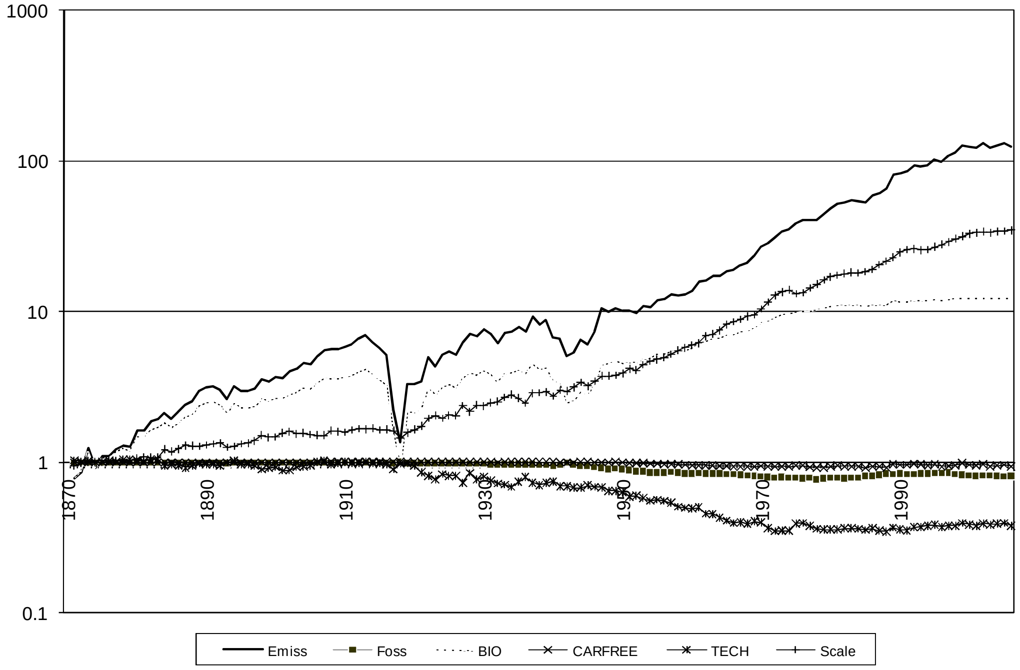
$$\frac{(CO_2)_t}{(CO_2)_{t-1}}=\frac{(C_{ff})_t}{(C_{ff})_{t-1}}\times\frac{(S_1)_t}{(S_1)_{t-1}}\times\frac{(S_2)_t}{(S_2)_{t-1}}\times\frac{I_t}{I_{t-1}}\times\frac{y_t}{y_{t-1}}\times\frac{P_t}{P_{t-1}}$$

which can be rewritten in the following form:

$$Emiss = foss\times bio\times carfree\times tech\times scale$$

where *Emi*ss represents the total effect, the changes in CO_2 fossil emissions; *Foss* represents the inter-fossil fuel substitution effect, due to changes in the emissions coefficients of the fossil fuel basket; *bio* is the biomass substitution effect derived from the transition to fossil fuels; *carfree* is the penetration of carbon free fuels such as nuclear, hydro, solar, geo wind or water power in the energy basket; *tech* is the technological effect derived from changes in energy intensity; *scale* is the effect of changes in income and population. These two factors are grouped together because they have already been dealt with, along with energy intensity factors, in the energy decomposition section[345].

Figure 3.19 CO_2 emissions drivers, accumulated effects



The accumulated drivers of carbon dioxide emissions from fossil fuels in Portugal are shown in the Figure 3.19.

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[345] This is of course due to the fact that CO_2 emissions are a function of energy consumption.

The results show a very large impact of the transition from biomass to fossil fuels on the changes in total CO_2 emissions. While the most important factor in the long-run was the scale effect, this factor only surpassed accumulated biomass effects around World War II. We can therefore assume that the history of the evolution of fossil CO_2 emissions in Portugal was until recently mainly associated with the reduction in the share of biomass fuels. The biomass factor only stopped being important during the 1980s. In fact, compared with the positive effects from biomass transition, the effects of energy intensity, carbon free penetration or transition from coal to oil and to natural gas had a very little part in the reduction of fossil CO_2 emissions. Below, we present the result of the decomposition per period expressed in annual growth rates in a comparative perspective.

3.9.1 1870-1938

Table 3.13 illustrates the main drivers of the change in CO_2 emissions (EMISS) in the period 1870-1938: Technology, Scale and Fuel Switching. Countries are ordered by their initial CO_2 emissions per capita.

Table 3.13 Drivers of CO_2 emissions, yearly growth rates (%), 1870-1938

	1870	EMISS	TECH	Scale	FSW	FSW		
	tCO2 pc					FOS (1)	BIO (2)	CARFREE(3)
Eng.&Wales	11.8	1.0	-0.7	1.7	0.0	0.0	0.0	0.0
US	2.6	4.0	-0.8	3.1	1.7	-0.2	2.0	0.0
Germany	2.0	3.0	0.1	2.3	0.6	0.0	0.6	0.0
Netherlands	1.4	3.2	-0.1	2.3	1.1	0.0	1.0	0.1
France	1.4	2.1	0.0	1.4	0.6	0.0	0.7	0.0
Canada	0.6	5.4	-0.5	3.1	2.8	-0.1	3.0	-0.1
Sweden	0.3	4.5	-0.9	2.6	2.8	-0.1	2.9	-0.1
Spain	0.2	3.2	-0.7	1.8	2.1	0.0	2.2	-0.1
Italy	0.1	3.9	-0.6	1.9	2.7	0.0	2.8	-0.1
Portugal	0.1	3.1	-0.5	1.6	2.0	0.0	2.1	0.0

The effects of fuel switching associated with biomass transition were in general quite important during the period of differentiated energy pathways for driving changes in CO_2 emissions in all countries except England, which had an early transition to coal. They surpassed scale effects in Sweden, Spain, Italy and Portugal, the lowest emitters. The effects of inter-fossil fuel substitution and primary electricity had an almost negligible effect, although the carbon-free energy effects should be interpreted with care due to larger efficiencies in relation to thermal options. In fact, efficiencies of thermo-electricity generation in this period in Portugal, for example, were in the 3-4% range before World War I and 12% in the 1930s. Leapfrogging to hydro-power in the case of Sweden, Spain, Italy or Canada allowed important savings in coal and therefore in emissions. However, the effect of higher efficiencies of hydro-power vis-à-vis thermo-power would be incorporated in energy intensity changes[346] - fuel switching represents only the changes in the emission content of the primary energy source.

3.9.2 1950-1973

Table 3.14 Drivers of CO_2 emissions, yearly growth rates (%), 1950-1973

	1950 tCO_2 pc	EMIS	TECH	Scale	FSW	FSW		
						FOS (1)	BIO (2)	CARFREE(3)
US	16.9	1.6	-0.9	3.9	-1.4	-1.5	0.2	0.0
Eng.&W.	13.8	0.7	-1.4	2.7	-0.6	-0.6	0.0	-0.1
Canada	11.5	3.6	-0.6	4.9	-0.7	-0.8	0.3	-0.2
Germany	7.6	3.1	-2.0	5.5	-0.5	-0.6	0.2	0.0
Netherlands	5.0	4.2	0.8	4.6	-1.2	-1.5	0.3	0.0
France	4.9	3.7	-1	4.9	-0.3	-0.7	0.5	0.0
Sweden	4.5	4.0	-0.1	4.1	-0.1	-0.6	0.9	-0.3
Spain	1.4	5.7	-1.4	6.4	0.7	-0.7	1.5	-0.1
Italy	1.0	8.5	1.2	5.4	1.9	-0.7	2.4	0.2
Portugal	0.6	5.4	-2.5	5.4	2.5	-0.5	3.3	-0.3

The period 1950-1973 is globally associated with a larger growth of emissions in Southern-Europe and a small growth in the US and England. The interesting point is that while scale effects explain much of the difference, the combined fuel switching effects also have a powerful explanation. For large polluters, fuel switching effects of the transition from coal to oil (and to natural gas, in the case of the US and Netherlands) had an important role in reducing emission growth. For countries with a large share of biomass, the impact of fuel switching from coal to oil also had equivalent explanatory factor, but was offset by the biomass transition.

Portugal is an interesting example of how fuel-switching factors interplayed with technology. The post-war years were a period of intense structural and technological change. Fuel switching from wood to modern

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[346] Countries with large hydro-power have historically lower energy intensities than countries which are thermal power based, due to the fact that efficiencies of hydro-power are considered as 100%.

energy carriers occurred in the household and industrial sectors. Tractors slowly replaced animals, and there was a transition from the agrarian economy to the industrial and service sector. As a result, the biomass impact was quite large, pushing up CO_2 emissions to +3.3% a year. However, this was also a period of transition from coal to oil and hydro-power expansion – the two combined factors pushed down CO_2 emissions to -0.8% a year. The result of the fuel switching impact on CO_2 emissions was then positive, as a combination of negative impacts of inter-fossil fuel substitution and increase of the hydro-power share, offset by a positive impact of the transition to modern energy carriers (+2.5). This intense fuel switching probably had large impacts on energy intensity (-2.5) as well, as a result of the incorporation of high-quality fuels in the energy basket.

3.9.3 1973 -1990

Table 3.15 Drivers of CO_2 emissions, yearly growth rates (%), 1973-1990

	1973					FSW		
	tCO$_2$ pc	EMIS	TECH	Scale	FSW	FOS (1)	BIO (2)	CARFREE(3)
US	18	0.6	-2.6	2.9	0.3	0.6	-0.1	-0.2
Eng.&W.	14	-0.8	-2.5	2.0	-0.4	-0.2	0.0	-0.1
Canada	4	0.7	-1.9	3.1	-0.4	0.0	0.0	-0.4
Germany	13	-0.6	-1.9	1.7	-0.4	-0.1	-0.1	-0.2
Netherlands	10	0.6	-1.6	2.3	0.0	0.2	-0.1	-0.1
Sweden	10	-2.6	-2.0	2.0	-2.6	0.1	-1.3	-1.5
France	9	-1.5	-2.5	2.4	-1.5	-0.2	-0.2	-1
Italy	6	0.9	-2.1	3.1	-0.1	-0.2	0.1	-0.1
Spain	4	2.1	-1.3	3.4	0.0	0.1	0.1	-0.2
Portugal	2	5.3	0.1	3.6	1.6	0.3	1.1	0.1

During this period, emissions grew very little in industrialized Europe, the US and Canada. Technological factors and fuel switching factors contributed to the decline of emissions in four of the countries. The most important fuel switching effect was the expansion of carbon-free technologies, especially nuclear power. Inter-fossil fuel substitution had a very small and mixed impact, as shifts to coal in power generation also occurred in many countries (for security reasons). Biomass effects reversed in some countries, especially in

Sweden[347]. Fuel switching had a smaller role in reducing CO_2 emissions than in the previous period, except in the cases of France and Sweden. In 1990, 50% and 70% of Swedish and French electricity came from nuclear power.

Portugal followed a reverse trajectory. The 1973 -1990 period was strongly marked by positive effects in all of the indicators. Economic activity is again the single effect responsible for most of the increase in CO_2 emissions. However, it is interesting to note that while emissions increased by 5.3%, scale effects were much less responsible for an increase in emissions (3.4%) than in the preceding period. While the remaining effects slowed down emission growth in most industrialized countries, it was not the case in Portugal. The effects of the three fuel switching factors contributed to an increase of 1.5% in emissions, mostly due to a still ongoing transition from biomass towards fossil fuels (+1.1%). The share of coal in total fossil fuels increased due to a governmental policy that sought to substitute coal for fuel-oil in electricity plants, making the effect of inter-fossil fuel substitution contribute 0.4% to emission growth. Effects from energy intensity and carbon-free electricity were negligible.

3.9.4 1990-2006

The last period, 1990-2006, allows an analysis of the evolution of each factor after the Kyoto protocol entered into force. As a group, the European Union agreed to an 8% reduction of 1990 baseline emissions in the period 2008-2012. The EU-15, however, established a burden-sharing agreement that allocated different reduction targets to its members. Portugal was allowed to increase emissions to 27% in relation to 1990, as it had lower per capita historical emissions, lower income and expectation of higher economic activity growth rates than other member states. Although at first hand, it might seem a good agreement in the face of the apparently more stringent environmental standards for Northern countries, see Table 3.14, this burden sharing agreement was considered by many to be an extremely ambitious target for Southern countries[348].

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[347] Due to a larger utilization of spent pulping licquor (a waste product) in the pulp and paper industry (representing half of the biomass) and a refinement of firewood into pellets which is a more dense product and easier to handle, see Kander (2002).

[348] According to Dessai and Michaelowa (2001), this burden share was determined by negotiating capabilities. During the negotiation period there were significant changes to the initial pre-agreement of 1997-1998. The changes penalized Southern European Countries in relation to Northern member states. For example, a climate correction factor was introduced in order to take into account different energy needs, but it only considered the heating needs (larger in Northern countries) and not the cooling needs (larger in southern countries).

Around 2006, only Sweden was able to meet the Kyoto targets for 2008-2012 relative to fuel combustion. Most of the countries were still far ahead of the target, and Spain and Portugal much further ahead.

Table 3.16 Drivers of CO_2 emissions, yearly growth rates (%), 1990-2006

	1990 tCO_2 pc	EMIS	TECH	Scale	FSW	FSW			% Change 90-06[349]	Kyoto target (%)
						FOS (1)	BIO (2)	CFREE		
Eng.&W.	12	-0.3	-2.0	2.4	-0.6	-0.5	-0.1	0.0	-5	-12.5
US	17	1.1	-1.8	2.9	0.0	0.0	0.0	0.0	19	
Neth.	10	0.8	-1.1	2.5	-0.7	0.0	-0.5	-0.1	14	-6
France	6	0.2	-1.1	1.9	-0.5	-0.3	0.0	-0.3	3	0
Canada	15	1.4	-1.3	2.8	-0.1	-0.1	0.0	0.1	25	-6
Germ.	12	-1.0	-1.9	1.7	-0.8	-0.4	-0.3	-0.1	-15	-21
Italy	7	1.0	-0.2	1.3	-0.2	-0.3	0.1	0.0	8	-6.5
Spain	5	3.0	0.2	3.0	-0.2	-0.5	0.2	0.1	61	15
Sweden	6	-0.1	-1.7	2.1	-0.6	-0.1	-0.8	0.3	-3	4
Portugal	4	2.5	0.4	2.1	0.0	-0.2	0.3	-0.1	48	27

Note: The US did not ratify the Kyoto Protocol.

In industrialized Europe, the most important factor was the scale effect. Energy intensity and fuel switching continued to have a role, offsetting scale effects in England, Germany and Sweden. In relation to the previous period, fuel switching increased its role in decoupling emissions in all countries, except Sweden and France. Fuel switching factors are mainly a result of climate mitigation policies and the most important fuel-switching factor resulted from inter-fossil fuel substitution in the energy basket. This was a result of a penetration of natural gas in the electricity, manufacturing and household sectors. Transition to biomass was an important factor in the Netherlands, Sweden and Germany and was associated with the establishment of carbon taxes in the early 1990s which sought to promote renewable energy sources. In general, the role of carbon-free energy was much more limited than in the preceding period due to public concerns over nuclear power after the Chernobyl

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[349] These values are from our own calculations. The changes do not differ more than 1% in relation to IEA reference approach, with the exception of Spain and Sweden, see IEA (2010a). The IEA reference approach gives an increase of 58% to Spain and a decrease of 5% to Sweden. The differences do not matter for our results.

disaster[350]. However, it is interesting to note that global climate targets did not accelerate the rate of decoupling of emissions in relation to the previous period. In fact, the combined effects of energy savings and fuel switching were smaller in all countries, with the exception of the Netherlands. As a result of weaker decoupling forces and stronger coupling forces, emissions grew at a higher rate than during the period 1973-1990. Hence, energy policies need to be much more accelerated in all the countries if the Kyoto commitments are to be fulfilled.

Portugal's achievements seem even smaller compared with the rest of Europe. At the time the Protocol was ratified by the European Union (2002), emissions in the energy sector were already 58% above the 1990 base year[351]. Despite the fact that the period 2001-2006 was marked by a structural economic crisis, Portugal only managed to slightly reduce its emissions in relation to 2002. By 2006, fossil fuel emissions were 48% above the 1990 levels implying recent major carbon mitigation efforts. Portugal is no exception to the European Union energy policy, which seeks to increase the proportion of carbon-free electricity, biomass and natural gas while adopting policies to increase energy efficiency. However, there are some limits to fuel switching. For example, biomass is mostly consumed in the household sector, and an increase of biomass in relation to fossil fuels is extremely unlikely given the already high share of biomass in total energy consumption (17%). Despite the introduction of natural gas and investments in wind-power, the effects of carbon-free electricity and inter-fossil fuel substitution have only contributed to slowing down growth to -0.1% and -0.2% of emissions. These effects are being offset by a still ongoing transition to modern energy (+0.3), making null the effects of fuel-switching policies. The indicator of the energy intensity of the economy is where Portugal fares worst in comparison to other countries. The inability to delink energy consumption from economic growth can constitute a serious disadvantage in the task of mitigating climate change.

Concluding; in the long-run, the incorporation of traditional energy carriers, along with modern renewable energy technologies, into our calculations contributes to a better understanding of the drivers of historical change in CO_2 emissions. Scale effects are the most important but fuel switching and technology are not irrelevant factors in explaining $CO_{2.}$ In the Portuguese case, the transition from biomass towards fossil fuels offsets the avoided emissions

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[350] The effects of carbon-free electricity reached a halt in Sweden in that period, with the decision to decommission existing nuclear plants and a freeze on new plants. This decision was reversed in 2010. Nuclear power was discontinued in Italy in 1990 but the decision was also reversed.

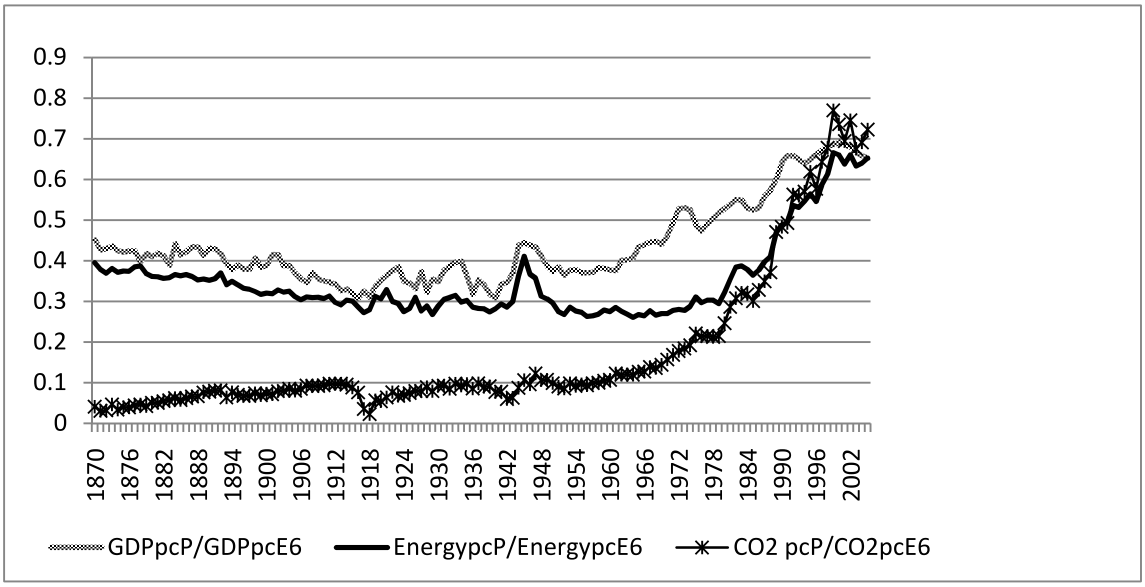
from carbon-free electricity and inter-fossil fuel substitution. The different results of the fuel switching factor in member states in the 1990-2006 period cannot be explained only in terms of successful climate mitigation policies. Countries with a large historical proportion of renewable energy, low coal consumption and no nuclear power might have more difficulty changing the energy system to achieve the desired targets.

3.10 Different energy and economic growth paths

One of the questions of interest is how Portuguese economic convergence and divergence, in relation to the European Core, is associated with convergence and divergence in energy consumption and carbon dioxide emissions.

Fig 3.20 and Table 3.17 show the evolution of the ratio of per capita GDP, per capita energy consumption, and per capita CO_2 emissions in Portugal compared with the average of six countries of the European core (England and Wales; Germany, France, the Netherlands, Italy and Sweden).

Figure 3.20 Portuguese per capita energy, per capita CO_2 emissions and per capita GDP in relation to the European core, 1870-2006



Around 1870, Portugal had only 45% of the income, 40% of the energy requirements and emitted 5% of the pollution (CO_2) of the average industrialized European country, which shows the extreme gap in fossil fuels consumption.

Table 3.17 Rates of convergence in per capita GDP, energy per capita and CO_2 per capita of Portugal relative to the European Core

	GDP pc	Energy pc	CO_2 pc
1870-1913	-0.8%	-0.7%	2.3%
1913-1950	0.4%	0.0%	0.1%
1950-1973	1.5%	-0.3%	2.8%
1973-1990	1.1%	3.4%	5.8%
1990-2006	0.1%	1.7%	2.4%

Note: Catching up is defined as $\Phi = \left[(Y_P / Y_6)_{(t+n)} / (Yp / Y_6)_{(t)}\right]^{1/(t+n-t)}$

Despite initial low levels of income and energy consumption, divergence in the two indicators occurred until World War I at a rate of -0.8% and -0.7% a year, respectively. A relative increase in the adoption of fossil fuels consumption is observable, but it is too low to make a difference: CO_2 emissions accounted for only 10% of the European Core in 1913. A period of instability followed, with a slow recovery to reach slighter lower ratios, compared to 1870, of GDP per capita and energy per capita around 1945.

After World War II, a major catching-up in income per capita is observable with Portuguese income surpassing 50% of the average in the pre-oil shock period, converging at a rate of 1.5% a year. This was surprisingly achieved with comparatively lower energy requirements. In 1973 energy requirements represented less than 30% of the average of European Countries. The ratio of CO_2 per capita increased from 10% of industrialized Europe to 20%, a result of the more intensive energy transition to modern energy carriers. Despite the relative increase in emissions, Portugal polluted relatively much less than is indicated by the income ratio.

After 1973 Portugal continued to converge with the six core European countries in terms of per capita GDP, energy per capita and CO_2 per capita. However, in this phase of growth, energy and pollution convergence was relatively more important than convergence in per capita GDP. The convergence process has now almost stopped. The fact that the CO_2 ratio became higher than the energy ratio around 1990 means that, for each energy unit, Portugal now pollutes more than the European core, and needs more CO_2 per unit of income than the average of the other countries and about the same energy. In conclusion, what the figure suggests is that catching up in economic growth proceeded along a comparatively low energy path until 1973, but trends seems to indicate that this will not happen in the future. The disproportionate convergence of energy uses and CO_2 emissions in relation to the convergence in income in the last decades suggest that, while energy might be important for

Portuguese economic growth, it is no longer such a huge differentiated factor of distinction across nations. Other factors might have become more important in explaining the different growth performances of nations.

3.11 Conclusions

In this chapter we compare the Portuguese long-run energy and environmental indicators with a group of seven European Countries and two New World Countries. The main goal of this chapter is to provide a characterization of how energy systems have evolved since the beginning of industrialization to the present day, and to look for both common patterns and differences across countries, with special attention to the Portuguese case.

In all countries long-run economic growth implies a shift in energy quantities and in the quality of energy carriers. With the exception of the US and Canada, where traditional energy carriers had an early phenomenal importance, the transition towards a high-energy system was made at the cost of fossil fuels and primary electricity (hydro-power and nuclear). At present, with the exception of nuclear-powers Sweden and France, more than ¾ of the primary energy consumed by modern societies comes from fossil fuels.

Although the transition towards modern energy sources is a feature of all developed societies, the pace and intensity of that transition show important differences across countries. The divergent patterns of consumption were especially relevant in the period until World War I and seem to have been partly associated with a differentiated endowment of fossil fuel resources. Countries with the highest level of coal consumption and energy in 1913 were also coal-endowed countries. The fact that some of these countries were the wealthiest in the world by that time suggests that there was some connection between natural resources and industrialization.

In comparison with European leader countries, the Portuguese energy transition in quantity and composition was remarkably slow. In relation to the countries mentioned here, Portugal followed a low resource energy path, sharing this characteristic with Spain and Italy, until at least the end of World War II. The energy system of the three countries was characterized by almost stagnant levels of energy consumption per capita, which were due to the relatively low coal usage per capita. In a group context, Portugal still differed significantly in relation to Spain and Italy in the sense that similar levels of energy consumption per capita were not a result of similar levels of modern energy consumption. Portugal had a much later biomass transition and hydro-power exploitation than the other southern European countries. Portugal was also the country with the slowest economic growth in the period. A study of why the technologies of the coal and electricity age failed to be adopted to any significant degree in this country is therefore essential to understand the failure to converge with the leading economies of the time. Southern Europe had to wait until the post-war period to significantly increase its energy consumption per capita. This period was associated with a faster economic growth in southern Europe than in all the other countries and with a different energy carrier, oil. In the Portuguese case, hydro-power also increased its share in relation to the energy system. It is therefore reasonable to question what the impact of the new energy system was in the Portuguese economic growth.

Energy intensity exhibits a long-term tendency to decline. Economic growth is possible with lower energy requirements than in the 19th century. Despite this tendency, periods of coupling occur, as a consequence of shifts in the production function. This was the case of England & Wales and Germany in early periods of industrialization. The long-run trend does not offset the large differences in energy intensity across countries resulting from technology or climate disparities. England & Wales, Germany, the US, Canada and Sweden followed a more intensive pattern of growth than all the other countries, differences that still persist nowadays in North America. The declining patterns in energy intensity accelerated in most of the economies after the oil crisis. In contrast, energy intensity increased in Portugal and Spain after the 1990s. These countries had lower energy per consumption per head of population, lower incomes and lower energy intensities in the early 1970s. This diverging trend should be further investigated. That is the subject of Chapter 5, where we decompose final energy intensities of our set of countries into structural and technological factors.

Changes in energy consumption were decomposed into technological effects, population effects and income effects. In general, energy intensity declines were not enough to counterbalance the effects of the growth of income per capita and population. However, from 1973 onwards declines in energy intensity were larger than growth in income per capita in six countries, contributing to the stabilization of energy consumption levels in some countries.

CO_2 emissions are a function of both energy consumption and pollution intensity of the energy basket. In Portugal, CO_2 emissions have been historically low as a result of a late transition to fossil fuels.

In the long-run, income and population growth (scale effects) are the most important drivers of changes in CO_2 emissions. However, changes in the energy basket (fuel switching) are also quite important. At low levels of pollution per capita, the transition from traditional energies towards fossil fuels is a factor which had great importance in determining the rise of CO_2 emissions. At high levels of pollution per capita fuel switching is also an important force, which, along with declines in energy intensity is halting the growth of emissions in some early-industrializers. In Portugal, the effects of transition from biomass towards fossil fuels were quite important during all the period, offsetting the negative effects of inter-fossil fuel substitution and carbon-free energy sources.

The impact of energy policies on changing CO_2 emissions since 1990 has been quite limited in relation to the negotiated Kyoto targets. Late-comers seem to have more difficulty in reaching the targets.

In relation to the European core, the Portuguese gap in energy consumption or CO_2 emissions has been historically much wider than the gap in GDP per capita. The divergence in economic growth which lasted from 1870 to 1913 was accompanied by low levels of energy, especially modern energy per capita. Nevertheless, the first phase of convergence (1950-1973) was possible with a slight divergence in energy consumption, an indication of a low-energy intensive type of industrialization, and low standards of personal consumption. The gap around 1973 was therefore huge. Most of the convergence in energy and pollution has taken place after 1973. The Portuguese long-run indicators that characterize energy transitions suggest extreme technological backwardness until World War II and a strong convergence in technology after the 1970s. In the next chapter we will analyze the reasons for the slow modernization of the energy system.

Chapter 4

Energy, Natural Resources and Industrialization

4.1 Introduction

The second half of the nineteenth century became known for the breakthrough of industrialization in many European nations that included, among other things, the widespread adoption of steam technology used in Britain several decades before. Coal was a key element in most of the technological adoptions which occurred in the period that lasted until the outbreak of World War I. It was the age of heavy engineering dominated by railways, steam and steel. In addition to a revolution in processes of making steel (Bessemer process and Siemen-Martins open hearth), in the early 1850s, and widespread use of steam in most of the economic sectors, the period was accompanied by a transport revolution (railways and steamships) that connected the world in terms of international trade, where the few leading industrialized countries supplied the rest of the world with coal, steel and manufactured products in exchange for food and raw materials[351].

Coal was the key element in industrialization, and with the available technology, impossible or difficult to substitute for in many uses such as steamships, railways and town gas. The main problem for many countries was that world reserves were unevenly distributed. England, Germany and Belgium were all well endowed with good quality coal, but some countries, like Sweden, Italy and Portugal were not so lucky in the lottery of natural resources. Coal could of course be traded, but being a bulky commodity, transportations costs could significantly increase its price. Transportation costs could impede the implementation of key heavy industries where energy costs were important, worsen competition with foreign products and enlarge or promote competitive disadvantages of regions. A relevant question in this context is to what degree the lack of coal influenced, shaped or delayed the industrialization process in coal-poor countries.

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[351] Grübler (1998)

The Second Industrial Revolution, that started in the late nineteenth century and had, as a major breakthrough, the emergence of electricity with potentially enormously productivity gains, has been pointed by many as a solution for the problem of lacking coal resources in poorly endowed countries. An automatic advantage of electricity is the possibility of being produced by almost any primary energy carrier. The line of argument follows, that with the help of relative high prices of coal during World War I, electricity, mostly hydraulic, had gained momentum and developed at increasing rates of adoption. Poorly endowed coal countries had probably more incentives to develop this technology than richer ones, and also more opportunities to gain technological leadership or catching up at this point[352]. Not only were the relative prices more advantageous to those countries, but also coal-intensive countries had comparatively more vintage capital to depreciate and could not so fully take advantage of this new promising energy form. A group of coal-poor countries (Sweden, Norway, Italy) hence took the leadership in many technological processes associated with electricity. The fossil fuel argument fades off.

Portugal was far from these breakthroughs for a long time. For almost one century (1850-1938), per capita GDP and per capita energy consumption continually diverged in relation to the most industrialized countries in Europe. We can even say that Portugal practically missed the two industrial revolutions. The country neither succeeded in the age of coal nor in the age of electricity. The Portuguese poor economic performance was only reversed after World War II – an achievement basically obtained during the age of oil.

The goal of this chapter is to provide a reflection on the failures and successes of the Portuguese industrialization process in the context of natural resource endowments, especially energy, as a limiting factor to growth. In order to do so, we compare energy costs in relation to other European countries and to wages and its reflex in the country industrial structure. The general research questions are straightforward: Did Portugal´s sluggish growth and generally low coal intensity path have something to do with relatively expensive coal in relation to other European Countries in the catching up phase of the First Industrial Revolution? In which way did the use of traditional renewable natural resources in a first phase, and hydroelectricity in a second phase, compensate for the lack of fossil fuels? Were they good enough to make industrialization viable? Lastly, what kind of parallelisms, differences and reflections can we find between the use of indigenous and renewable energy sources in the past and the recent European Union renewable energy policies?

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[352] Bétran (2005).

4.2 First Industrial Revolution lost: without steam in the age of coal

Around 1750-1800 a major set of technological breakthroughs occurred in Britain, allowing, for the first time in history, a major and sustained increment in the living conditions of the population. These transformations, known as the First Industrial Revolution, were particularly evident in a cluster of industries: cotton, iron and railways with the steam engine as a converter and coal as a common energy input.

Authors such as Cipolla, Wrigley or Malanima argue that coal was a necessary, albeit not sufficient condition, for the industrial breakthrough, and that traditional sources of energy made continuous growth unattainable[353].

If in fact the availability and cheapness of coal were essential conditions for the emergence or sustainability of the Industrial Revolution, one can try to evaluate the relative success of the diffusion of the Industrial Revolution to other parts of the globe that did not possess coal reserves. Without any major coal reserves, Portugal was, at the beginning of the second half of the nineteenth century, one of the most backward countries in Europe. The literacy was much inferior to its European counterparts; the country had lost the important market of Brazil a few decades earlier and had just suffered Napoleonic invasions and civil wars. The major part of the labor population (68%) was employed in agriculture.

Portuguese economic historians agree that it would be very difficult for agriculture to produce a large surplus of the products that the external market was demanding, such as grain or animal products. The poor Portuguese soils made grain productivity as low as ¼ of the British one, although wine productivity was quite high, even more than in Italy or Spain. Despite agriculture's low productivity, there was an untapped labour force, as can be seen on the extremely high levels of emigration. According to the indices of industrial production constructed by Reis and Lains, until 1913 manufacturing grew at a higher pace than agriculture, at rates of 2.5-2.8% a year[354]. However, one of the main points is that growth was too small to catch up with the leading economies, unlike the economies that began their industrialization process with an only slightly better income. By 1860, Portuguese GDP per capita was 25% of the English, 50% of the French, 62-65% of the Italian and German, 75% of the Spanish and only slightly lower than the Swedish and Finnish ones. At the turn of the century, income per capita had maintained this gap in relation to England,

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[353] Cipolla (1962); Wrigley (1988); Malanima (2006b).

[354] Lains (1990); Reis (1986); Reis (1994).

but declined enormously in relation to other European countries, becoming 40% of the German and French per capita GDP, 57% of the Italian, 67% of the Swedish and 66% of the Spanish. Did differential conditions of access to coal determine the relative lack of success of the Portuguese Industrial Revolution?

4.2.1 The lack of coal resources in the periphery: imports prices

When the Continent began its industrialization, coal was already established as a superior technology in Britain in almost every aspect of economic life. However, some countries were more endowed than others. The UK, Germany and the US belonged to the group that produced more than they consumed. Austria and Czech Republic fulfilled their needs[355]. France, Canada and Spain had mixed situations, where coal was lacking in some regions but was abundant in others, or with large reserves with high costs of extraction, with respectively 30%, 40% and 60% of coal imports by the end of the nineteenth century.

Table 4.1 Coal prices at the pithead in current shillings per ton, 1850-1900

	United Kingdom	United States	Germany	Canada	France	Spain	Portugal
	Pithead	Pithead	Pithead	Pithead	Pithead	Pithead	Pithead*
1850s	5.3						
1860s	5.6						
1870-72	6.5			6.6			
1879-81	5.4			7.2		9.3	25
1884-86	5.1	6.2	5.2	7.2	9.4	9.4	31
1889-91	7.5	5.3	7.1	7.6	9.5	9.5	28
1899-01	9.2	5.2	8.7	8.8	11.5	12.3	13
% auto-sufficiency							
1890	119	101	98	61	70	40	2

Sources: Average UK (from 1870), German, US and French prices come from Bardini (1997). Prices in the UK from 1850s and 1860s come from Clark and Jacks (2007). Spanish pithead price is from Coll (1985). Canadian prices from Urquhart and Buckley (1965). Portuguese prices obtained from MOPCI, *Inquérito Industrial,* 1890 and INE, *Anuário Estatístico*. Portuguese prices take into account the low quality of Portuguese coal (1 ton British coal = 1.7 ton Portuguese Coal). Exchange rates for Portugal using data from Bastien (2001) from 1891 onwards, and before that year from Clarence-Smith (1985). Auto-sufficiency is calculated from Mitchell (2003).

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[355] Assuming the territorial boundaries of the time.

In the lottery of coal resources Portugal belonged to the group that was poorly endowed, on pair with Sweden, Italy or Finland, which imported almost 100% of their needs, contrasting deeply with the coal nations of the World.

How important was it to have domestic coal reserves to emulate the Industrial Revolution? Compared with pithead costs in the UK, the US and Germany already had very low costs of extraction by the 1880s (see Table 4.1). Not surprisingly, iron and steel production was transferred to those countries with England losing its market share [356]. All these three countries had possibilities of extensive industry located around the mining regions. Canada also had low costs of extraction. France and Spain had almost the same level of pithead prices in relation to UK prices, ranging from 1.7-1 in 1879-81 to 1.3-1 by the end of the nineteenth century. In the case of Spain, prices at the coalfield are misleading. Most of the valuable reserves are located in the mountainous region of Asturias and the region is not well off in terms of transportation, which does not make it an ideal location for a new industry. In the 1860s and 1880s domestic coal needed to be shipped to the main ports of the country which made it as expensive as imported coal[357].

In the Portuguese case there were many mines at the beginning of the nineteenth century, but the coal was of low quality anthracite, which did not suit British steam engines, without first being boiler adapted or mixed with high quality coals due to the very high content of ashes in Portuguese coal. Boiler adaptation was practically untried by the end of the nineteenth century. Production was insignificant and represented some twenty thousand tonnes. At the end of the nineteenth century, the 1890 Industrial Census reported the status of the coal mines. The three most important mines produced insignificant quantities, mostly directed to household consumers. Even in that market, it was difficult to find buyers, as prices at the pithead were higher than prices at the ports (see Table 4.1). This said, with the high costs of internal transportation, prices practically doubled in relation to the pithead price at the local destination.

Coal had therefore to be imported if it was to be used. Coal prices were much higher for price takers in general and the difference was especially high in the early period. Until 1880, coal arrived at the Portuguese ports at double the price of exports from the United Kingdom and three and half times more than pithead prices (see Table 4.2).

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[356] Allen (1979).

[357] Nadal (1975).

After 1880, the use of steam navigation lowered costs and freights significantly declined. By the end of the 1880s, the introduction of duties was not enough to counterbalance price declines, and the price had decreased to about two times the pithead price in England. At the time, maritime freights represented only 20% of the final costs and coal was sold in Lisbon at a lower price than the best coal in London, a non-industrial city with the most expensive coal in all Britain.

Table 4.2 Coal prices FOB, London and import destination in current shillings.

	UK	London	Genoa	Bilbao	Portugal			
	FOB	Price	Imports	Imports	Imports	Portugal/UK (pithead)	% of freight as a fuel price	% of duties as a fuel price
1850s	8.9	19.1			18.6	3.5	51	1.5
1860s	9.6	19.3			19.2	3.4	50	0.0
1870-72	11.8	21.0	29.3		23.0	3.6	49	0.0
1879-81	8.9	16.8	23.5	18.1	19.8	3.6	53	0.0
1884-86	8.9	16.3	20.7	17.7	17.4	3.4	41	8.2
1889-91	11.7	18.5	24.8	16.9	16.0	2.1	19	8.6
1899-01	13.8	20.7	28.8	15.8	18.1	2.0	18	5.5

Sources: Free on Board (FOB) and London best coal prices are from Mitchell (1962). Bilbao from Coll (1985), Genoa from Bardini (1997) and Portugal own elaboration from INE, *Comércio Externo*, several years.

Around 1910, the prices at Lisbon Port were equivalent to Copenhagen, slightly more expensive than Hamburg or North of Spain, and slightly cheaper than Stockholm[358]. Coal prices were still relatively cheaper in Portugal if compared with Mediterranean ports. In Barcelona or Genoa, the freight represented a significant percentage of the total import price but Lisbon and Oporto were a closer route to England.

Concluding, the level of coal prices among coal-poor countries was much higher than the pithead prices of endowed countries, although the transport revolution minimized those differences by the end of the nineteenth century.

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[358] Jevons(1969).

4.2.2 The costly nature of alternative energy: wood and water versus coal

Many environmental historians have pointed to the role of alternative sources of energy in the beginning of industrialization. The case of the USA is a famous one, where the vast wood resources of the region, transport problems and the early problems associated with the application of anthracite for industrial uses made wood an important energy carrier, used vastly in the beginning, not only for household purposes, but also in steam engines and steam boats[359]. More examples emerge from coal-poor countries. In Finland and Sweden, vast wood resources also make it possible to postpone the fossil fuel-based industrialization until the twentieth century. Collective innovations in the field of stove efficiency dramatically reduced household heating needs, keeping firewood prices low or competitive with coal prices, despite an increase in population and industrial use[360]. In Finland, about 87% of the industrial energy consumption was provided by wood and water in the late nineteenth century[361]. In Sweden, the difference in relative prices was not as pronounced as in Finland, but firewood used in industry was equivalent to total coal consumption around 1870. And differences in prices were enough for fuelling the very energy-intensive Swedish mining industry with charcoal until as late as 1900. The use of wood in railways was also common. Most of the coal was used in railways, steamships and gas works[362].

Water power also had its role in the late nineteenth century. The costs of water power were about half the costs of steam in the 1840s in America, even if costs of steam were already lower than in Britain[363]. This made it possible for water power to be dominant in the cotton, paper and wood industries as late as 1870, though not in the heaviest industries. Alpine regions such as Switzerland, part of Italy and the south of Germany also benefited from extremely low costs of water power. In the case of Barcelona, where energy costs were higher, the high costs of coal made industrialization with water power a strong alternative in the textiles of the region[364].

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[359] Melosi (1982); Schurr and Netschert (1960).

[360] Kander (2002), Kunnas and Myllyntaus (2009).

[361] Kunnas and Myllyntaus (2009).

[362] Kander (2002).

[363] Christensen (1981), p. 322. In an early work Temin (1966) suggested that steam and water costs were about the same. Christensen uses the same original material as Temin, but changes some of the assumptions.

[364] Carreras (1983); Nadal (1975).

It is then of relevance to understand if indigenous renewable natural resources were an interesting alternative source of power for Portuguese industrialization needs. Did the Portuguese economy rely on wood and water resources? Or was coal steam power making its breakthrough?

Table 4.3 Steam and waterpower, manufacturing and mines, around 1880

	Lisbon[a]	Oporto[b]	Covilhã and Guarda	Other regions	Mining[c]
Factories[e]	67[a]	47	98	49	
Hp	4 146[a]	1 619	1 384[g]	1 680	1 952[d]
Steam,% hp	93%	73%		19%	77%
Steam/Water, % hp	7%	27%	41%	61%	
Water, % hp			59%	20%	23%
Steam users, from whom	67	47	11	34	
Firewood users	5	1	11	11	
Coal users	66	46	0	6	
Unknown	0	0	0	14	
Coal prices (Escudos /ton)	4.2 to 6	5 to 8	20	6 to 11	
Firewood prices (Escudos/ton)	3.4 –5.4[f]	2.8-4.5[f]	2 to 4.8	2 to 6	

Sources: MOPCI, *Inquérito Industrial de 1881.* [a] Includes the power of steam cereal grinding factories (7/1021 hp) that were not visited in 1881 but are included in MOPCI, *Inquérito Industrial de 1890*[365]. [b] Small industries are not included. [c] INE, *Anuário Estatístico de 1885*, for 1882. It was not possible to investigate which mines used both steam and water, as data is national. We did not include 945 hp installed in railways in one mine. [e] Number of factories with motors. [f] Values outside and inside the cities. State industries are not represented. Absolute values differ from other studies, due to the fact that they are based on the values of the Census text and not on its summary, which includes duplication of steam power in some cases, as includes also boilers. Excludes water and wind cereal grinding mills[366]. [g] Missing data for Guarda was corrected by the average of the power of other wheels in the region.

The first steam engine was imported to Portugal from England, to be used in a coal mine in 1804, but was never used due to lack of capital to hire an engineer capable of assembling it[367]. The first steam engine ever used was brought to Lisbon, to be used in a steam-mill around 1820. Between 1835 and

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[365] Ferreira (1999) provides a detailed account of the most important mills. His work was used as an auxiliary source, to check wether the factory existed in 1880.

[366] Because most of them belong to the small industry, and due to its expression would bias what is happening in other industries in the rural industries of the country. See chapter 2 for a quantification of its importance in total water power.

[367] Matos (1999), p. 110.

1852, 69 steam engines with 960 hp were installed in the country, the majority of them in Lisbon, but we know little about water power[368]. The Industrial Census of 1881, with its limitations on coverage[369], is the first that can give a global idea of how the diffusion of steam had proceeded around the country, as it allows a comparison between water and steam, wood and coal usages.

Table 4.3 shows the distribution of power in manufacturing around 1880 in the two major coastal cities (Lisbon and Oporto), Covilhã and Guarda and other regions. Three major points can be made by the analysis of the first Industrial Census. First, the low use of power, and the limited diffusion of mechanized industrialization in general, which is given by total installed power and number of motorized factories. The Portuguese power market is small, at the level of less than 1% of the England power market in 1870[370]. Second, Lisbon and Oporto (to a smaller degree) followed generally and rationally the British steam model, with 93 and 73% of power installed in only steam systems. The third point is that unlike Scandinavian countries or others, there was hardly any cheap alternative power source in Portugal. However, there are many aspects of the problem which require a more detailed and systematic analysis.

Fig 4.1 presents the relative prices of wood and charcoal versus coal in Lisbon and Oporto and in Sweden. Unlike Nordic countries, where firewood competed with coal, as soon as coal started to be imported[371], in Portuguese ports it arrived with prices at least half the price of wood (per GJ). The trend towards an increase of relative prices proceeded to peak around 1895, when both charcoal in Lisbon and firewood in Oporto were sold at 4.5 times the price of coal (see Fig 4.1). Apparently, this market difference in fuel prices was not enough to convince household users, at least outside Lisbon and Porto, to switch from wood to smoky bituminous coal.[372] One possible reason for the residual

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[368] MOPCI, *Inquérito Industrial*, 1881.

[369] The 1881 census was both direct and indirect, but some regions are better covered than others. There was another inquiry made in 1890, which is totally indirect and is more complete for State Industries, Mining and steam cereal grinding mills, see Chapter 2. The 1881 Industrial Census is more informative about the uses and prices of fuels and in the discussion of water and steam power and that is why we use it here. We correct Lisbon data for steam cereal grinding mills and use a national source for mining.

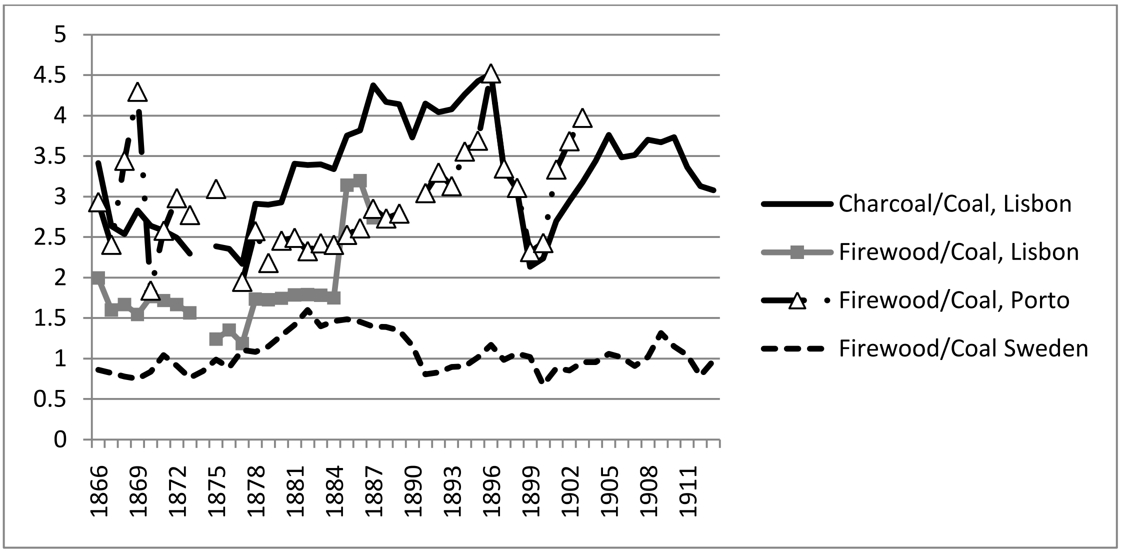
[370] Musson (1978).

[371] This differential, although not shown here, was already present back in the 1800s when Portugal imported only small amounts of coal.

[372] Teives (2006). In a previous work, I found only little evidence of the use of anthracite or bituminous coal in Portuguese households. In the late nineteenth century, only coke, a byproduct of coal distillation for town gas production, was able to compete with charcoal in the urban household markets. The closing of the Lisbon gas factory during World War I, and the subsequent reduction of gas production thereafter, contributed to a revival of charcoal consumption in the interwar years.

use of coal in Portuguese households was that the adoption of well-designed chimneys and iron stoves was a necessary condition for minimizing coal-related indoor pollution.[373] Even in Lisbon, the use of iron stoves was uncommon (perhaps because there was not a well developed iron industry). The development of railway transportation from Lisbon to Alentejo, an important charcoal production zone, enlarged the more limited and traditional areas of charcoal supply and halted the diffusion of coal to urban households somewhat[374]. However, in manufacturing, prices did matter and wood was expensive in the sea port cities of the country. All but one steam user for each region (Lisbon and Oporto) reported the use of imported coal as the first choice, although wood was used in some boilers and ovens, especially in ceramics or glass making (see Table 4.3).

Figure 4.1 Relative prices of wood and charcoal versus coal (1866-1913), Lisbon, Oporto and Sweden, GJ



Sources: Firewood prices: Kander (2002) for Sweden. For Oporto, Pereira (1983), the cheapest firewood type and conversion in oxen carts=500 kg. For Lisbon, based on taxation data, *Estatística da Alfândega*, several years. Coal prices: Ljungberg (1990) after 1890 and revised coal series 1866-1889 based on railway costs kindly provided by Astrid Kander for Sweden. INE, *Comércio Externo*, my compilation, for Portugal.

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[373] See Allen (2009) for an account of the improvements in chimney and stove construction that accompanied the transition from wood to coal in London.

[374] This is one example of how a new technology (railways) can solve some of the bottlenecks of a traditional energy carrier (in this case, the distance to the area of supply). Rosenberg (1972) gave a similar example of how steamships also improve vessel technology.

The diffusion of steam in Portugal's two main cities was mainly due to the introduction of cotton textiles manufactures, for which they had privileged locations in relation to mainland regions, as cotton was also imported. Coal also became relatively important in other textiles, cereal grinding mills, machinery and tobacco. Coal had its relevance for development of the main cities as it was cheaper than wood and, as we will see later, water. The question is to know if higher costs in relation to industrial leaders made a difference in economic performance.

Things were less easy for other regions of the country. Outside Lisbon and Oporto there were 54 steam engines accounting for little more than 1 000 hp distributed by 45 users, but usage of steam as the only power source was rare (see Table 4.3, Covilhã and Guarda and other regions) and even more rare was the usage of coal. The census only mentions 6 coal users and they all correspond to locations where coal arrived at the low range of national prices (6 Escudos, *i.e.,* 150% Lisbon prices). Coal could become extremely expensive in some inland industrial centers, despite the small size of the country. Just outside the limits of Lisbon, the price went up from 4.5 to 5.5 Escudos. The same happened in the suburbs of Oporto region were coal paid 1.7 Escudos for the 52 km of railway transportation. There was also a railway line connecting Lisbon to Alentejo (200 km), but Portalegre wool industries complained that costs of transportation amounted to 5–6 Escudos per ton, making coal prices more than double the one in Lisbon. Coal would have been even more expensive in the mountainous regions of Guarda and Covilhã, where railway construction had not finished yet, *i.e.*, 20 Escudos (and even with railways, 8 to 11 Escudos), about 5 times the Lisbon price and almost 10 times the British pithead price. Therefore, for the production of steam there was only wood; that was relatively cheaper outside the cities. However, the price of firewood at 2 Escudos/ton, in the very low range of wood prices (Table 4.3), was equivalent, to the inquired factories, to work with coal at a cost of 8 Escudos/ton, the double of Lisbon. The respondents were probably overstating the energy content difference between wood to coal, as they were valuing 1 ton of British coal at four or five times the value of 1 ton of wood, far away from the more established relation of 1 to 2.5[375], but it is also true that wood has poorer conversion efficiencies than coal when used in boilers and steam engines[376].

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[375] In modern energy balances the energy content of 1 wood ton is considered to 0.43 tce, this is 43% of 1 coal ton.

[376] Kunnas and Myllyntaus (2009).

The point from the above is that, even using a more conventional conversion figure, wood would always be on average much more expensive than coal at the ports. Of course there were privileged locations such as the State forests in Leiria, where the government provided a yearly subvention of 21 000 m^3 of pine wood a year to the Royal Marinha Grande Glass Factory, the most important known single user of firewood around the 1880s[377]. However this was more an exception than a rule. Examples from the early 19th century show the limits of a wood-intensive-based industrialization. The last known charcoal smelting iron work of the nineteenth century closed its doors at a time when charcoal works were still operating in all Europe. It consumed 7 tons of wood a day, which boosted local firewood prices. Due to the impossibility of finding enough wood in an area of 45 km, and due to high transportation costs of importing coal from Lisbon, it went bankrupt in 1830[378].

There was enough non-conventional forest to fuel rural household needs, but probably not enough forest to sustain a wood-based industrialization, of the type that occurred in Nordic countries. In manufacturing, wood was a poor alternative to coal and was only a second best choice in the face of expensive steam energy costs outside the cities**.**

Was water power a good alternative to steam in a coal expensive country and especially in more distant regions? On the question of localization of an industry, the comparison between water and steam costs has to take into account not only the capital costs (price of motors, foundations) and variable costs (reparations, cost of fuel, machinists, wages) but also the cost of transportation, which for the majority of industries was much higher in the case of water power, as it is a natural resource that cannot be moved. The advantages of water power in the late nineteenth century would always have to be measured against distance to ports – on imported raw materials (cotton, wheat, iron, steel, for example) – and distance to major centers of consumption.

Although it would seem that the cheapness of hydraulic power was a major advantage in relation to steam[379], the distribution of power in the 1881 Census

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[377] MOPCI, *Inquérito Industrial* de 1881.

[378] Madureira (1997).

[379] The studies of Corvo (1883) and the budget proposal for the acquisition of power by a factory located in Bacia do Ave, 25 km from Oporto, transcribed in Cordeiro (1993) are the best known studies that compare steam power with water power costs. The studies suggested a difference in favour of water to steam of 1–2.3 (in the case of the budget) and 1–1.1 and 1–15.7 (depending on the number of days and horsepower, in the case of Corvo). Santos (2000) argues that many of the conclusions were biased in favour of water due to the fact some assumptions were wrong: number of working days at full power in the water case (too high); cost of coal (too high); machinist wages (too high). We

(Table 4.3) and the opinion of the commissioners in the various regions of the country suggest the contrary.

The only regions where water is preponderant (Guarda, Covilhã), the wool centers before the emergence of the industrial revolution, are the ones where coal arrives at exorbitant costs (Table 4.3). However, the quality of the streams was bad when compared by international standards. In Covilhã, the waterfalls are on average only 4 to 7 meters, and the volume of the water is no more than 100 liters per second; enough for only some tens of hp per factory. All the factories requiring larger power needed the complement of steam power, but steam for itself was an almost impossible solution as demonstrated by the immediate closure of the only factory that was installed there with the idea of using coal steam power. During the summer, the water power went down considerably and was necessary to work during the night and even so it was not enough and the factories needed to stop or use steam as a complement. Maybe the serious situation of these regions could have been alleviated by a more efficient use of water[380]. However, when one includes expenses of transportation of raw materials, even if one accounts for cheaper wages, there was apparently no compensation for locating the industry so far away from the market centers. And indeed, these two industrial zones were somewhat stagnant, with only some new industries, opposing to the more dynamic situation of steam regions).

In other regions, the common solution were mixed systems (61% of the installed power), see Table 4.3. In fact, while some streams could deliver the power of 100 hp in the winter, there was no industry with more than 50 hp of constant need, without steam as a complement or as an alternative to water power during the summer droughts, with the increasing costs in terms of capital (acquisition of steam engine) and fuel costs much above those of Oporto and Lisbon centers[381]. This means that, with a very high degree of certainty, water

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agree with Santos except in the case of machinist prices, as the Industrial Census clearly shows, when it is reported, that the wage for a machinist is substantially higher than for normal workers.

[380] In Covilhã, the commissioners point to the fact that, when larger falls are available, the industrials prefer the use of 3 hydraulic wheels of 6 m of instead of a turbine, which will be much more economic. They also suggest that the power could be increased by the improvement of forestation and construction of water galleries (but not weirs, which would not be appropriated to the stream). In Guarda, they point to the fact of low scientific knowledge of industrialists, who do not even know how many turns does a wheel make per second. MOPCI, *Inquérito Industrial* de 1881.

[381] Some concrete examples of this situation are expressed in the 1881 Industrial Census. The Companhia de Fiação e Tecidos de Alcobaça had a 120 hp turbine which did not give more than 80 hp in the best conditions. Hence, it was waiting for a new 100 hp steam-machine, even if it was going to be costly in terms of coal. The Fábrica de Fiação de Algodão do Bugio (1879) had a waterfall of 21 meters and its location was determined by waterpower. However, the water was not as constant as had been expected and the two 35 hp turbines did not provide water for more than 7 months of the year, so there was a wait for one 80 hp steam engine from Belgium.

was also a second best alternative to steam, and there were strong limits to scale in the adoption of water systems, even with the acquisition of more efficient turbines instead of wheels by larger units. Then, it is not surprising that the persistence of water power in some units of woolen and cotton spinning and weaving in Oporto region made industrial commissioners apprehensive about their future. They give an interesting example of the results of locations of two cotton factories, one with water power and one constructed for steam. Not being entirely comparative in terms of power needs and efficiency of motors[382], it is interesting to show the results as they are an illustration of water power constraints all over the country.

As we see in Table 4.4, the water-power factory had serious disadvantages in terms of total expenses per ton or hp. Most hydraulic factories were compromised by larger transportation costs (both fuel and raw materials) and by the duplication of capital costs due to severe droughts. This made Portuguese energy costs quite large. There was a high price to pay for distant regions. With

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[382] An alternative way to compare water and steam costs was to use the budget proposal for the acquisition of two turbines, as presented by Companhia Industrial e Agricola Portuense to their stockholders in 1877 (Cordeiro, 1993). The budget proposal compared the yearly costs of steam and water power in a hydraulic region near Oporto, with good access to the railway network. The yearly water power costs were calculated to be 7 755 Escudos/year, which included variables such as capital costs (hydraulic works, the installation and acquisition of 4 turbines (180 hp), interest and depreciation on capital), and operating costs (yearly repairs and the wage of one machinist). It was assumed that turbines would work at full power for 12 hours a day. If the factory was located in Oporto, steam would be the option. Two Woolf steam engines (including installation) totaling 180 hp, burning 1.5 kg coal/hp/hour at the price of 5 Escudos/ton, at an interest rate of 6%, with 2 machinists receiving 800 réis (0.8 Esc.) a day, during 300 days a year would cost 12 430 Escudos a year, a difference of +4 675 Escudos in relation to water power. The results of the budget proposal were criticized by Santos (2000) due to the optimistic assumptions of constant water power. In fact, if we assume a more realistic drought of 90 days for the water power site, the steam engine should be used as a complement of water power. Employing one Woolf steam engines of 90 hp, plus a machinist, and coal at the cost of 6.5 Escudos (the factory was well located, at 25 km from Oporto, with good railway transportation network, so transportation was estimated to be 1.5 Escudos/ton), additional costs would amount to 4 500 Escudos/year, just a little lower than the initial difference for the turbine (4 675), but with high marginal costs for expansion of power. The success of the location would be determined by the transportation costs of raw materials (400-600 tons of cotton a year), wages and rents, but not by cheaper power. The history of the factory confirms that water power was not the ideal solution. Due to initial capital problems, the factory postponed the acquisition of the turbines. It started in 1880 with a wheel of only 13 hp. According to the commissioners who visited the factory in 1881, the waterfall had 150 hp in the winter, but was reduced to 20 hp during the summer. The company was planning to acquire a steam engine to complement water power in 1881. By 1908, the main source of power was steam; two modern 400 hp steam engines powered the factory. The factories of this area had relative success in the twentieth century, due to lower wage costs in comparison with the Oporto region. Despite being an important reason for the initial location of the factories, water power was hardly a factor of cost reductions.

both higher transportation and energy costs to peripheral regions, the coal revolution was first limited to the cities of Lisbon and Oporto. From 1881, transportation improved and lowered energy costs inland. By 1892, with the introduction of new railway tariffs, coal transport paid in one of the main railway lines probably half of the costs of the maximum tariff that was introduced in 1861[383]. All over the country mixed systems emerged. However, there was still an idea that costs of transportation were high – in 1933 coal arrived in Covilhã at 4 times the UK pitheads price[384].

Table 4.4 Comparison between two cotton factories, water and steam power

	Valongo (water)	Porto (coal)
Type	Spinning	Spinning, weaving
Water power	30 hp (8 months)	
Steam power	30 hp (4 months)	280 hp
Steam efficiency	4.2/hp/hour	1.5/hp/hour
Power capital (Escudos)	40 000[a]	25 000
Annual Interest (Escudos)	2 400	1 500
Transport per ton (Escudos/ton)	1.89	0.725
Costs with coal (Escudos)	700	7 500
Transports (Escudos)	964.6	1 595
Expenses (Transports+ Interest+ Fuel Costs)	4 064.6	10 595
Production (ton.)	55	340
Cost pert ton (Escudos)	74	31
Cost per hp (Escudos)	68	38

Source: MOPCI, *Inquérito Industrial*, 1881[a] Does not include the cost of steam engine, which would give stronger differences.

4.2.3 The relatively high coal-wage ratio

Energy costs were higher than in coal endowed countries and there was very little recourse to alternative energy sources such as water or wood. An additional way to investigate the economic incentives to adopt steam technology is to compare the relative coal to labour prices, see Fig 4.2.

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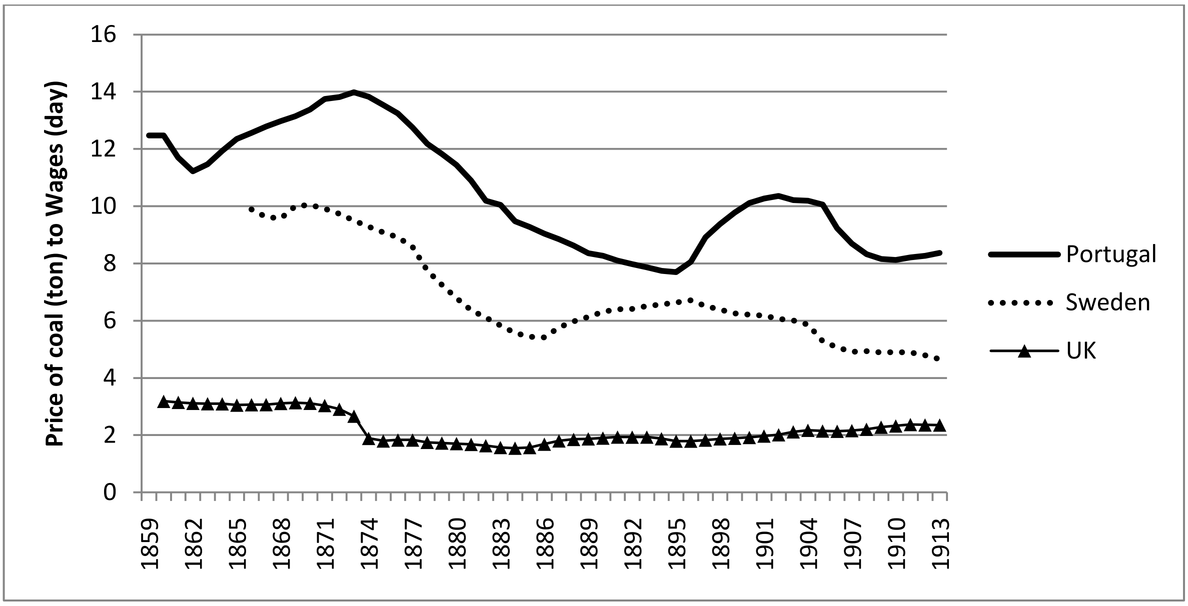
[383] In 1861 coal paid 2.5 Escudos for each 100 km, see Pinheiro (1986). In 1890s-1900s the tariffs of Companhia Real dos Caminhos de Ferro for a coal wagon of 8 tons of coal, paying a minimum ticket of 60 km were 1.2 Escudos at 100 km, 2.3 at 200 km and 3.3 at 300 km, values in Gazeta *dos Caminhos de Ferro de Portugal e Hespanha*, years 1890, 1899 and 1903. Due to transportation costs no more than 15% of the coal unloaded in Lisbon port was transported by railways until 1913.

[384] Miranda (1991).

Figure 4.2 Coal price ratio to wages in the UK, Portugal and Sweden, moving averages (9 years)



Sources: For Sweden: hourly wage data given by Prado (2010) adapted to daily wages considering a working day of 10 hours. UK: Builders wage refers to South Eastern England and are taken from Global Price and Income History Group/ Clark, *English Prices and Wages 1209-1914*. Pithead coal prices are taken from *Digest of Welsh Historical Statistics: Coal, 1780-1975*. For Portugal: data from Martins (1997) which is a simple average of 14 urban or industrial tasks.

While relative coal to labour prices declined substantially in Portugal in the last quarter of the nineteenth century, revealing a relative incentive to mechanize, the ratio coal/wages was relatively high in comparison to the more coal-endowed England (Fig 4.2). In England, 1 ton of coal was equivalent to the wages of three men in 1860 and the wages of two men in 1913; for Portugal the equivalent was the wages of twelve men in 1860 and eight men on the eve of World War I. In Sweden, a country that managed to catch up better than Portugal in the late nineteenth century, the coal

In a context of international trade, Portugal presented a structure of relative prices that incentivized specialization in the factors that were relatively less costly, in this case labour.

4.2.4 Energy consumption in the productive structure of Portuguese economy

What were the results of high costs of coal in the Portuguese productive structure?

Table 4.5 Comparison between coal consumption (thousand ton) in some sectors, UK, Portugal, Spain and Sweden

	UK c. 1870		Portugal c. 1880		Spain c.1870		Sweden c. 1870	
Sectors	1 000 ton.	%	1 000 ton.	%	1 000 ton.	%	1 000 ton.	%
Pig Iron, Metals and steel	33 306	47	0	0	450	47	76	61
Mines	7 225	10	10	5	270	28		
Manufactures	22 618	32	82	48				
from what, Textiles	20%		42%		22%			
Railways	2 027	3	33	19	193	20	23	18
Gas	6 312	9	45	27	50	5	26	8
Sum	**71 489**		**170**		**963**		**125**	
Firewood to coal industry ratio	0		0.3		n.a.		6	
Coal p.c. (kg)	2 828		39		60		30	
Solid fuels p.c (kg)	2 828		50		-		142	
GDP per capita ($1990)	4 000		1 000		1 200		1 100	

Sources: Warde (2009) for the UK, Kander (2002) for Sweden, Coll and Sudrià (1987) for Portugal and own calculations for Portugal based on Pinheiro (1986) for railways and CLIG, *Relatório.. 1880* for gas. Lowest coal values for manufacturing are based on the calculations for power in Table 4.3., information on coal consumption per hp given in MOPCI, *Inquérito Industrial de 1881*. About 230-270 tons of coal equivalent were consumed in the territory in 1878-1879. The differential in relation to the sum (170) includes consumption for ships, industries not considered in the Census and others.

Table 4.5 compares the structure of coal consumption in the UK and the three most backward countries of our sample (Portugal, Sweden and Spain) around 1870- 1880. All seem to have lost out on the first wave of steam that succeeded in countries such as the US, Germany, France or Belgium. In order to emulate UK type of industrialization, what was needed was an increase in energy by a factor of 60 in the case of Portugal, and 20 in the case of Sweden. In the three backward countries, railways represented a much higher proportion of coal consumption despite the much lower levels of km per capita in relation to the UK. It seems then that the diffusion of coal was more concentrated in sectors where coal could not be easily substituted such as transportation. Still, the structure of Portuguese industry was more affected by the lack of coal endowments than Sweden or Spain. In the case of Sweden, coal consumption per capita in the sectors above was even lower than for 1880 Portugal. However, firewood was used in a proportion of 6 to 1 in manufacturing, especially in the heat intensive industries. In the case of Spain, the industrialization was more inclusive. Despite the high costs of domestic coal in the coastal areas, where it hardly arrived at the same cost of imported coal, national coal was important in railways and the mainland regions. And even with imported coal, the Basque iron reserves were of such good quality that they managed to be competitive with the English in some branches[385].

In the Portuguese case, one of the most important differences is that there was no capacity to develop the heat-intensive industries of the Industrial Revolution. Besides being poor in coal, the country was also poor in ore (and other metals). Although there were plans to create this industry with a basis in wood resources from Leiria pinewoods and coals, the proposals were destined to fail as they were based on resource evaluations that hardly had a correspondence with the truth.[386] This feature had impacts on the possibility of the spurring effects of railway investments and mechanization in general. Having to import all the iron and steel from abroad, the expansion of railway network had little impact on boosting metal and engineering sectors [387]. Merchant navigation, also relying on large quantities of imported material, was never developed based on Portuguese technology. Machinery, working with imported iron and imported coke, could only be internally competitive in small market segments, less energy intensive, and in the very ultimate phases of metal transformation[388]. To be honest, only if the country had a large advantage in the quality of at least one of those resources to make exports possible would iron works have made the difference. Besides being intensive in natural resources, steel needed a minimum operative scale that exceeded the demand in the country.

Around 1890, most population employed in industry (447 000 workers, 18% of the total)[389] did not appear in the Industrial Census, which were mostly

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[385] Sudrià (1995).
[386] Rollo (2005).
[387] Pinheiro (1988).
[388] Santos (2000).
[389] Valério (2001), census data.

concerned with larger units (more than 10 employees). What kind of work did they perform? Certainly manual and traditional activities which did not differ so much from the agriculture work. In the larger units, the structure of the Portuguese manufacturing sector was based on consumer goods of which textiles employed about half the workers and power (Table 4.6). It was a logical specialization based on industries with lower energy costs, small but not depreciable. This preponderance in one sector was mainly based on the internal market and made possible by internal protection to cotton and wool textiles. Unfortunately, a second problem with the lack of coal was caused by the spread of industrialization and determined in part by the high costs of coal in any city other than Lisbon or Porto. With such a small national market to absorb the products, any specialization, which was not based on exports, faced limits in their capacity to attain the levels of growth that were needed to catch up with the leading economies.

Table 4.6 Workers, horsepower (hp) and hp per worker, Portugal, 1881 and 1890

	1881			**1890**		
	Workers	hp Total	hp/worker	Workers	hp Total	hp/worker
Textiles& Clothing	14 018	5 574	0.4	21 572	10 758	0.5
Mines	2 049	1 952	1.0	2 541	2 413	1.0
Food	1 971	1 763	0.9	4 600	1 741	0.4
Clay and Glass	1 920	91	0.0	4 535	246	0.1
Cork and Wood	1 605	44	0.0	5 342	3 160	0.6
Cork				1 992	12	0.0
Wood				3 350	3 148	0.9
Tobacco	3 936	185	0.0	4 504	150	0.0
Metals	1 780	433	0.2	6 726	684	0.1
Paper	1 256	709	0.6	2 618	879	0.3
Chemicals	155	117	0.8	1 406	345	0.2
Leather & Footwear	777	29	0.0	2 593	14	0.0
Others	120	26	0.2	431	343	0.8
Total	**29 587**	**10 923**	**0.4**	**56 868**	**20 732**	**0.4**

Note: excludes cereal water and windmills.

Source: MOPCI, *Inquérito Industrial* (1881), based on text information including factories or works with 10 or more employees. For 1890, industrial population is from Vasconcelos (1998) and power is from Santos (2000) and includes smaller units.

By 1890, the protected textile market already satisfied 90% of the demand for linen and 75% of the demand for wool and cotton[390]. However, in the external market lower wages in the textile sector did not compensate for the higher cost of raw materials, energy and capital. Even the colonial African market was not capable of absorbing more than 10% of the production[391]. Lains estimates that *value added per worker* in woolen and cotton textiles would have been around 15% and 25% of the British in a situation of free-trade[392]. Certainly, one important reason for such low labour productivity was the nature of biased technical change in favour of capital (and energy) in relation to labour across most of the traditional sectors of the First Industrial Revolution. In 1881, the best equipped cotton spinning factory in Portugal had only 88 fuses per worker, less than half the English average in 1878[393]. The average power per worker, in the 1871 British cotton and woolen factories, was about 0.7 hp and 0.5 hp[394]. The 1881 Portuguese Industrial Census gives a mean power per worker of 0.5 hp and 0.4 hp for the same sectors, differences that would be higher if we took into account the duplication in capital of mixed systems of water and steam.

In fact, the only relatively successful manufacturing exports were based on indigenous natural resources and in almost exclusively manual methods of production. This was the case of cork and fish preserves, the latter based on extremely low seasonal female labour cost. However, these exports were very dependent on the fluctuations in international markets and never reached a sufficient level for a sustained capital accumulation. In the export balance there was an absence of the technologies of Industrial Revolution.

4.3 Second Industrial Revolution lost: without dams in the age of electricity

The second Industrial Revolution gained momentum in 1890 and was based on a new energy carrier (oil) and a new form of secondary energy (electricity), along with their converters: the internal combustion engine and the electric motor. For industrial power, electricity would become the most important. Electricity emerged during the 1870s-1880s and was successfully

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[390] Reis (1993), pp.171

[391] Lains (2003).

[392] Lains (2003).

[393] Reis (1993).

[394] Musson (1978).

applied first to telegraphs and lighthouses, then to lighting in general, in competition with gas, and thirdly on trams and finally in factories. It is not the goal of this chapter to explain the detailed advances of electric motor technology[395], but electricity started to be considered as an alternative source of power to steam around 1900. Prices apart, the technical advantages of electricity as motive power in relation to steam were great. Before electricity, steam engines were located in the center of the factory and connected to the machines by a system of pulleys and belts, which would lead to huge losses of energy due to friction as well as suboptimal factory organization. At first, the substitution of steam engines by electric motors did not change the composition of the working process, but soon it was realized that production could be organized by groups of machines through smaller line shafts and powered by motors, a process that lowered coal costs by 20 to 25%. After some trials and adaptations, the electric unit drive became the most important system around 1910-1920. Although capital intensive, the advantage of this system was that even the smaller machine had its own electric motor, so that it eliminated all the power losses due to friction. It also decreased energy consumption since it would eliminate any transmissions to machines out of order. Most of the advantages become apparent in factory organization and the possibilities of increasing labor productivity: more working space and ease of plant expansion; flexibility in task arrangement (the position of the motor could be changed); improvement of working environment (ventilation, illumination and hygiene) and improved machine control[396]. Electricity did not only substitute for motive power in big factories, it was equally important to the small workshops[397].

While most of the advantages of electricity in relation to direct power were more related to total factor productivity gains than with energy saving possibilities, the fact that electricity could be produced with any primary energy carrier and the possibility of transportation of electric current, making the point of consumption somehow independent of the point of energy production, had very large impacts on the developing process of coal-poor countries. It has often been argued that it was possible to develop their electric networks, with hydropower produced based technology, precisely because coal was so expensive in those countries. The difference in energy costs relative to the most endowed countries is an argument that disappears from the historic literature after the period of the war. However, while we know something about relative

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[395] See Hughes (1983) or Smil (2005) for the competition between AC/DC technology.

[396] Devine (1983).

[397] Sudrià (1995).

prices of coal versus electricity and how they increased substantially during the period of World War I, we know very little about differences in absolute prices between countries. We are going to show that in the Portuguese case, these differences in energy cost seemed to have persisted during the inter-war period, making Portugal a country with relatively expensive energy until the eve of World War II.

4.3.1 Early and late transitions to electricity in coal-poor countries

The emergence of electricity changed the allocation of energy resources. If power could be cheaply produced and transported, there was hope for a more intensive industrialization. In this context, poor coal-endowed Norway, Sweden, Finland, Italy and Spain adopted hydro-electrical power systems very early. All of them were coal-poor countries where steam introduced many limits to a continuous and sustained growth.

All of these countries had an early incentive to replace expensive coal by hydropower, but the outcome in some of them was larger than expected. A first group formed by Norway, Sweden and Finland (accompanied by more endowed Switzerland) managed to attain not only a quick transition to electricity, but also very high electricity intensities. Norway has, probably along with Switzerland, the best water resources in the world: abundance of steep waterfalls of any size and large lakes for regulation all over the country. The costs of hydro plants were extremely low when compared with thermal plants. Due to its geological conditions the model adopted before the World War I consisted of medium or small hydro-plants powering one industry or one town, without any need for large transportation investment. Norwegian natural resources quickly attracted foreign capitals and technology. Around 1900, electrochemical and electrometallurgical industries entered the scene and became the most energy intensive branch of the economy[398]. Norway became an important producer of calcium carbide, aluminum, nickel and ferro-alloys, even though it lacked some of the raw materials such as bauxite for aluminum production. Sweden was also well provided with water resources, the problem being that the best were in the North while most of the population lived in the South. In the case of Sweden, we can say that the high costs of energy in the very intensive branches were probably a further incentive to the development of these early electricity systems. It was in the mining districts of Sweden that in 1893 the first commercial three-phase power transmission system in the world connected Lake

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[398] Kaijser (1995), Thue (1995).

Hällsjön to Grängesberg, a distance of 14 km. The first electrical businesses were connected with mining capital until the State took over the role of provider of water resources in 1909, building three large hydropower plants in the 1910s. New power intensive industries such as electrochemicals and metallurgy industry were established near these new hydropower plants before World War I[399].

In Finland, as in Sweden, long-distance transmission was introduced in ore mines in 1899. Before the war, electricity expanded to activities such as printing, wood, paper and pulp. Finland, though, had a slower development in hydro-power than its neighbours. Firstly, thermo-power retained some importance as wood industries needed steam for their industrial processes. With the use of back pressure turbines, power and steam could be provided at very high levels of efficiency by using cheap wood-refuse as a fuel. Secondly, the instable political situation was an obstacle to the exploitation of long-distance hydro-power. When Finland gained independence from Russia in 1917, the state decided to build a large power plant at Imatra rapids in order to provide cheap electricity for the country industries. Early electrification in Finland was practically induced by the demands of pre-existent energy-intensive industries. The amounts of civic consumption remained quite low by European standards, and electrochemicals never reached the same importance as in Sweden or Norway[400].

Italy also managed very mature hydro-electrical systems. Milan´s thermal power plant in 1883 was one of the first to be built in the world. Electrical networks before the war were built mostly with foreign capital. Italy was a natural country for the expansion of electricity due to its extensive water resources and glaciers in the north of the country. By 1913, most coal imports went to transportation but electricity had spread in industry. By 1911, the percentage of electrification in Italian industry was already 48%, mostly from hydropower, as compared with England with only 13%[401]. Between 1910 and 1916, 230 miles of railway line were electrified[402]. In the 1910s, Italy was one of the countries in the world with a largest proportion of exploited hydropower in relation to its total hydro-electrical potential. It never reached the electricity intensity of the Scandinavian countries however.

In Spain, developments were also quick, but they came in a different form. Thermal plants emerged first and they sought first of all to light urban

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[399] Kaijser (1995), Myllyntaus (1995). Jakobsson (1995).

[400] Myllyntaus (1991), Myllyntaus (1995), Kaijser (1995).

[401] Bardini (1997).

[402] Bianchi (1931).

populations. As the penetration of gas consumption was low due to the very high costs, electrical companies found an early market with growth possibilities. In Madrid, the appearance of many electrical companies had led to a price war in the city, already before 1900, with evident advantages for households and small industries[403]. However, by 1900 the boom of hydroelectric plants started, financed mostly with Basque capital[404], and the costs became even lower with the supply of hydroelectric plants to the capital. By 1910, about 80% of the electricity produced was from hydroelectric origin and by 1927 about 80% of the Spanish population was lit by electricity, performing very well in comparison to European indicators[405].

Developments in hydropower were already evident around 1910 (see Table 4.7), and the First World War accelerated the process of electrification in all these countries, at least in the industries where steam could be substituted. Cut off from coal supplies, coal and gas prices rose steeply in relation to electricity. As thermal electricity could be produced with wood, even thermal systems were advantageous in relation to gas; however hydro power had more potential. The run to hydropower concessions reached new heights, which was important for a renewal of the system in the interwar years. Household consumers, without oil, gas or paraffin to light their houses, switched fast to electricity. The same happened to many light industries working with steam engines and gas motors.

The period after the war brought the maturation of electrical systems, with national grid connection, the continuation of industrial electrification, etc. Around 1930, and despite intensity differences, the share of electric motors in total horsepower was already very high in 11 European Countries, Japan, USA and Canada; and it was relatively higher in countries that had pursued hydroelectric schemes[406]. This can be seen as a kind of leapfrogging of catching up economies in relation to one of the economic leaders, the UK, that still maintained steam power in many industrial sectors. The main difference in the role of electricity in the poor endowed countries was in intensity and in per capita consumption. Sweden, Norway, Switzerland, Finland and Canada were the leaders in electricity intensity. This switch to such high intensive electrical systems was due not only to substitution in manufacturing, households and even railway systems but also to the development of entirely new industries such as

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[403] Aubannel (1992)

[404] Antolin (1999); Sudrià (1995). The capitals were associated with the mining sector and with a well developed banking sector. Most of the early projects were made with Basque capital, with the exception of Barcelona, where foreign capital had a large importance.

[405] Bartolomé (1995).

[406] Bétran (2005); Myllyntaus (1990).

electrochemicals and electrometallurgy, based on extremely cheap hydropower. This could not be achieved to the same degree in all the countries. For example, the development of Italian electrochemical and industrial electricity consumption during the interwar period was financed by extremely high tariffs for the household consumers[407]. By 1930, there was already an idea that Spain could not pursue the intensive path of the Nordic countries. Following the same hydropower technique, the potentialities of hydro resources were smaller, reflecting a relatively high cost for intensive users[408].

Portuguese electrification is different from the movement in coal-poor countries that happened well before the First World War. Not only the development of electricity is slow, but the movement to hydroelectricity systems was made only during the 1940s. As Table 4.7 shows, Portugal did not leapfrog in any manner: consumption was extremely low; both in per capita and in intensity terms, and coal savings through the use of hydropower resources were very small. In the 1920s, for instance, Portuguese electricity consumption per capita was about 2% of the Swedish, 5% of the Italian and 12% of the Spanish ones. By 1920, Italy and Sweden managed to substitute about 50-70% of coal imports and Spain saved 1/5 of coal consumption. In Portugal, not more than 3% of coal imports were avoided. By 1950 hydropower had slowly expanded to about ½ of the production and substituted 20% of coal consumption. Whereas there was some catching-up, consumption per capita remained low, at 45% of the Spanish and 20% of the Italian, but only at 4% of the Swedish consumption.

The late introduction of electricity in Portugal cannot be explained by a single factor. A closer look reveals that Portuguese initial conditions were not exactly the same as other coal-poor countries; Portugal did not participate in the scientific innovations of the 1870s-1880s as Sweden did; nor were Portuguese engineers as trained in this new technology as the Spanish engineers[409]. Moreover, Portugal did not benefit from the presence of early international companies as Italy did. The capital for initial investments might have been lacking. After 1890, the country left the gold standard and foreign capital became more difficult to obtain, which was reflected in lack of investments[410] and also troubled public finances that lasted until the mid 1920s

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[407] Storacci and Tattara (1998), Bartolomé (1995).

[408] Bartolomé (2007).

[409] Bartolomé (2007) points out that electricity was already a mandatory subject in the engineering curriculum by the mid nineteenth century. See *Matos et al.* (2004) for an account of the late development of technical schooling in Portugal.

[410] For example railway investment slowed down during this period.

Table 4.7 Comparison of electricity development in Europe and the US 1900-1950

	Electricity intensity (kWh/ 1990 dollars)					Hydro share in electricity production%				
	1900	**1910**	**1920**	**1930**	**1950**	**1900**	**1910**	**1920**	**1930**	**1950**
Norway	15	326	734	749	954					100
Sweden	15	73	167	236	434	60	68	73	74	79
Finland	4	16	168	131	244	71	49	46	72	88
Italy	2	17	47	86	145	69	83	97	97	93
Spain	3	8	25	51	113	49	82	87	91	73
Portugal	0.3	2	6	25	56		27	23	34	46
UK	2	10	40	71	191	0	0	0	2.5	2
US	23	60	93	151	262	47	37	34	31	26
	Electricity per capita (kWh)					Coal saved from hydro (%)				
Norway	28	765	2 011	2 718	5 182					46
Sweden	26	162	441	834	2 605	7	23	45	32	52
Finland	6	31	92	350	1 039	15	21	69	23	52
Italy	5	42	126	260	531	6	21	51	37	55
Spain	6	15	55	134	249	2	7	19	20	19
Portugal	0.4	2	7	38	113	0	1	3	5	19
UK	11	52	200	397	1 301	0	0	0	0	0
US	95	298	515	935	2 550	4	4	4	6	12

Source: Electricity production and hydro share is taken from the following sources Italy, Malanima (2006); the UK, Mitchell (2003) and Etemad and Luciani (1991), Sweden. Kander (2002), shares of hydropower kindly provided by Astrid Kander; Spain, Bartolomé (2007) 1900-1930, Rubio (2005) – hydropower and Mitchell (2003) for 1950; Finland, Myllyntaus (1991), Coal imports: Mitchell (2003); Norway, Etemad and Luciani (1991); Portugal, see Chapter 2. GDP and population of Finland and Norway from Maddison (2008). Coal saved from Hydro: own calculations based on efficiencies of US thermal stations for all the countries except Portugal, where country-specific efficiencies were used. Coal consumption, Norway and Finland: Mitchell (2003).

Some institutional differences may explain the differences in the rhythm of the expansion of electrical networks in the first decade of the twentieth century. Both in Lisbon and Oporto the institutional setting did not favor the establishment of electrical networks as in Madrid or Barcelona. The two gas companies operating in each city had the monopoly (regulated by the municipality) of private and public gas and managed from an early date to obtain the privilege of electric current distribution[411]. Hence, in an early phase

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[411] In Lisbon, the gas and electricity monopoly (60 years for gas and 30 for electricity) started in 1891 with the merging of the two gas companies after a difficult period of co-existence (1889-1891). The

they were not very interested in competing with their core business of gas and adopted a wait and see strategy in relation to technological developments in the electricity field[412]. In fact, they operated micro-scale utilities without capacity for expansion and it was the pressure from the municipalities for the substitution of gas by electricity for public lighting that ultimately drove them to construct new thermo-power centrals, already running the year of 1903 for Lisbon and 1908 for Oporto[413]. In the capital, there was already a latent market for industry, which responded well, and power had to be increased two times before World War I to accommodate expansion of consumption. Even after a late start and with a monopolistic situation, the advantages of electricity in relation to other systems were already apparent before the war – a study in 1911 suggested that the daily cost of a 10 hp electric motor compared well with anthracite gas motors[414]. In fact, the first references to the increase of electricity consumption by the Lisbon utility confirm that most companies entering in the electricity market were replacing old gas motors (either town or anthracite)[415].

In the remaining of the country, there were very few public power stations of any dimension built before the war. After the thermal power stations of Lisbon (6 500 kW) and Oporto (2 516 kW) and the two cities urban traction systems, follows from far away the largest (but still small in international terms) hydropower utility in Serra da Estrela constructed before the war with 370 kW. The first power stations were probably private and only a reflex of the nineteenth century fuel choices. In most places, the preference was for steam powered systems while, in the regions were water systems prevailed, electric motors are incorporated in the factories, reducing losses in transmission, but had similar problems to the old water systems during the long summers. As early as

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Oporto monopoly started in 1900, after the gas company acquired a small electric power central in operation since the 1880s. See the detailed history in Matos *et al.* (2003) and Matos *et al.* (2004).

[412] This wait and see perspective can be found in many Annual Reports of the CLIG - Companhia de Lisbonense de Iluminação a Gás, *Relatório*... Running the year of 1883, "there is no big reason to be afraid of economic competition between electricity and gas". In 1884, "if the electric light, in the limits of the progress, would reach a profitable existence, we will also be their producers and distributors".

[413] In Oporto, the municipality, upset with the constant delays, will even concede around 1907 distribution licenses to two other companies, (one of them an intended to be hydroelectric company) only to see their authorization canceled by a Royal Decree due to contractual violation. See Matos *et al.* (2004) and Matos et al. (2003).

[414] Amaral (1911). The author first compared fuel cost per hour of 20 hp steam engines and town gas, anthracite gas and gasoline motors and concluded than in our market, fuel costs were smaller for anthracite gas. He then compared a 10 hp anthracite gas and electric motor using complete elements such as fuel, lubes, water, interest, amortization, reparation costs, counter and wage costs. Daily expenses were 2 069 Escudos for the 10 hp electric motor against 2 125 for the anthracite gas motor.

[415] CRGE, Annual Reports.

the 1913, the general idea among engineers reproduced the feelings of the late nineteenth century and what was the nature of the hydroelectric problems at that time: 1) the problem of the dry summer; 2) very few waterfalls in the national rivers, far away from the consumer centers, *i.e.*, the problem of transportation; 3) the lack of capital for the large investment needed in water power regularization and transportation networks[416].

World War I was the first real big shock for Portuguese energy dependence. A 1917 estimate calculated the pre-war coal needs, excluding navigation, to be 1 290 thousand ton[417], 17% for railways, 53% for manufacturing and 29% for gas works. From 1915, the price of coal spiked and reached 16 times the price of 1913 around 1918. During the war, imports were less than half the needs, attaining an all time low of 119 thousand tons during the most critical year of 1918. Portuguese coal mines were given a sudden boost and production increased from 10 thousand to more than 100 thousand tons of equivalent coal[418], which was clearly not enough to solve manufacturing problems. All over the coal regions, the common resource was the intensive use of firewood as a substitute, though at a very high cost. As in other coal-poor countries, the few gas companies that existed were also severely hit by the coal imports blockage. Around 1916, the Oporto gas factory delivered such bad quality gas that the municipality considered it a contractual violation and municipalized both gas and electric services in 1917, introducing a new type of institutional setting more favorable to electrical power. In Lisbon, the impossibility of acquiring coal led to the closing of the gas factory (36 000 clients) which only reopened in the fall of 1922. The conversion to electricity had gained a sudden boost, at least for lighting. The number of electric clients doubled in Lisbon during this period, from 6 219 to 13 635. However, exploration was made during the war with extreme difficulties, using expensive alternative fuels such as national coals or wood, and restrictions in electricity production were also felt. For example, electricity consumption declined from 8.9 GWh, in 1914, to 6.9 GWh in Lisbon. At the same time, production in Oporto power station declined from 7.7 GWh to 3.7 GWh and the municipality even refused to accept the entry of more than 1 000 consumers. Clearly, and

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[416] Galvão (1913)

[417] Miranda (1987).

[418] The lower calorific value of Portuguese coal is accounted for.

unlike Spain, Italy or Sweden, Portuguese industry and households could not benefit from electricity as an alternative during the war[419].

Although Portugal had a late start in electricity, the war eliminated at least the constraints of the gas monopolies and led to a change in the perceived benefits of hydropower. During the war, the run to water concessions had increased significantly, although most of the projects were never realized. In the early twenties, some medium hydroelectric companies extended operations in the North and Center of Portugal. They were run-of-the-river dams, regulation of water was scarce and the use of thermal support was usually required. The claims for energy autarky definitely increased with the end of the Republic and the establishment of the dictatorship in 1926. At that time, imported coal was increasingly being perceived by the authorities as an undesirable source of energy dependence that led to an unnecessary drainage of gold. Rules were set to make it mandatory for a certain proportion of national coals to be mixed with foreign coals in railways and manufacturing in general[420]. This implied the adaptation of boilers for that end. It could only be a partial solution for the energy problem, not only because it would always need a mixture, but also because in some of the cases national coal was more expensive than the simple importation of coals[421]. The independence of the energy sector would have to come from hydro-electricity. However, despite being a period fertile in regulation and heated discourses, the initiative remained private and consumption remained mainly thermal, especially in the south of the Country. Electricity statistics show that industrial self-generation of electricity was important. In terms of intensity of use, the power was lower than in other countries, indicating less equilibrated chart diagrams, preponderance of small units and the existence of reserve power in case of failure in the distribution of hydroelectric power utilities. Even in 1950, only 20% of Portuguese houses had electricity (47% urban)[422]. Around the same date, the percentage of electric motors in total motive power attained was 60%-66%, in contrast with international statistics reaching 80-90% (see Table 4.8).

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[419] This is not to say that electricity was a viable alternative to coal to all industrial uses. For heat-intensive industrial uses coal-poor Italy, Sweden or Spain also suffered with the severe coal shortages during the war.

[420] Decree-Law 14009 28/07/1927.

[421] The advantage of using national coals seems to have been dependent on the region. In Coimbra, national coal was being used for electricity production with some important savings in coal imports, see Vasconcelos (1930). Reports from the electrical utility of Lisbon around the late thirties show that the cost of kWh was still more expensive with national coal. (CRGE, *Elementos Estatísticos*)

[422] Teives (2006).

In 1934, the Portuguese Industrial Association mentioned the power problem in the following way:

> In Portugal, as a rule, steam engines last a very long time, stopping only from exhaustion[423].

This observation entails a suggestion of shortage of capital or/and high electricity to coal relative prices. We explore this last hypothesis in the next section.

Table 4.8 Percentage of electric motors in total motive power (%) in some selected countries

	1913	1925	1938	1950
Canada		67		
Finland	32	63	87	93
France		49		
Japan	30	88	82	
Italy	48	74	88	88
Portugal	<5[a]		<50[b]	60[c] /66[d]
Norway		67	82	89
Sweden	48	77	89	97
UK	23	49		
USA	36	77	85	84

Source: Myllyntaus (1990); France: Bétran (2005); Portugal: INE, *Estatísticas Industriais*.[a] Estimate[424] [b]1943 [c]Installed [d]In use

4.3.2 The costs of electricity relatively to coal

The evolution of the ratio between electricity and coal prices has been employed in previous research as a measure of stimulus to electrification[425]. In most research, household or average electricity prices relative to coal are used in

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[423] Portuguese: “A máquina em Portugal tem uma vida muito longa; vai, em regra, até à utilização pelo cansaço” *Indústria Portuguesa*, 75, May 1934, in Matos *et al.* (2004), p. 341.

[424] Most motor statistics produced until the 1940s do not account for electric motors but it is possible for some regions to advance with partial statistics. In 1911, the districts of Aveiro, Guarda, Coimbra, Viseu and Castelo Branco had a total motive power of 9 718 hp, but only 242 hp (2.5%) were relative to electric motors, see Matos *et al.* (2004). The urban region of Oporto (city center) accounted 23 073 hp in steam engines in 1916, see Santos (2000). The number of electric motors in the municipal grid in 1919 was 2 430 hp (SMEGP, *Relatóri*o…1919). Fernandes *et al.* (1992) estimated a power of 2 500 hp of electric motors in Lisbon factories around 1917. The primary motive power in Lisbon district was 48 819 hp. These partial statistics seem to indicate that electric motors comprised less that 5% of total primary power before World War I.

[425] Svennilson (1954), Antolin (1988); Sudrià (1990); Bétran (2005).

order to compare the differential of that stimulus across countries, which can lead to some mixed interpretations[426]. Household or average electricity prices are probably not the most appropriate measure for explaining stimulus to industrial electrification, as they can be dramatically different in level and trend compared to industrial prices[427]. The incentives to replace steam engines by electric motors across countries could be better explored by using the ratio of industrial electricity prices to coal.

Table 4.9 compares the industrial prices of electricity relative to coal for several countries and in the two main Portuguese cities, Lisbon and Oporto. The relative prices, expressed in MWh/ton, indicate how much coal in tonnes can be bought for the price of an industrial MWh of electric current.

Coal prices refer to the most likely price faced by industry, that is, import prices for Portugal, Italy and Sweden and Canada[428] and pithead prices for France, UK, USA and Japan. For Spain, we use North of Spain coal prices[429]. Industrial electricity prices for Lisbon represent the lowest industrial tariff charged for motors until the 1920s and average industrial prices afterwards[430].

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[426] This is evident in the study of the Spanish electrification. Antolin (1988) argues that, between 1913 and 1929, relative electricity to coal prices and to wages did not fall as much as in the US, which should be interpreted as smaller incentives to electrification and capitalization. She concludes that the cost of electricity in relation to other countries was much larger than the cost of steam. Therefore, electrification was slow and there was not much connection between electrification and economic growth, see also Antolin (1990). Sudrià (1990) compares not only the trend, but also the level of relative prices around 1913, and concludes that countries with hydraulic resources and poor coal resources (including Spain) had a much higher incentive to early electrification.

[427] Monopolistic behavior and high regulation occur in electricity markets. Price discrimination benefiting one class of consumers, with higher elasticity of demand in relation to the lighting market (where elasticity is low), is common. Different energy policies may also result in disparities in the ratio household/industry across countries. Bétran (2005) discussed some of the differences between industrial and lighting prices, although she used lighting prices in her analysis.

[428] National coal could also be used but for the years in question imports (around 50%) have a lower value than pithead prices.

[429] Coal imports to Bilbao until 1913 and national coal due to Bilbao afterwards and not pithead prices, due to the special condition of Spanish coal (high transportation costs, absence of industry located at the pithead, etc.).

[430] In 1916, minimum industrial tariffs in Lisbon were set at 0.09 Escudos in 1916 for the time period between 0-19h30, and higher tariffs of 0.18 were set for household peak time from 19h30-00h00 (Matos *et al*., 2004), which shows that indicated tariffs were more connected with management of chart diagrams than with different prices charged according consumption. Therefore, we have chosen the minimum tariffs, representative of the time that industries were working. After the 1930´s prices revenue data is used in order to determine average industrial prices.

Table 4.9 Relative prices electricity versus coal MWh/ton

	Lisbon	Porto	Canada	Sweden	Spain (Bilbao)	Italy	US	UK	Japan	France (Paris)
	Thermo	Hydro	Hydro	Hydro	Hydro	Hydro	Thermo	Thermo	Hydro	Thermo
1910	14.1			1.4	1.7	7.7	21			
1913	17.9			1.1	1.5		12.8			11
1917	6.9			0.2	0.1		9.3			6.7
1923	5.5			0.9	1.2		5.6			3.6
1925		2.6-5.5		1.6	1.4		6.9	5.2		3.7
1928		3.6-5.2		1.5	1.6	1.6	7.1	5.2		3.5
1933	4.2		2.2	1.6	1.4		10.2		5	3.3
1935	4.2	5-6.6	1.4	1.2	1.8		6.8	4.3	4.2	3.4
1938	2.8	3.2-4.8	1.4	0.9	1.7		5.6	3.3	2.6	2.5
1943	1.8	0.9	1	0.5	1.1		3.1			2.1
1948	1.8	0.9	0.7	0.3			2	1.7	0.6	1.5

Sources: US: US Department of Commerce (1975); Melman (1956); UK: Svennilson (1954); France: Barjot (1991). Italy: Bardini (1997) and Storacci and Tattara (1998); Canada: Urquhart and Buckley (1965); Spain: Coll (1985), Antolin (1988), Garrues-Irurzun (2008). Porto: own calculations from SMGEP, *Relatório*.. (1917-1950) Lisbon: own calculations from CRGE, *Relatório*…(1909-1948). Coal prices for Portugal my own calculations from INE, *Comércio Externo*. Japan: EDMC (2009). Thermo and Hydro words below the countries/regions entries are used to express the source of electric power: from fossil fuels in thermo and from water in hydro.

We present two series of prices for Oporto. The highest refer to High Voltage prices charged by the municipality for industrial consumers, and the lowest refers to the price charged by the distributor of the municipality[431]. For USA, Canada, UK and Japan average industrial prices are given[432]. For France we use average prices for commercial and industrial uses in High Voltage. For Italy and Spain we rely on scarcer information[433]. For Sweden, we present one

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[431] The larger part of the important clients in Oporto was supplied directly from the distributor, which means that the price of the municipality was probably on a higher level. As a lower level, we use then the price charged to the municipality by the same company, its bigger client.

[432] Urquhart and Buckley (1965) calculations, dividing the revenue of industrial sales by industrial consumption. The US Department of Commerce (1975) *Historical Statistics of the United States* are also based on average industrial prices.

[433] For Spain, I use average prices from Hidroeléctrica Ibéria (Antolin, 1988 and Garrues-Irurzun, 2008) who operated in the Basque country electricity market. In the case of Hidroeléctrica Ibérica, average prices were biased to the High Voltage market. For example, in 1935 and 1945, Garrues-Irurzun (2008), price discrimination of Hidroeléctrica Ibéria shows that only 5-7% of Ibéria

series for high intensive uses in industry, due to its large share in total consumption[434].

The results clearly show that relative prices of electricity versus coal have declined enormously in all the countries/regions employing thermo-power, something that should be associated, with among other things [435], the significantly gains in efficiency of thermo power production. For example, data from power centrals in the US and Portugal shows that efficiencies in power centrals increased from a mere 5% and 4% before World War I to 22% and 16% around 1950. Comparing the relative electricity to coal prices in the Portuguese capital with the other thermal countries, we observe that they behaved quite similarly even if in relation to the respective coal prices electricity seemed to be somewhat lower in France and a bit higher in the USA[436]. So the incentives to electrify in relation to the steam option did not seem to be worse in thermal Portugal than in other thermal countries, at least not after World War I. These results are less optimistic than they seem – similar electricity to coal prices in relation to the main Portuguese coal exporter, the UK, means that double coal prices correspond to double the electricity prices.

The case was much different in the early hydro countries, Sweden, Spain, Italy and Canada. As we see, the fall in relative prices, was less pronounced than in thermal countries. This has mainly to do with the fact that efficiencies in hydraulic equipment were already very high, having less room for improvement. It is striking that the level of the relative attained prices of electricity versus coal was already much lower than in thermal countries before World War I. While an industrialist in Lisbon could buy 14 to 17 coal tonnes in 1910 -1913 for the price of 1 MWh, in Sweden or Spain they could buy only 1 to 2 tonnes, which indicates a much stronger incentive to electrification. As coal prices in North of Spain and in Sweden were similar to the Portuguese ones, we can say that prices

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consumption was going to household uses. The series of prices used relates to the price of kWh produced, so I adjust the price to incorporate 15% losses. This procedure will give for 1935 about the same range of industrial prices that Bartolomé (1995) suggested for all Spain in 1935 (0.11 ptas) though a bit higher than the average industrial electricity prices from Garrues-Irurzun (8.23). With all the reservations, I believe this series is acceptable to express industrial prices in Northern Spain. Relative prices vary from region to region. For example, Barcelona Traction who operated in an initial phase with thermo power, but changed to hydro during the war, electricity to coal prices were in MWh/ton: 1900 – 7.2, 1905 – 11.1, 1910 – 4.1, 1915 – 1.3, 1918 – 0.15, Urteaga (1998).

For Italy, indication on prices is given in Storaci and Tattara (1998) for 1928 and Bardini (1997) for 1908.

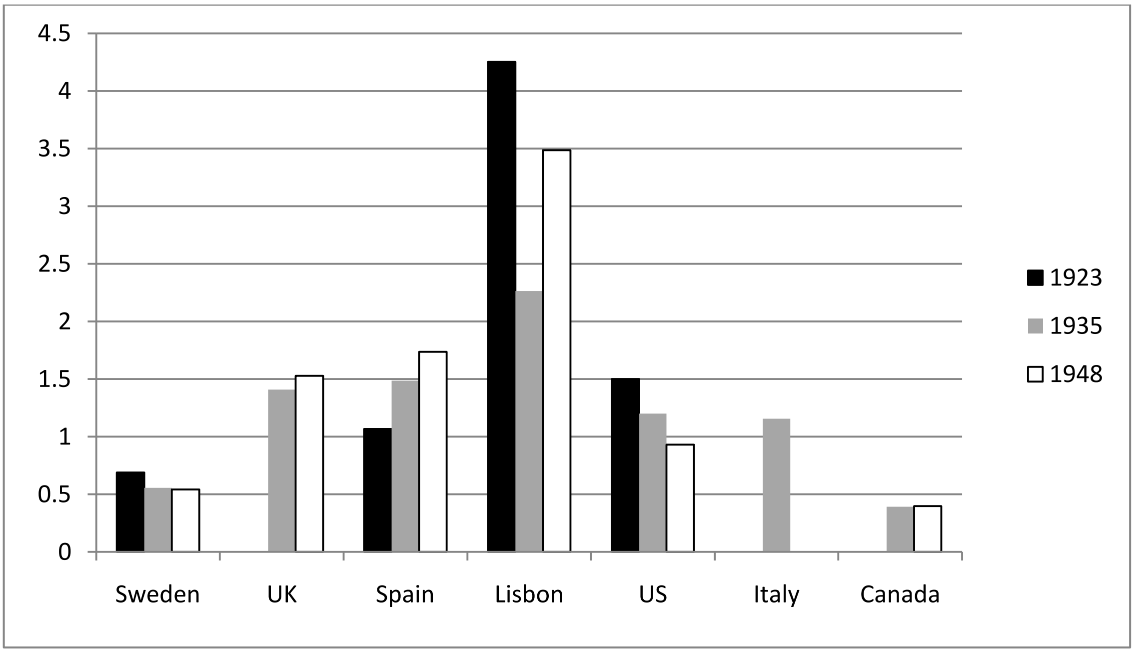
[434] Ljungberg (1990).

[435] Gains in transmission, transformation of energy and also decline in exploration costs due to the use of larger power centrals. These are variables that can also improve in hydropower centrals.

[436] There is a bit of sensitivity in the data used, due to the use of pithead prices.

of electricity were in fact much lower than in Lisbon. Even comparing the relative prices in hydro countries with the ones in the region of Oporto, which was supplied by hydropower since 1923, differences seem to persist. This can be an indication that hydropower possibilities in Portugal were more limited than in other places but also points to other reasons, such as market power[437]. In any case, the comparison between relative prices suggests that electricity was not an escape from the burden of pre-war costly energy resources, at least relatively to other countries. While Sweden, Spain, Italy and Canada had benefited in reducing energy costs relative to coal endowed countries, electricity was still more expensive in Portugal.

Figure 4.3 Electricity prices, selected countries 1923, 1935 and 1948, dollar cents



Sources**:** See Table 4.9 Exchanges rates are from Officer (2009).

In sum, what is relevant in a cross-country comparison is not really the relative decline in electricity to coal prices but the low electricity prices that were charged in countries with hydropower. In nominal terms[438], the Basque Spanish region, Italy, Sweden or Canada managed to leap-frog in an amazing fashion during the twenties and thirties, having lower electricity grid prices than

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[437] In the Oporto case Bartolomé (2009) suggests these factors. As market power could also be common in other countries, we do not enlarge the discussion to incorporate the reasons for differences in prices.

[438] Using exchange rates, to express electricity prices in US cents.

the coal-endowed UK and in the case of Sweden and Canada also lower prices than the US. On the contrary, Lisbon industry faced electricity prices which were about the triple of US prices in the early twenties and the double of UK in the mid thirties, see Fig 4.3.

In Portugal, hydro-electricity prices from Oporto and thermo-electricity prices from Lisbon began to follow different paths only at the outbreak of World War II, see Table 4.9. This coincided not only with another spike in coal prices in the thermo-regions, but also with the renewal of Oporto contract, which allowed the municipality to charge lower prices for all consumer categories[439].

Around 1950, differences in industrial electricity prices charged to the consumers in hydropower regions versus thermo-power regions were already visible[440]. Still, while hydropower prices in Oporto started to compare well with the British prices by the end of the 1940s[441], average industrial prices were still much higher than both coal endowed and hydro dependent countries.

4.3.3 Natural resources, industrial development, technical choice and path dependence

Countries that pursued the hydropower technique managed to supply their industries with electricity at a price that was competitive or even lower than the coal endowed UK or US. At least in relation to the UK electrification, it seems to have occurred sooner. Portugal missed an early advantage of hydropower and lagged behind in the electrification of manufacture. As the country eventually became hydro-dependent in the 1950s and the 1960s, it is reasonable to question if the initial choice for thermo-power was justifiable or if in fact it represented a missed opportunity which was to have a strong impact on the growth trajectory of the country.

Arguments for the missed opportunity get stronger, comparing calculations of hydropower potential which became available in the 1950s[442]. Portugal

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[439] Matos *et al*. (2003) has a detailed explanation of the renewal of the contract with UEP, the distributor.

[440] With Industrial Statistics we can produce some estimates of the electricity price by sector and by regions. For example in 1950, for regions supplied by hydroelectricity, the price per kWh for cotton or woolen textiles was: Covilhã – 0.46 Escudos/ kWh; Guarda–0.43 Escudos/ kWh, Porto – 0.52 Escudos/ kWh; Braga – 0.52 Escudos/kWh, Coimbra -0.52 Escudos/kWh. For thermo-power regions, the prices charged for a combination of sectors like textiles, ceramics, cork and fish cans were around: Lisbon – 1 Escudos / kWh; Faro –1.2-1.4 Escudos/ kWh, Setúbal – 0.9 -1.3 Escudos/ kWh, Santarém – 0.7 -1 Escudos/ kWh. INE, *Estatísticas Industriais*.

[441] Prices in Oporto were about 20 to 30% higher than the UK during World War II, if we apply Officer (2009) exchanges rates.

[442] This was previously noticed by Bartolomé (2005).

appeared in a better position than Finland, France and Spain, in terms of economic potential per km^2 and with a per capita resource dotation much worse than Scandinavian countries and Switzerland, but comparable to France or Spain, and in a better position than Italy. Despite this fact, the actual hydropower production corresponded to only 3% of the economic hydroelectric potential[443] , contrasting with Italy (43%), Finland (28%) and France (25%), but also with other countries with 10-15% percentages of economically exploited resources, which managed to attain high percentages of hydro production (see Table 4.10).

Table 4.10 Hydroelectric potential in some European countries around 1950

	A	B	C	D	E	E/A	E/B
	Technical potential (GWh/yr)	Economic potential (GWh/yr)	Economic potential (MWh/yr/km^2)	Economic potential (per cap.)	Hydropower production (GWh)	Technical potential exploited (%)	Economic potential exploited (%)
Spain	76 639	48 220	96	1 724	5 079	7%	11%
Finland	18 100	13 000	38	3 243	3 650	20%	28%
France	100 000	65 000	119	1 554	16 072	16%	25%
Italy	58 000	50 000	166	1 069	21 605	37%	43%
Norway		158 000	487	48 390	16 920		11%
Portugal	17 000	13 500	146	1 599	437	3%	3%
Sweden	130 000	95 000	211	13 491	14 394	11%	15%

Source: Bartolomé (2005) first three columns and my calculations for the rest. (based on sources for Table 4.8).

Of course these calculations are very superficial: they say little about the type, cost and regional endowment of water resources in a country. The bulk of hydro resources are concentrated in the North of the country (river Douro and its tributaries) and in the international stretch of the river, where most of these resources could only be harnessed in a later period after agreements with the Spanish Government and water regulation in the Spanish part[444].

One of the limitations of Portuguese hydropower resources was the deficit in smaller size resources. In an early phase the first water resources to be harnessed in Europe were of smaller dimension and the cost of exploitation was extremely low. These newly converted establishments were the natural follow

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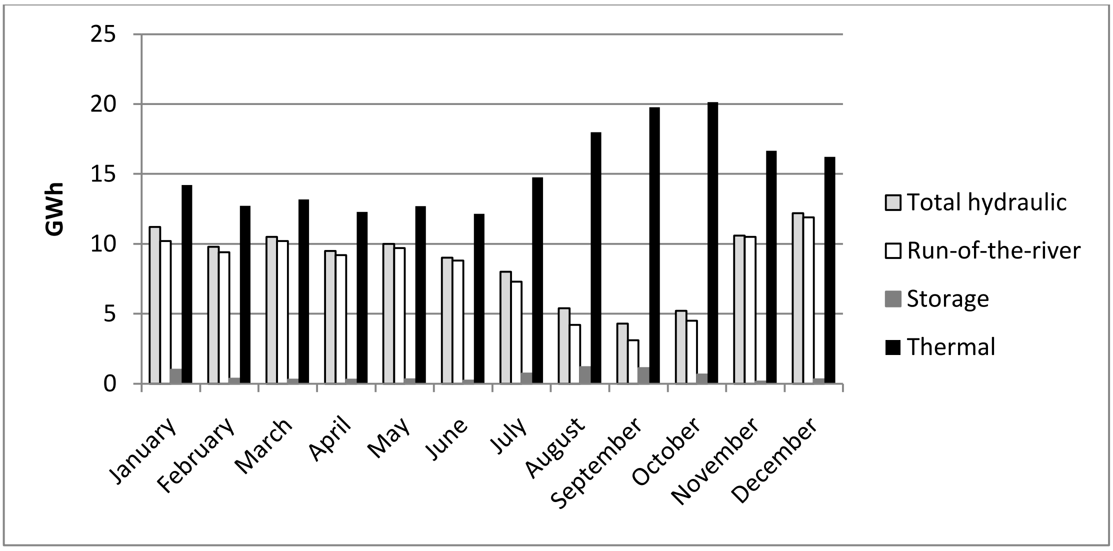
[443] Resources that can be economically harnessed in relation to other alternatives.

[444] For geological conditions regulation had to be made in Spain. An author pointed in 1928 that regulation in Spain could improve the potential 13 times. Galvão (1928).

up to early hydro-mechanical technology and even earlier to the establishment of long distance transmission. In the Portuguese case, these kinds of waterfalls near the consumer centers were very limited. Even in districts other than Lisbon and Oporto, where water power had dominated, the direct use of steam was becoming more important. Turbines and wheels in those regions declined from a 47% to 24% of total primary motive power[445] between 1890 and 1917[446]. In a sense, earlier industrialization using water power in Italy, Finland, Sweden and some regions of Spain now became a small advantage for the early appearance of hydroelectricity. While self generation with hydropower was common in those countries, for Portugal it was mainly provided by thermal centrals.

Even if the technological problems in long distance transmission were solved around 1900-1910, a second bottleneck remained: Portuguese hydro resources had large needs for water regulation. The type of centrals that existed around 1935 (mostly run-of-the-river, the less expensive type) shows the irregularity of the flow of Portuguese rivers. Production varied between 12.2 GWh in January to only 4.2 GWh in September (Fig 4.4). Regulation was only practiced on a very small scale and only 7% of production was through storage, which meant that thermal support was needed during parts of the year, increasing the costs to the consumer.

Figure 4.4 Monthly chart of Electricity Production in 1935



Source: DGSE, *Estatísticas das Instalações Eléctricas*, 1935.

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[445] Excludes electric motors.

[446] Santos (2000).

To increase the productivity of the rivers, significant investments in the building of reservoirs would be needed, especially in the south of the country, where the rivers flows were subjected to much stronger variation. That meant very large installation expenses and was one of the reasons behind the persistent use of coal in the south. In fact, the Portuguese water resources were more adapted to larger establishments where only large-scale consumption would lower costs. Unlike Scandinavian countries, natural lakes for regulation were not available, so to take full advantages of a more regular power, artificial reservoirs had to be constructed. Although Spain also had water regulation problems, Isabel Bartolomé suggests they seem to have been less serious than in Portugal and occurred in a later period of electrification[447]. At least, the historiography in Spain associates the early success of hydropower in the regions of the Basque country with a group of waterfalls that did not fluctuate badly in the summer droughts[448].

An extreme demarcation of the Spanish resources should not be too emphasized. In fact, some initial projects in Spain also required large sums of capital to be viable and it was not for that reason that they were abandoned. The mega project of Barcelona Traction just before World War I, for example, requested large initial investments in water regulation and transportation, but attracted foreign investment due to an already pre-existent industrial demand. For sure, in places where demand existed and coal was expensive, capital to cover for the initial investments also appeared[449].

Therefore, in my view, what explains the Portuguese early choice of thermo-power and general low level of electrification was not simply the inadequacy of natural resources. In order to fully exploit the Portuguese natural resources, the Portuguese economy lacked both the capital and the potential industrial demand that was already present in other economies.

In fact, capital was already chronically scarce by the end of the 1890s. The industrial structure and the development of the country did not allow for a large capital accumulation and banks participated little in industrial credit. During and after World War I, the conditions worsened and Portugal was one of the countries in Europe with more inflation in the 1920s. Although Italy (also with inflation) managed to finance their electric in foreign markets by clever financial instruments[450], that option was not easily available to Portugal. That many

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[447] Bartolomé (2005).

[448] Antolin (1999) points that in the Basque Country, during the first 20 years of activity of Hidroeléctrica Ibérica (1901-1921), the constructed dams did not need water regulation, p. 433.

[449] Capel and Urtega (1994).

[450] See Storaci and Tattara (1998) for an analysis of the financing of Italian electrification.

projects of hydroelectric utilities were not pursued due to lack of capital is visible in the work of Ilídio Simões[451].

On the other hand, the lack of capital is associated also with the scale effects, which were smaller than in other countries. Sweden and Finland, despite the low use of coal during the Industrial Revolution, were already two high energy intensive countries that managed to industrialize with wood and water[452]. In that case, the demands of high energy intensive industries such as mining, metallurgy and pulp and paper favored early electrification but also large size investments in dam building with the help of the state. Demand was assured. On the contrary, the previous model of Portuguese industrialization had resulted in a low intensive use of steam and a high intensive use of low skilled labour. Traditional industries such as textiles, food and ceramics constituted the demand, being ceramics the most electricity intensive industry[453]. On the other hand, previous levels of development also resulted in an incipient urbanization at the turn of the century, where Lisbon and Oporto were the only cities with a sizeable dimension, 356 and 168 thousand inhabitants respectively, followed at a distance by Setúbal (22 000), Braga (24 200) and Coimbra (22 100), meaning also that market for urban electrification was small and very concentrated at the two poles.

Because of the low demand, hydropower exploitation was also affected by considerations of level of consumption. Hydropower was not always the best solution. Being more expensive to operate than hydropower stations, thermal power stations were less expensive to construct and more adaptable to variations in demand which determined the technological choice. In fact, both due to the natural resources and demand, intensity of use was low[454]. By 1931-1935, the use of power in hydro-electrical centrals had not surpassed 2 000 hours, as against 2 786 hours in Spain, 3 450 hours in Canada, 3 800 hours to 5 400 hours in Italy and 4 895 in Finland[455]. That says much about the relatively high initial power costs of hydroelectric companies. Because prices were higher, consumption was low. This created a vicious circle where consumption was low

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[451] Simões (1997).

[452] Myllyntaus (1995) shows that motive power per industrial worker around 1910 in Sweden and Finland was higher than in the UK, and the double of France and Germany, falling only behind the US. With that example he points: “therefore, electricity did not make Finish, Norwegian and Swedish industries power intensive: the ample use of energy is an old tradition in those countries”, p. 102.

[453] DGSE, *Estatísticas das Instalacões Eléctricas*.

[454] There was not enough consumption in normal exploration conditions but power was successively increased in order to cover for problems during the summer. In many cases this was preferred to as water regulation, which seems to point to a lower cost in the first option. (DGSE, Estatísticas das Instalações eléctricas, 1935)

[455] Myllyntaus (1991), p.71-99.

because prices were high and prices were high because consumption was low. This did not help electrification: for the low wage level of the Portuguese economy, industrial prices would have to be substantially lower to give an incentive to capitalize. While in Sweden and the US, relative prices electricity versus wages fell by 2.51 and 2.89 times between 1914-34, and 1.41 from 1925 to 1934 in the UK, in Portugal those incentives were less visible, even reversing from 1925 to 1934 (Table 4.11).

Table 4.11 Relative electricity prices versus wages (1934=100)

	Sweden	US	UK	Portugal
	1934=100	1934=100	1934=100	1934=100
1914	251	289		107
1925	127	110	141	73
1934	100	100	100	100

Source: Prado (2010); Mellman (1956); *Boletim do Trabalho Industrial* (1934).

It seems that the Portuguese lag in electrification was a path-dependent process where the previous level and type of industrialization determined the speed of adoption. In an early phase, and due to their factor endowments Portugal adopted steam technology only in the sectors where energy and thus capital were of minor importance. The sectors where steam had more chances to act as a catalyst of further growth[456], such as iron, metals, mining, etc, simply did not exist. On the contrary, in Sweden or Finland, these sectors were maintained with indigenous resources, especially wood. In Italy, most steam advantages were also missed, but water-power was widely used in many light intensive sectors. It was not the best technology and made these countries miss most advantages of the First Industrial Revolution. However, they worked in a production function that was more capital intensive than the Portuguese. When possibilities of hydropower arose, the switch was more natural for Italy, which already operated with water technology, and for Sweden or Finland where the demand for power in the heavy sectors favored the switch. In Portugal, hydroelectricity could not be cheap at a low level of industrial demand, as the small resources were not adequate. Hydroelectricity could be relatively cheaper if there was demand, and the best Portuguese resources would necessarily have to be harnessed in a capital intensive way. However, Portugal produced at a very low level of intensity. As natural resources were clearly inferior to be applied

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per se to new sectors such as electrochemicals, hydropower was not harnessed, and Portugal continued to produce in a very low energy intensity way. As relative electricity prices were high in relation to wages and the coal/electricity difference was not enough to compensate immediately for capital differences, Portuguese sectors remained at a very low level of mechanization and essentially labor intensive. The limitation of natural resources was not only applicable to Portugal. In Spain, the low relative prices of electricity in relation to coal produced a strong incentive for electrifying their previous manufacture structure. However, the difference in natural resource endowments was not enough to drastically change the production structure of the Spanish economy[457].

4.4 Hydropower, oil and postwar convergence

4.4.1 Electricity and industrialization plans

The best Portuguese hydropower resources required large initial investments and the only possibility of investment and lower electricity prices was the guarantee of sufficient electricity demand. However, the consumption of electricity in Portugal was very low due to characteristics of demand (low industrial intensity, low living conditions of the population) and supply (thermal option, high prices). How could Portugal expand consumption and change the structure of its industry to incorporate more electricity intensive sectors? In order to turn the vicious circle into a virtuous one, the central government planned to give a supply push that would be capable of changing the incentives to electrification and boost industrialization, on the eve of the Second World War. There was a strong belief that industrialization should not be postponed. First, because of the negative effects of World War II that exposed the Portuguese energy dependence and lack of industrialization. In energy terms, World War II was practically a repetition of the restrictions of 1914-1918. The capacity of hydropower stations was practically saturated during the war and more than one million of hectares of forest had to be cut in order to supply the needs of thermal power stations, railways and manufacturing, with the share of firewood reaching 70% of industrial energy use in the most critical years. Restrictions of manufactured products such as chemicals, steel and machinery, which could not be produced in the country, incited wishes for more autarky. Second, capital was no longer such an important constraint. As a neutral

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[457] Bartolomé (1995). Especially the electrochemicals.

country, Portugal had benefited from the exportation of consumer goods and wolfram to the belligerent countries, and accumulated large gold reserves during the war; these were good conditions for the big leap[458].

In 1944, the vast electrification plan elaborated by José Nunes Ferreira Dias[459] was made law[460]. It was the first real Portuguese energy plan which had the double objective of substituting thermal production with hydraulic sources (with reserve thermal units burning national coal), and increasing the electricity supply to a level that would accommodate the normal growth of industrial and household consumption and would lead to the creation of new electricity intensive industries. The law predicted the interconnection of the main producer centers and the obligation of the producer and transportation companies to supply directly, at reduced prices, special consumers such as traction (railway electrification was in the plans), waterworks, electro-metallurgy and electrochemicals. Energy at normal prices would be sold to the distributors, formed by federations of municipalities (the idea was to eliminate the extremely small distribution) or their concessionaries, and tariffs for both high and low voltage were to be indicated by the government to these distributors, with the idea of tariff unification high voltage and the application of a tariff structure that would stimulate uses other than lighting with low voltage. The state was supposed to have the role of coordinator and regulator of the new electrification plan and to distribute incentives in the form of long-term-credit, help in the construction of transportation and distribution lines up to 50% of their cost, exemptions in imports of machinery and provide some of the capital of the companies, without substituting completely private initiative and without ambitions to intervene in the exploration of the new utilities[461].

Cheap hydroelectric power was supposed to promote the growth of industrial and household electricity consumption, and also give birth to some new industries. A law from 1945 included the basic industries that would be given production licenses[462] and that would be able to benefit from some state

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[458] It would also benefit from the Marshall Plan funds, from 1950, despite the neutrality during the war.

[459] Famous minister and Engineer of the Dictatorship of Salazar – “Estado Novo”, responsible for the architecture of the future national electricity grid and new basic industries.

[460] Law n. 2002.

[461] *Diário das Sessões*, n.79, 24/10/1944, Assembleia Nacional, “Proposta de lei acerca da electrificacão do país”.

[462] Law n. 2005. One of the characteristics of the New State (Estado Novo) economic policy was the industrial conditioning policy that had the goals of promoting concentration and eliminating pernicious competition. One of the reasons for this policy was the lack of mechanization and the scale of Portuguese industry. This led to the belief that concentration would solve technological backwardness and make industries more competitive internationally. That meant that the creation or the industrial

industrial credit. They were capital-intensive industries with low prospects of increasing direct employment but which had in common, accordingly to the author, the possibility of using national raw materials and having an important drag effect on the remaining of the economy, as the products they would produce were raw materials for many other industries. The technological methods were relatively well known and used for many years in other countries, and the new industries represented about 13% of the value of total pre-war imports, an important consideration given the large structural deficit in the commercial balance.

Table 4.12 Basic-industries to establish

Industries	Workers	Electricity consumption (GWh)	Annual imports thousand escudos (1937-1939)
Iron metallurgy (ingots,laminates, tubes,tinplate)	3 900	436[a]	221 600
Copper metalurgy (ingots,laminates, tubes)	700	5	31 399
Ammonia Sulfate	250	330	51 200
Cyanamide and nitrates	100	25	12 100
Cellulose	1 500	20	17 300
Total	**5 900**	**816**	**333 500**

Source: *Diário das Sessões*, n.85, 02/11/1944, “Proposta de Lei de Fomento e reorganização industrial”

a) assuming the viability of electro-steel.

The basic industries to be established included electrochemical industries (cyanamide, ammonium sulfate) copper metallurgy, cellulose, and steel works[463] (see Table 4.12). The energy question was a fundamental requisite in the heavy industries: it was assumed that for substitute importations, 816 GWh of hydroelectric power was initially needed, only for these new sectors, especially if the electro-steel technology proved viable to employ. This corresponded to more than four times the amount of hydro-electric energy that was already produced in the country. Accounting for the energy that would be needed to substitute thermo power and to accommodate for growth of consumption, about

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capacity of an industrial unit required confirmation from the state, something that sometimes did not occur.

[463] From Ferreira Dias a famous expression - *Country without steel is not a country but a garden*. Portuguese: “País sem siderurgia, não é um país, é uma horta” – Speech at the opening of the works in 1961.

1 500 GWh of hydropower was needed around 1952 which is about three times the electricity production at the time.

For most industries, especially for fertilizers and steel, the price of electricity was a determinant of its viability. In sum, the two laws were overall an ambitious attempt to initiate the catching up process, change the structure of Portuguese industry incorporating leading sectors of the Second Industrial Revolution and, at the same time, increase the welfare of the urban population. In the words of the author of the laws:

> Electricity is a means to an end – the goal of industrial development; (…) it is necessary and urgent (...); the future of the Portuguese people depends largely on the execution of the plan.[464]

The questions that obviously follow are: Was this plan successful? Was autarky achieved in electricity production through hydropower? Did hydropower production lower electricity prices and if so, in which cases? Was electricity the motor of industrialization? Did national energy sources make the new basic industries viable?

I will analyze the outcomes of the plan with a special focus on prices and their impact on electricity usage and industrial growth.

4.4.2 The transition to hydropower: building the grid, changing price incentives

In practice, the State intervention in electricity was much larger than predicted by the 1944 law. Instead of investment in electrification mainly supported by private companies, the application of the law led to a mixed type of economy where the State had the preponderant role in decision-making, financing investment and exploration. The new national grid was constituted by new big hydropower centrals formed with both public capital (in majority) and private capital, including the more important electricity distributors[465], which would sell their energy to the new transportation company, Companhia Nacional de Electricidade (1947) constituted in the same models of mixed economy, with

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[464] In Portuguese:"A energia eléctrica é um meio para um fim: o fim industrial a que é destinada (..), (...) É necessária e urgente, (..) porque de executá-la ou não depende em larga medida o futuro do pôvo português. *Diário das Sessões*, n.79, 24/10/1944, Assembleia Nacional, "Proposta de lei acerca da electrificacão do país".

[465] Hidroeléctrica do Zêzere (1945), Hidroeléctrica do Cávado (1945) and Hidroeléctrica do Douro (1953) which took the names of the rivers they exploited. Construction of new reserve hydroelectric central: Empresa Termoeléctrica Portuguesa (1954). The state owned 51% of the capital.

the capital of the new hydroelectric companies, main distributors, banks, and the State. This company would distribute the energy to direct consumers at reduced prices and by a poll payment (for the use of the primary transportation network) to the main distributors who would then resell the energy to other distributors without sufficient weight to enter into a grid and to their clients using secondary lines. The old producers (who were also the main distributors) were allowed to continue to sell the energy from old hydropower stations to their clients (but not thermo). However, as no new projects were allowed outside the mixed economy regime, the result was that the price of the primary grid was soon the reference one, the contribution of the primary grid to total production, which was slightly above 50% in 1954 would reach 90% at the end of the 1960s.

Table 4.13 Main hydroelectric dams constructed in the period 1951-1965

	Built year	Hydraulic Power (GW)	Mean Power (MW)	Electricity production in average year (GWh/yr)	Hours of production at maximum power (average year)	Cost (million escudos)
Until 1950		**153**				
1950-1965		**1 243**	**104**	**497**	**4 397**	
Castelo do Bode	1951		157	465	2 962	674
Venda Nova	1951		87	365	4 195	482
Salamonde	1953		40	220	5 500	216
Cabril	1954		110	355	3 227	512
Caniçada	1955		62	315	5 081	395
Paradela	1956		55	260	4 727	957
Bouçã	1956		50	190	3 800	202
Picote (ID)	1958		180	1 090	6 056	706
Miranda (ID)	1960		156	950	6 090	886
Alto Rabagão	1964		72	115	1 597	1 573
Bemposta (ID)	1964		210	1 190	5 667	1 098
Vilar-Tabuaço	1965		64	170	2 656	967

Source: Comissão do Aproveitamento das Grandes Barragens. Ribeiro et al. (1987).

ID – International Douro

In production terms, dam construction began immediately after the war and the first results of the government plan emerged in 1951 when the first two large reservoir dams started to supply Lisbon and Setúbal, and the North of Portugal, thus starting Portuguese hydro-dependent period. From 1950 to 1965, hydraulic power was to increase by a factor of almost 10, and the medium size of the power centrals from 700 kW to 100 MW (Table 4.13). Hydropower production already attained 90% from the mid 1950s and was maintained more or less at this level until the late 1960s.

The first investments were relatively costly in relation to the possibilities of production in an average hydraulic year, but followed a logic of minimizing the costs of transportation to the consumer centers and also constructed the reservoirs that were essential for regulating water power in the summer[466].

Around 1950, it was estimated that the hydroelectric price of the primary grid for the distributors (0.34 Escudos/kWh) would be significantly lower than exploration costs at the Lisbon thermal power station (0.52-0.54 Escudos/kWh). This was the first visible success of the application of the electrification law: increasing at a good pace the electrical power available, decreasing to insignificant levels the dependence on coal, saving foreign exchange and, at the same time, managing to get lower prices than the thermo option. Despite all the advantages, the estimated average cost of a kWh (0.34 Escudos/kWh) was still significantly higher than the average costs of thermal utilities in the US and UK (Table 4.14).

Table 4.14 Costs of a kWh of a thermal and hydropower: US, UK and Portugal around 1950

	US	UK	Portugal	
	Thermal	Thermal	Thermal	Hydro
Exploration costs	0.12	0.163	0.38 -0.42	
Fixed Costs	0.103	0.042	0.12	0.19[467]
Transportation				0.11[468]
Thermal reserve costs				0.04
Total	**0.223**	**0.205**	**0.52-0.54**	**0.34**

Source: Ferreira Dias (1998), pp. 219-233

It seems then that only a minimum convergence to thermal country prices had been achieved, which was somewhat disappointing for a government that wanted to promote industrialization based on cheap electricity. However, producer prices (0.19 Escudos/kWh) and the huge transportation costs (0.11 Escudos/kWh) were expected to decrease significantly in the future with increasing consumption and amortization. Also, in the matter of pricing, the

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[466] Not without criticism from some international planners who suggested priority of construction based solely on production costs, this is, giving preference to the run-off-the-river International Douro power centrals. See Pintado (2002).

[467] Including electrochemicals.

[468] True transportation cost is set at 0.065 Escudos/ kWh . The difference corresponds to an amount aimed at compensate the low use of the grid in the first years.

intention was to incorporate the idea in vogue of lower marginal costs of hydraulic production in relation to thermal production in the structure of the tariffs.

Ferreira Dias considered the tariff elasticity to be much bigger in a hydro power central than its thermal equivalent and explained the fundamental difference between the two types of production in the following way:

> (…) in a hydraulic utility the very small exploration expenses are practically constant and the production cost is obtained, almost in its entirety, from fixed costs (interest and amortization) (..), in a thermal utility, the price results from the sum of two clearly differentiated parcels – fixed costs and variable exploration costs. (…) there is no minimum selling price for a hydraulic kWh, as it is always possible to sell a parcel of production at any given price, as long as it is compensated by other parcels sold at a higher price (…) It is different if the production is thermal, because there is a minimum cost below which is not logical to sell the kWh (…). It is true that even if you sell some thermal energy below the cost of production, you can compensate the producer by paying for the remaining electricity a price high enough to cover all costs. However, you don't eliminate the fact that there was a transaction at a loss (…) that didn't cover the amount that one actually spent to produce the article sold (…) it is psychologically unsustainable[469].

Of course this idea was not entirely correct because it assumes, among other things, that the generating capacity is unlimited. It made, however, some sense for the first years of Portuguese electrification: low consumption and large increase of capacity waiting for new consumers, chart diagrams that could be improved in off-peak hours and impossibility of storage beyond the capacity of the reservoirs.

Due to the characteristics of low marginal costs of hydroelectric production, his idea was actually to charge each consumer group at levels corresponding to their economic capacity and tending to their marginal utility, as

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[469] Portuguese: "(..) enquanto numa central hidráulica as despesas de exploração, aliás muito pequenas são praticamente constantes, pelo que o custo de produção resulta, na quase totalidade, de encargos fixos (juro e reintegração) (...), nas centrais térmicas (...), o preço resulta da soma de duas parcelas diferenciadas – encargos fixos e encargos variáveis de exploração. (...) Resulta daqui que não há preço mínimo de venda para o kWh hidráulico; é sempre possível vender uma parcela da produção hidroeléctrica a qualquer preço, por mais baixo que seja, desde que haja compensação de outra parcela vendida a preço mais alto (..) As coisas passam-se diferentemente se a produção for térmica, porque há um preço mínimo abaixo do qual não é lógico vender o kWh (...). É verdade que ainda que se venda parte da energia térmica abaixo do custo de exploração, se pode compensar o produtor, dando-lhe pela restante um preço suficientemente alto para cobrir todos os encargos; mas não se elimina o facto de que houve uma venda com prejuizo que efectivamente se desembolsou para produzir o artigo vendido (..) é psicologicamente insustentável". Ferreira Dias (1998), p.280-281.

long as they did not influence too negatively the peak periods and as long as, in the end, distributors could cover their costs with the selling of all electricity. According to Ferreira Dias, besides the gains in prices that all consumers will obtain by having lower production electricity costs, there were two groups of consumers that could benefit the most from marginal pricing: the electrochemicals and electro-metallurgy in one side, and the households in the other.

In the first case electricity needed to be consumed in great quantities to guarantee one unit of production (3 800 kWh per ton. of ammonium sulfate, 28 000 kWh per ton of aluminum),[470] and the price of electricity is normally a condition to assure the viability of the industry. A value of 0.12 Escudos/kWh in the beginning of the 1950s for the new fertilizers industries was assumed to be a condition of viability for their industries, quite below the producer price (0.19 Escudos/kWh). That price would be sustained, because these industries would mostly consume temporary and overlap electricity, this is, energy that was produced in excess during the raining season and that could not find any other useful consumption, with very low marginal costs. In fact, in the case of a dry year and in peak periods, electrochemicals would be the first to stop production, given the fact that their consumption corresponded to some hundreds large textiles factories.

The idea of benefiting the households was to promote all the use beyond lighting uses, uses for which price elasticity was much larger not only due to the larger volumes of electricity consumption and capital expenses that they required, but also due to the existence of multiple substitutes.[471] Ferreira Dias was not only an industrialist; he was interested in the impacts of electricity on the impacts of electricity in the welfare of the population. In 1934 he attended the UNIPEDE[472] congress and he marveled at the results of the application of regressive tariffs in many European cities. The idea of the *regressive tariffs* was to charge lower prices as the consumption of electricity increased. Regressive tariffs were divided into three steps, also taking into account the number of rooms of a house to determine the size of each step. In the first step, corresponding to the first kWh consumed by a family (lighting), a higher price was charged. This price was supposed to be the highest in the scale of all electricity prices due to its low price elasticity; it was a type of consumption with great influence on peak loads and there was a need to sustain lower

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[470] Ferreira Dias (1998). In a first phase, aluminum was out of reach.

[471] The uses I am referring are space and water heating.

[472] Union Internationale des Producteurs et Distributeurs d'Energie Electrique (International Union of Producers and distributors of Electric Power).

industrial electricity prices. A second step, which usually corresponded to the use of small electric appliances, was normally set at 1/2-1/3 of the first; the third and last step, for the remaining kWh, was normally set at 1/4- 1/8 of the first step and would be for large uses such as hot water, heating and cooking. Only after consumption occurred at this last level, would Ferreira Dias consider a Portuguese house as electrified. The application of the regressive tariffs obeyed the principle of utility, as price decreased with decreasing marginal utility of consumption. It was believed that it would not affect peak demand as power for new applications, besides lighting, was spread throughout the day, contributing to an improvement of the chart diagram.

4.4.3 Economic growth with cheap energy: the success and limits of hydropower

The post-war period was an important turning point in Portuguese economic growth path. All of Europe witnessed impressive economic growth rates boosted by strong investment in reconstruction and increasing international market openness. The most backward European countries, among them Spain, Greece, Yugoslavia (all three recovering from devastating civil wars) and Portugal, were the ones that grew more. Between 1950-1973, the industrial sector in Portugal was the motor of the economy, growing consistently at annual rates of 8-9%, one of the highest in Europe, and surpassing agriculture in both value (1963) and employment (1969)[473]. In relation to the world´s leading industrial countries[474], GDP per capita converged from about 1/3 of the average in 1950 to about ½ in 1973, a convergence of almost 20 percentage points, making the last two decades of dictatorship the only period of continuous convergence in the last two centuries[475]. If this growth is undisputable, the role of indigenous natural resources in helping economic growth is a matter waiting for deep reflection.

Table 4.15 shows the evolution in electricity prices and electricity consumption to the various consumer groups for benchmark years until 1973. In terms of primary grid prices, the expected decline in producer prices took place as predicted[476] (with the exception of 1953, which was an extremely dry year).

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[473] Lains (2003), Pinheiro (1997). Industry never outnumbered the service sector.

[474] Leading 15 countries: Germany, Australia, Austria, Belgium, Denmark, USA, Finland, France, Italy, Norway, New Zealand, UK, Switzerland and Sweden.

[475] Amaral (2010).

[476] Table 4.14 for initial prices.

Table 4.15 Electricity prices and electricity consumption in Portugal 1935-1973

	1935	1945	1953	1958	1963	1968	1973
			Escudos/kWh (Current)				
Producer price to the primary grid			0.2[a]-0.30	0.17	0.17	0.24	
Average price primary grid to distributors and high intensive users			0.31[a]-0.39	0.25	0.25	0.31	0.32
High intensive uses: direct supply							0.23
Electrochemicals *			0.12-0.17	0.12	0.14	0.15	0.25
Steel					0.23	0.21	0.25
Traction					0.25	0.28	0.29
Distributors:							0.33
Industry	(0.6)	0.74	0.61	0.62	0.55	0.55	0.58
Households	1.5-4						0.8
Porto							
Esc/kWh (Current)	1.70	0.75	0.38	0.42	0.39	0.50	0.48
Constant prices (1935=100)	100	25	11	11	10	11	8
kWh/client	155	348	1 985	2 535	3 171	3 346	3 397
Lisbon							
Escudos/kWh (Current)	1.89	2.50	1.58	1.28	1.07	0.95	0.88
Constant prices (1935=100)	100	75	42	31	25	18	13
kWh/client	200	180	336	524	801	1 062	1 691
Electricity consumption (GWh)	**301**	**452**	**1153**	**2 261**	**3 640**	**5 261**	**8 192**
Civic (%)	19	19	26	24	26	27	33
Electrochemicals and electrometalurgy(%)	4	3	14	25	18	10	8
Manufacturing (%)	62	64	54	46	52	59	57
Traction (%)	16	13	7	5	4	4	3

Source: Electricity consumption: DGSE, *Estatística das Instalações Eléctricas*; Producer and primary grid prices:1953-1968: CNE, *Relatório...*, 1973: CPE, *Relatório....*, Electrochemicals, based on annual reports from sulfate ammonium companies: UFA, *Relatório...*; AP, *Relatório...*; Steel: INE, Estatísticas Industriais. Traction, represented by subway prices: Metropolitanho de Lisboa, Relatório... Industry: average industrial electricity prices represented in Industrial Statistics with the exception of electrochemicals and steel. Households: Porto: SMGEP, *Relatório…* Lisboa: CRGE, *Elementos Estatísticos…*[a]Values for 1952

That decrease in the producer selling price, together with the decrease in the poll price that was charged for distributors to use the grid, made the average selling price of the primary grid (including electrochemicals) about 0.25 Escudos/kWh in the early 1960´s. To get a perception of how significant this nominal price decrease was, we can compare it with the electricity prices charged for the Area Boards (distributors) in the post-war nationalized electricity grid in England and Wales, the traditional coal supplier. There, especially due to nominal price increases of 70% in the price of coal, electricity prices had increased from 0.22 Escudos/kWh in 1948/9 to 0.36 Escudos/kWh in 1962[477]. This means that, in less than 10 years of hydropower production, Portuguese grid prices had become cheaper than the English prices. Hydropower was seemingly becoming not only a relative advantage but an absolute advantage for industrialization needs.

As Table 4.15 shows, from 1945 to 1973 electricity consumption increased by a factor of 18, with households and electricity-intensive industries growing faster than industry in a first phase, and with transportation continuously loosing consumption share. In a second phase, both industry and households increase their consumption share at the expenses of electrochemicals. The following subsections discuss the impacts of the electricity policy in the growth of electricity consumption of basic industries, traction, households and manufacturing, having into account the evolution of electricity prices.

4.4.3.1. Basic industries and traction

How relevant was the Ferreira Dias import substitution plan based on cheap and plenty electricity and in indigenous natural raw materials for Portuguese economic growth? Economic historians agree that some credit should be given to import substitutions as one of the sources of growth in the 1950s, although not the only one[478]. In fact, until the mid 1960s, some of the most dynamic sectors of the economy were mainly new industries, intended from the beginning as substitutes for imports: new branches of chemicals, basic metallurgy and cellulose, all with growth rates of about 9-11% a year[479]. In general, the most important basic sectors and railway electric traction were the ones that received a great deal of attention in electricity pricing (Table 4.15, see electrochemicals, steel and traction prices). However, hydroelectricity had a mixed role in the development of these industries. If the abundance of energy and fall of electricity prices were a pre-condition for the emergence of new industries and

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[477] Sayers(1963), Vidigal (translation).

[478] Lains (2003); Lopes (2002). Some input-output calculations of the contribution of internal demand, import substitutions and exports for economic growth using during the period 1959-1974 suggest that internal demand was clearly the most important factor of economic growth, followed by exports and import substitution, with more or less the same degree of importance (although the contribution of exports increases during the period).

[479] Lains (2003).

expansion of consumption, electricity failed to be a source of clear advantage to most of the basic industries that the state sought to promote. The model of industrialization by import substitution, mostly based on natural resources, was only very partially achieved. This happened for a variety of reasons: the limited potential of hydro-resources, a tariff policy that promoted the use of electricity by many consumers without an even stronger incentive for the basic industries, an international scene more favorable to trade than to protectionism, but mostly because electricity would not be able to sustain competition with another high quality energy carrier, oil, that, due to its falling price (Middle East discoveries) and continuous technological innovations, was soon applied with strong advantages to many industrial processes. In practice, some of the technological processes, which were considered viable during the war, no longer made sense in a 1950 or 1960 context. For some uses, hydropower had just come too late[480].

The fertilizer industry was a clear example that illustrates both the limits of hydro resources and the oil competitive advantage. The share of electrochemicals and electro-metallurgy in electricity consumption grew from only 4% around 1935 (represented by only one calcium carbide factory[481]) to 25% around 1958 (35% of industrial consumption), see Table 4.15. During the 1950s and 1960s, the share of fertilizers (ammonium sulfate and cyanamide) in this consumer category was more than 80%. The license for cyanamide production was given to the calcium carbide factory and we do not have knowledge of any problems with its production; due to the reduced demand for this fertilizer in the internal market, import substitution was rapidly achieved; both in production and in electricity consumption, the share of cyanamide in the new fertilizer industry was only 5-10%[482]. Things were different for ammonium sulfate. Ammonium sulfate is a nitrogenous fertilizer that is produced by reacting ammonia with sulfuric acid, which in turn needs pyrites, something that the country possessed in abundance. The key step was obtaining hydrogen for ammonia production, a process which was (and is) very energy intensive. After World War I, coal countries obtained hydrogen mostly by the residual gas of metallurgic and coke ovens or by the gasification of coal; countries that lacked steel industries or coal but possessed plenty hydropower obtained hydrogen by electrolysis, which was the solution considered for Portugal. Two new industries

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[480] On this topic see also Cruz *et al*. (2005) or Madureira (2008).

[481] The calcium carbide factory (Companhia Portuguesa dos Fornos Eléctricos) was in operation since 1917 and received temporary energy from Empresa Hidroeléctrica da Serra da Estrela. Calcium carbide main application was lighting.

[482] Own calculations from INE, *Estatísticas Industriais* and company reports UFA, *Relatório*…. and Amoníaco Português, *Relatório*…

of ammonium sulfate[483] initiated production in 1952 with 60 000 tonnes capacity[484]. In 1953, an extremely dry year, production was reduced to 30 000 tonnes, with the factories being practically closed for 6 months. Obviously, the limited use of capacity was having repercussions for costs. Not even the price of electricity was a factor of agreement: in 1948 there were still discussions about the price being 0.8 -0.9 Escudos. In 1952 the price of 0.12 Escudos was promised but during all of the 1950s the real electricity price supported by the industries surpassed that value, sometimes reaching 0.15-0.16 Escudos[485]. One of the companies, Amoníaco Português, immediately initiated the planning of a second phase of ammonium sulfate production based on hydrogen by the gasification of national coals (an initial government requirement was the use of national resources), ordering studies of its viability to Germany[486]. Also in its first year of existence, the second company, União Fabril do Azoto, was already suggesting, as an essential condition to reduce costs, the continuous use at full capacity, new electrolysis installations to allow the use of more overlap energy during the winter and the complement of chemical hydrogen[487]. The first condition could never be accepted by the government: it would put too much strain on all the system due to the irregularity of hydrological years. The initial solution was to double production capacity, and the companies managed some cost reduction. However, prices were still higher than international prices and only a system of bonus and subsidies per ton would allow for production runoff in the first years[488]. The solution for the problem come from the oil refinery created just before the war, SACOR. A unit of catalytic cracking was installed in 1954 for the production of high octane gasoline, butane and propane. As Portugal was a country with poor motorization this led to a large naphtha surplus. This naphtha surplus could be gasified to produce chemical hydrogen, a solution that is inferior only to natural gas in terms of cost, a fossil fuel that the country did not possess. Electrolytic hydrogen was the most expensive solution, even more than national coal. A year before the cracking installation, the company proposal to the government involved the launching of a new unit of

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[483] União Fabril do Azoto and Amoníaco Português.

[484] Pereira (2005).

[485] Ferreira Dias (1998); UFA, *Relatório….*; Amoníaco Português, *Relatório…*The cyanamide industry was paying lower prices, averaging 0.10-0.11 Escudos for example (INE, *Estatísticas Industriais*). One of the reasons for higher prices than promised was the different pricing between temporary and overlapped energy.

[486] Pereira (2005)

[487] UFA, *Relatório…* 1954. Pereira (2005), Ribeiro *et al*. (1987).

[488] The agriculture paid an invariable price of 1900 Escudos/ton. The bonus was being reduced due to the fall in international prices. See Pintado (2002).

ammonia that would simultaneously fuel the ammonium sulphate companies, a new unit of nitrates (fertilizers for which consumption was increasing in Europe) and a new type of town gas (a mixture of ammonia with refinery gas) that would allow the ceasing of coal imports for gas production[489]. There was a powerful reason: despite the large consumption of electricity, subsidies were expensive and the internal market for fertilizers was far from being saturated. The final solution to the problem involved clear frontiers on the type of fertilizers that each company could produce and three new chemical hydrogen units, one in each company. The refinery supplied naphtha from 1961 to the ammonium sulfate companies, losing some of the advantages of scale that only one unit could bring. The solution did not imply the total substitution of the processes. The production of electrolytic hydrogen continued, although, after 1958, its capacity never again increased, and only ceased between 1968 and 1973, a time which coincides with the increasing prices for electrolytic industries[490]. The increase in the thermo component and the expansion of other types of consumption made overlap and temporary energy an old fashioned concept. Between 1958 and 1967, the electrolytic hydrogen consumed a minimum of 434 GWh in 1965, a dry year, and a maximum of 637 GWH in 1966, the most humid year to the time[491].

The competition of oil and natural gas with other natural resources in the production of chemicals, and specifically fertilizers, was not specific for Portugal[492]. Many other countries would soon lose the interwar advantage of chemical production. The cases of Sweden and Switzerland, for example, leadership could only be maintained in some niche markets requiring extremely skilled research, such as pharmaceuticals[493]. Others, such as Italy and the Netherlands, would see the importance of the industry rise, due to the possibility of using recently discovered natural gas reserves. Unfortunately for Portugal, these changes were not foreseen and a large electricity consumption industry was created in a moment of already dubious viability. Could this large electricity consumption have been used in more viable industries? Probably yes, but only in part. We should always keep in mind that the electricity that they consumed had a strong temporary characteristic, dependent on good hydrological years;

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[489] Vaz (2002).

[490] UFA, *Relatório*… and Amoníaco Português, *Relatório*….

[491] Idem

[492] In 1957, the annual report of União Fabril do Azoto mentioned the fact: “The evolution of the chemical industry has been so fast, that rendered outdated most of the fertilizers industries of the world” (…) If Portugal applies the new methods, we could have an ammonia price equal or below the foreign one.” UFA, *Relatório*… 1957.

[493] Aftalion (2001).

only consumers that did not require continuous production would be able to take full advantage of this type of energy. That was in part what happened. Slowly, the large electricity consumption to produce ammonium sulfate was in part re-directed to other electro-chemicals and electro-metallurgy uses that were probably more viable. The *Companhia Portuguesa dos Fornos Eléctricos* was such an example. In the second-half of the 1960s and in 1970s, besides the small production of cyanamide, the company produced pig iron in electric furnaces for the internal market and silicon-iron and silicon-metal for the external market, becoming an important supplier of the Portuguese metal-mechanics and steel industry[494]. There electricity made the difference.

Another basic industry, where indigenous energy sources never did what they promised to do, was steel. The initial idea of Ferreira Dias was an electro-steel (low-heat reduction electric oven) solution although the option should be subjected to viability studies. In 1952, when the State found the industries ready to receive the generous State loans and advance with the investment, the hydroelectric construction was still short of planning to make the regular supply of electricity to such a large consumer. The alternative presented by Ferreira Dias was now the installation by phases of a steel works with 100 000-150 000[495] tonnes capacity: in a first phase a steel work based on poor national coal, poor national ores and pyrite ashes based in WWII technologies,[496] and in a second phase the electro-steel, when electricity was available. The final solution was actually quite contrary to the initial predictions. A viability study made by the company showed that the traditional coke blast furnace, complemented by an electric arch in the steel mill and two LD convertors, was the most economic solution, rejecting the autarkic technologies based on national coal. The government was not pleased with that proposal, as it would require coal imports. In the following three years, intense discussions took place and the government tried to impose an autarkic technological option. But by 1957 the company had won the battle of technology. Arguing that the new European integration processes (EFTA, EEC) would require a competitive steel industry in ten years due to a necessary reduction in protectionist tariffs, the company was able to convince the government that the blast furnace was the only viable solution[497]. The company started operating in 1961 and until 1969, the year of a new coke oven installation, the coke was imported. The company still benefited from large electricity price reductions (Table 4.15), as it was still a very important

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[494] Loio (1996).

[495] Small in an international scale, where 1 million tonnes seems to be the optimal size.

[496] Basset (from cement production) and Krupp-Renn. Pereira (2003) and Pereira (2005).

[497] Pereira(2003)

electricity consumer (even without electro-steel). The history of the industry is too complex to be fully discussed here. More than energy price differences, the constraints of this industry were mostly its small scale (in a type of industry that benefits from scale) and the problems of the survival of an infant industry in a world market where the practice of dumping was common[498]. It generated less demand from derivate industries than more complete steel works as the principal products were destined for civil construction and had a great deal of protection (including import restrictions)[499]. It never totally satisfied Portuguese steel demand and would have to be restructured in the 1980s due to the European Union rules. Ironically, the blast furnace closed in 2001 and was replaced by an electric reduction furnace[500].

One of the few basic industries that achieved a great amount of success was the paper and cellulose industry. The National Reforestation Plan, ongoing since 1938, had in mind to reconvert land of dubious agricultural productivity, commons and other wastelands, into pine wood forest land. This plan benefited the expansion of fertilizer consumption and it was considered a pre-condition to provide raw materials for the cellulose and wood industry[501]. However, not even here, was cheap electricity to be a factor contributing to the viability of the industry. The Companhia Portuguesa de Celulose started operating in 1953 and was originally conceived to be an import substitution industry: it accumulated two types of pulp processes (mechanical and chemical) and many types of paper, without a clear specialization. Soon it was obvious that the mechanical pulp used to produce the lowest type of quality paper such as newspaper, could not compete in price with the Nordic pulp. Mechanical processes used enormous quantities of electricity, representing 30% of the costs. Unlike steel or fertilizers, no special electricity price was given to the industry, making electricity about four times more expensive than in Nordic countries[502]. Instead, the viability of this industry would be found in the chemical cellulose processes, less electricity-intensive, and with a type of wood totally different from the one which was being used to forest the country – eucalyptus. In 1957, the company became the European pioneer in the production of bleached eucalyptus pulp, a pulp that was not cheap but produced high quality paper. The sector had found its export market niche based in a fast growing plant that could be easily adapted to the

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[498] Guimarães (2005); Pereira (2003).
[499] Guimarães (2005); Pereira (2003); Pereira (2005).
[500] Pereira (2005).
[501] Estevão (1983).
[502] Alves(2000).

Southern European climate[503]. Although Portuguese paper and pulp production is very small compared with Nordic Countries or Germany, the company continues to be European leader in this type of pulp and high quality office paper, configuring this industry one important Portuguese export in value[504].

Finally, railway electrification was also a goal of Ferreira Dias. But here, the need for large amounts of permanent electricity at reduced prices and the competition with oil proved to be a limiting factor. The initial idea was to electrify most of the railway grid and use diesel as a complement. In the late 1950s, the advantages of substituting diesel for coal were enormous; the oil costs of the ton-km were about 5 times lower than the equivalent in coal[505]. Although at that time some would argue that electricity prices could be even lower[506], the fact is that only the subway in Lisbon (1960) and the electrification of the main line Lisboa-Porto were held during the period 1950-1973. The share of traction in electricity consumption declined from 16% in 1935 to only 3% in 1973 (Table 4.15) and trucks and buses were used to meet the increasing demands for transport of goods and passengers. Oil won, once again.

4.4.3.2. Remaining uses: Industry and households

For the rest of the manufacturing sector, such a strong investment in energy production was something that the country had never seen and all indications were that, besides boosting cement and other sectors related with construction, it also created a demand for the appearance of many new sectors such as electric cables, transformers and hydraulic equipment. Although the incorporation of imported materials and technology was always high, the use of national equipment significantly increased during the period, developing capabilities in machinery making and engineering[507]. In terms of pricing, there were also nominal price decreases for industrial needs, which were significant if measured in real terms. Some of the real price reduction was achieved during the war, with

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[503] Alves (2000). Not without consequences for the management of fires during the summer, as eucalyptus is a tree that burns very quickly.

[504] The sector of Paper and pulp represented 5 to 6% of the Portuguese exports between 1990 and 2003.

[505] *Diário das Sessões*, Assembleia Nacional, 164S,7/4/1960, p.130. Fuel costs per ton/km in 1960 were estimated to be 0.078 Escudos for coal and 0.015 Escudos for diesel.

[506] *Diário das Sessões*, Assembleia Nacional, 164S,7/4/1960, p.130.
The Annual Report of the Railway company for 1957 indicated fuel cost per km of 11.78 Escudos for coal locomotives, 4.28 Escudos for diesel locomotives and 3.20 Escudos for electrified lines. In *Diário das Sessões*, Assembleia Nacional, 46S, 8/10/1956, 95.

[507] The evolution of proportion of national machinery in dam construction rose from 2% in 1951 (Castelo do Bode dam) to 30-76% between 1960 and 1976. See Ribeiro *et al.* (1987). Most of the machinery was produced through international license (assembling).

the freezing of tariffs in hydroelectric regions. After the war, the reduction in nominal prices across the period was mainly due to the convergence of nominal prices in the southern regions in relation to the North and Central regions. The energy transition in manufacturing was on its way: together with oil for heating processes, electricity increased its share in the final energy consumption, replacing wood and coal[508].

Table 4.16 Electricity prices in Europe around 1962, dollar cents

	Households			Industry	Large consumers	
	400 kWh/yr	1000 kWh/yr	3600 kWh/yr	500 kW, 1900 hours	High Voltage	Average household/large consumers*
Belgium	6	4.7	2.7	2	1.8	2.6
Italy	4.8-5.8	3.8-4.2	2.8-2.9	2.3		
France	4.3-5.3	3.2-4.3	2.2-2.9	1.5 - 1.8	1.2	2.6-3.6
Luxemburg	8.6	4.3	3.2	2.5		
Netherlands	4.2-4.7	2.8-3	1.8-1.9	2	1.9	1.6
Germany	5.7	3.5	2.5	2.8-3.5	1.8	1.9
United Kingdom	4.2	2.6	1.9		1.6	1.6
Portugal	3.9-4	2.2-2.7	1.3-2	1.9	1.5	1.5-1.8

Source: Sayers (1963). Marteaux (1963). Portugal: own calculations.* Average household = 1000 kWh year.

Industrial prices also seemed to converge with other European countries after the war, see Table 4.16. In nominal terms the average industrial price in 1962 (excluding steel and electrochemicals) was 1.9 dollar cents. Comparing with the electricity prices for an average industrial unit (1900 hours year and 500 kW) of a European Community state member, electricity prices were not at all disadvantageous: they were higher than in France (1.5-1.75 cents), at the level of Belgium and Netherlands (2 cents) and lower than in Italy (2.3), Luxemburg (2.5) and Germany (2.75). If we adjust the industrial prices to include steel and electrochemicals in order to compare with English prices, we also obtain a similar price level (1.6 cents)[509]. Everything indicates that despite the convergence of most of the European countries, industrial prices were

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[508] This transition can be expressed in proportions of final energy. In 1948, final consumption was: Wood (44%), Coal (41%), Oil (11%), Electricity (4%); in 1973 the fuel share changed to: Wood (11%), Coal (15%), Oil (59%), Electricity (15%). INE, *Estatisticas Industriais*, Cruz *et al*. (2005).

[509] Sayers and Vidigal (transl.) (1963).

significantly higher than in Sweden (about the double)[510]. Although we should bear in mind that small differences in electricity prices were not very important for most of the light industries due to the low percentage of costs, there was something incoherent about all the system. Households were getting most of the benefits from tariff reduction at the expense of industry, in a country that was pursuing a very strong effort to industrialize.

As we see in Table 4.16 household prices were the ones that decreased with more intensity. Despite being a period of strong growth in manufacturing and electrochemical production, household consumption managed to maintain and even increase its share of total consumption – from 19% in 1935 to 33% in 1973. In real terms, household electricity prices in Lisbon and Oporto in 1973 were only 13% and 8% of what they were in 1935. The regressive tariffs, which were supposed to provide an incentive for uses other than lighting, had already been put into practice in many regions after 1937, but during World War II were only maintained in regions supplied by hydroelectricity. The prices offered for the third step in the region of Oporto and Coimbra were very competitive compared with other cooking alternatives from the start, but due to the absence of advertising, consumers were slow to adjust to the new tariffs. However, with the outbreak of the war and the disappearance of fuels such as coal, wood, charcoal and kerosene from the market, cooking with electricity become an extremely cheap alternative even accounting for the acquisition of new equipment, and household consumption increased accordingly[511]. By 1950, ¼ of the families in Oporto had an electric stove, a percentage clearly above the European average. A family in Oporto consumed 1300 kWh of electricity a year, 1000 kWh more than a family in Lisbon (270 kWh) and also far more electricity than any large Italian city (404 kWh), Paris (425 kWh), Stockholm (684 kWh) or The Hague (740 kWh), falling only behind Zurich (1800 kWh) or a small English town (1700 kWh)[512]. On a smaller scale, the same was happening in other towns such as Coimbra. The negative point of this expansion of consumption was the renaming of the tariffs as political ones. In fact, the freezing of tariffs during the war, and the very small adjustments from the government until 1968 made household prices unsustainable in the very short run. Not only were average household tariffs in Oporto much lower than industrial prices (Table 4.15) during the whole period, they were unsustainable from the point of view of the distributor. Revenues were not covering needs for

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[510] Ljungberg (1990) for Swedish prices.

[511] Teives (2006).

[512] SMEGP, *Relatório*...1950.

financing the increasing distribution costs. After 1951, the regressive tariffs were extended to other regions, just when hydropower practically supplied almost all the important towns in Portugal. In Lisbon, consumption did not reach the same intensity as in Oporto because of higher tariff for more intensive uses and the use of town gas for cooking. If the new tariffs in Lisbon were not unsustainable from a distribution point of view, households once again benefited in relation to industry. The Lisbon tariff reduction of 1951 allocated much more discounts to households than to industrials. It was a strange policy, more based on satisfying the masses than on a coherent industrial policy. As table 4.16 shows, Portugal had one of the highest incentives for household consumption in Europe and one of the lowest household-industry differences. It followed a policy close to the UK government which did not have a special aim to benefit industrial consumers[513]. It drastically diverged from the 1930s Swedish policy, who sustained the larger intensive branches of the economy at the expense of households, with a household-industrial ratio of 7 to 9. Although the Swedish policy was never in the mind of Ferreira Dias, the tariff discounts for household consumers in Lisbon, Oporto and other major towns were so large compared to industry that even he, now away from the government, would strongly criticize the scale of prices of the regressive tariffs. In fact, it was not in his initial plans:

> (…) having industrial companies and small distributors paying dearly for their energy usage, while Oporto household consumers cook steaks at the price of 0.24 Escudos, surely the lowest price in all of Europe[514].

Incentives apart, urban electrification was not only important for welfare reasons, it created a demand that was very limited until now for consumer durables such as irons, cookers, heaters and other electrical appliances. However, it is ironical to observe that even with large incentives for urban household electrification, electricity also failed to compete with oil in most of the household aggregates. The use of electricity for cooking and water heating was mainly an experience of war that created a model of consumption in the regions of Braga, Oporto or Coimbra. These regions continued to expand consumption in those terms, firstly due to lower electricity tariffs, secondly due to a path-dependence phenomenon[515]. In most of the other towns the great

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[513] Chick (2002).

[514] Portuguese: “(…) para evitar que se comentam a injustiça e o erro de ter a indústria, ou os pequenos distribuidores, a pagar a energia cara para que no Porto se façam bifes com energia a 24 centavos – hoje, seguramente, o preço mais barato da Europa”, Ferreira Dias (1998).

[515] The difference in regional household patterns of consumption is still visible in the present days, even if electricity is today priced at the same rate across regions.

decline in household firewood consumption was not due to the electric cooker but once again the oil. Butane gas (LPG) started to be imported and commercialized in 1938 having only an initial moderate success – 8 000 consumers by 1951. In 1954, with the installation of the cracking unit, the Portuguese refinery started the production of butane and propane and prices fell quite quickly[516]. After that, it was an immediate success among Portuguese population not only due to good advertising and distribution networks but also because it was almost comparable to town gas in use, at the same time as being less capital intensive. In the urban centers, oil quickly replaced firewood consumption. The transition from firewood to LPG in the rural areas was slower and was only initiated in the mid 1960s. It is interesting to note that along with the improvement in rural incomes,[517] this transition might be connected with the post-war forestry policy, *i.e.*, the industrialization of the forest[518]. Old wastelands and commons converted into forest for industrial uses were in many places subjected to partial restrictions of free access for household needs. By 1974, the consumers of butane gas from the main distributor company (60 to 80% of the market) numbered more than one million, meaning a coverage of at least 40% of the population, and by the end of the 1980s a LPG stove was present in about 80% of the Portuguese homes[519]. It is important to note that the electricity policy for households had very little to do with rural electrification. While most of the urban centers were electrified by 1970, electricity would only be a reality in the 1980s for most of the rural households.

4.4.3.3 The end of the autarkic dream

Ferreira Dias autarkic dream based on cheap electricity finally came to an end by the mid 1960s. The whole system was compromised. Cheap household prices were putting pressure on the distributor’s revenues, but producer prices were also too low, especially due to the expansion of electrochemicals and electro-metallurgy consumption. The system was not practicing marginal cost pricing; it was selling below cost. Distributors and producers were not able to attain the levels of auto-financing necessary to cover new investments. After a period of 15 years of seemingly inexhaustible large sums of capital invested in the hydroelectric system, capital seemed to be an important constraint again.

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[516] Teives and Bussola (2005). Teives (2006).

[517] Induced by rural exodus, mostly to abroad; emigrant remittances and increasing demand of the urban sector.

[518] The increasing demand for wood products is also pointed as one of the reasons for the decline in industrial fuelwood combustion in post-war Finland. Kunnas and Myllyntaus (2009).

[519] DGE (1989).

Due to the lack of capital and rapid expansion of consumption of inexpensive oil, the new investments were now directed mostly to fuel-oil power stations. The loan that was obtained from BIRD in 1963 in order to cover new investments in the grid imposed some conditions of auto-financing. Afterwards, the principle of auto-financing was extended to the whole grid and the prices began to increase[520]. In 1968, the new financial rules were already observable in producer and household prices (Table 4.15). The consumers that were more penalized were those with prices clearly under costs: Porto households. After 1970, with the increasing component of oil in the electricity system, electrochemical prices also increased (Table 4.15).

In sum, the model of development based on electricity and other indigenous natural resources was not continued for a long time after the relative advantages of electricity disappeared. First, as a complement to electricity, lastly as the motor of economic growth, oil became increasingly important in the energy system of the Portuguese economy. The increasing dependence on oil did not mean an immediate continuation of a perpetual disadvantage of energy prices *vis à vis* other European countries. If Portugal lacked oil, so did most European countries. The world most wanted resources had changed definitely to the periphery, to Middle Eastern Countries and to a lesser degree Latin America, and its reserves were controlled by large multinational oil companies. If Europe was practically auto-sufficient on energy by the end of World War II, it became increasingly more dependent on energy since then[521]. Now that distant developing countries were supplying the rest of the world with oil, much cheaper than coal, oil price differences between European countries were more a reflection of national refinery capacity or different taxation policies[522] than price at the origin. The model of development of the late 1960s has less to do with hydropower and import substitution than with oil and exports. After the entry into the EFTA in 1960, Portugal rediscovered its cheaper resource: labour. As the only developing country in that organization, Portugal managed to benefit from some protection of the new emerging basic industries, at the same time that a favorable market to labour intensive products opened up, especially for textiles and clothing[523]. The envisioned plans to capital-intensive industries now comprised a large refinery complex in Sines, south of the country, destined

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[520] Madureira and Bussola (2005).

[521] In 1950, Western Europe imported only 11% of their commercial energy. By 1973 energy dependence was 63%. Colitti and Baronti (1981). In Portugal energy dependence around 1950 was 83%; by 1960 was about 78% and by 1973 it increased to 87%. Nowadays, European Union imports 50% of their energy (wood included). Portugal imports 85%, see EUROSTAT.

[522] Taxes were always historically large (maybe to protect national industries).

[523] Lopes (2002).

mainly for re-exports, and a large shipyard, Lisnave, specialized in oil tanker repairs. The first of the projects would only be inaugurated around 1979, when most of the advantages had already disappeared (oil shock, loss of the colonies). The shipyard, inaugurated in 1967, largely benefited from the temporary closing of Suez[524] and the reintroduction of the old Cape route, and soon became the largest repair shipyard in the world[525]. It was one of Portugal main exports until the oil shock, only second to cork and woods[526]. It would suffer with the reopening of the Suez and the decreasing dimensions of tanker size and would decay after the oil crisis[527]. Despite the change in economic model and natural resources, one conclusion is valid for the whole period: Portugal industrialized and converged with other European countries in a period of cheap energy and strong convergence of energy prices. However, indigenous natural resources were not a sufficient condition to assure the viability of the most energy intensive industries. Despite the enormous growth in electricity and fossil fuel consumption after the 1950s it is interesting to note that during this period electricity and energy intensity differences among other European countries remained quite large at the same time. Portugal was still a low energy intensity country.

4.5 Renewable energy policies and climate change – How far can we go?

The oil shocks of 1973 and 1979 were an important turning point for the energy policies of European Countries, leading to the perception that the period of cheap energy was coming to an end. The rise in oil prices was reflected not only in the rates of economic growth of the European core, but also in oil demand. Common policies began to include energy conservation and efficiency, subsidies to conventional energies (coal), incentives for district heating, and shifts to natural gas and nuclear energy as well as R&D programmes on renewables (most of them discontinued in the 1980s)[528]. Although nuclear energy was introduced in some countries around the 1960s, most of the programs were not extended due to further declines in oil prices, but after the oil crisis most of the OECD countries had at least one nuclear plant by the 1980s

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[524] In consequence of the Arab-Israeli war.

[525] Fernandes and Oliveira (2002). Ribeiro *et al.* (1987)

[526] Fernandes and Oliveira (2002). Ribeiro *et al.* (1987)

[527] Fernandes and Oliveira (2002). Ribeiro *et al.* (1987)

[528] Colitti and Baronti (1981).

[529]. The reasons for nuclear plants instead of investments in hydropower had a lot to do with the hydro-resources being almost fully exploited. There was also a clear overcapacity in heavy industries (steel and heavy chemicals) and a structural change towards lighter branches also occurred. As mentioned in Chapter 3, oil peaked in most of the countries by 1973.

In Portugal, things were different. The oil crisis came at the same time as the transition to the democratic regime (1974), so more attention was given to political issues. Nationalization of the most capital-intensive industries (including steel, refineries and petrochemicals and the electricity sector) followed, as did an explosion in nominal and real wages[530].

In terms of energy, one good thing was that the share of hydropower in electricity production was still very high by 1973 (75%), so electricity generation costs were initially only partially affected. However, national coal reserves for electricity production were practically exhausted and most of the investments, either in the planning or in the construction stages, were energy intensive: fuel-oil thermo plants, petrochemical complexes and other heavy industries. In terms of conservation energy policies, the fact that Portugal was still a developing country with low levels of energy per capita also played a significant role. When the First Portuguese Energy Plan of the post-revolutionary period was published in 1982, the pre-1973 projects had been continued and oil consumption had grown 70%. In 1982 the share of oil in total energy consumption had increased to 66%, while the percentage of hydro in electricity production had dropped to 45%[531]. Due to increasing demand and high energy prices, imported fuels as a share of total imports rose from 6% in 1973 to more than 20% in the early 1980s[532].

From the early 1980s until 2000, the share of oil started to decrease especially due to the shifts in electricity production to include a larger component of imported coal in 1986 (diversification strategy) and natural gas by

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[529] As we have already seen nuclear power expansion had a short duration. It peaked during 1974 but, even before Chernobyl, orders were reduced because of public concerns about environmental and health issues, cost escalations, and decreasing needs for power expansion due to slow economic growth. See Colitti and Baronti (1981).

[530] Nominal wages increased about 80% in 1974 and 1975. Real wages in those two years increased almost 1/3. Mateus (1998).

[531] Spain also followed the continuation of oil-based industrialization in petrochemicals or aluminum production, becoming an indirect energy exporter, although it imported most of its fossil fuels, see Sudrià (1995).

[532] Lopes (2002), pp. 158-159. The impact of the oil crisis, aggravated by the increasing demand for energy and the substantial rise in internal wages, is considered the main cause of foreign trade imbalance, which led to monetary devaluations to keep labour intensive exports competitive, and to the intervention of the International Monetary Fund (IMF) in 1977-1979 and 1983-1985.

1997 (environmental strategy). Nuclear power was an objective of the 1982 plan, but it never became a reality due to lack of capital and demand[533]. Despite some investments in hydropower production (1 556 MW installed in 1970, 3 903 MW installed by 2000), the period witnessed such increases in electricity consumption that the hydro share declined to 45% of the power and 30% of the electricity consumption by 2000. Relative to six industrialized countries in Europe (Sweden, England, France, the Netherlands, Germany and Italy) expansion in energy consumption per capita was large, from 27% of the average of the six countries in 1973 to 63% in 2000, and energy intensity grew in inverse sense to other European countries from 4.2 MJ/$1990 in 1973 to 6.1 MJ/$1990 in 2000[534].

A new cycle of investment in indigenous and renewable energy sources was initiated by Portugal at the end of the 1990s. The reasons were somewhat different from the ones that led the state to invest in large dams at the beginning of the 1950s. Both policies had the aim of replacing fossil fuels and reducing external dependence, but, while the main reason in the 1950s was the promotion of economic growth through cheap electricity, the main aim of the 21st century renewable energy policy is to reduce the burden on the environment**.** The Portuguese environment policy is mainly the product of a common European Energy Policy to mitigate climate change. Regarding renewable energy, a European directive in 2001/77/EC established the general common target of achieving 22% renewable electricity by 2010[535]. Portugal was requested to maintain its share of renewable electricity in relation to 1997, 39%[536]. A new system of feed-in-tariffs[537] to promote renewable electricity production was established in 2001, and revised in 2007 in order to establish further incentives (except for the use of wind power which was reduced). It offers guaranteed prices for renewable electricity for a minimum of 15 years through a formula that depends on, among other things, technology and environmental avoided costs[538].

On the consumption side, favourable feed-in-tariffs, together with regional incentives to avoid local resistance,[539] seem to have put Portugal at the forefront

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[533] Direcção Geral de Energia (1982).

[534] The reasons for that divergence are mainly explored in Chapter 5.

[535] OJ L283, 27.10.2001,2001/77/EC.

[536] OJ L283, 27.10.2001,2001/77/EC.

[537] Portugal was one of the first European countries to introduce the system of feed-in-tariffs in 1988, but the support level was clearly too low to promote renewables.

[538] Avoided costs of building conventional power stations or of the CO_2 emissions saved, for example.

[539] Municipalities receive 2.5% of the profits.

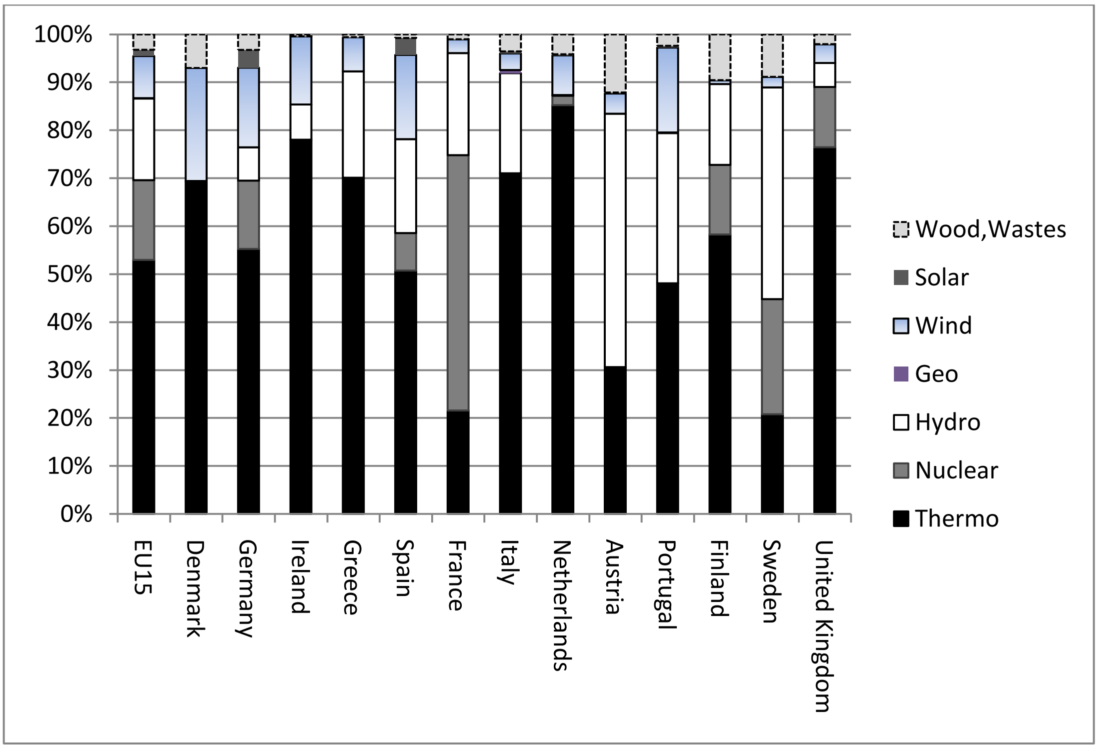
of the renewable energy revolution. Table 4.17 shows some of the outcomes of this ambitious policy.

Table 4.17 Evolution of renewable power in Portugal 1997-2010

	FIT (Eur/MWh)	MW		
	2007	**1997**	**2010**	**PNER2020***
Big Hydro (>30 MW)	0	3 783	4 234	8 600
Small Hydro (<30 MW)	75-77	434	595	200
Wind	74-75	45	3 802	8 500*
Biomass	102-104	350	466	
Waste	53-54		88	
Biogas	115-117	1	21	
Photovoltaic	310-450	0.7	111.1	1 500
Concentrated Solar Panel	267-273			
Wave	260		4.2	250
Total		**4 614**	**9 321**	

Source: DGGE (2010) and *Plano Novas Energias Renováveis*.
* includes off-shore.
FIT= Feed-in-Tariffs.

Figure 4.5 Electricity capacity by source, 2008



Source: EUROSTAT

In terms of installed power, the progress of renewable electricity, especially wind, was impressive and comparable in scale to Ferreira Dias' autarkic plans in the early 1950s. From 1997 to June 2010, power basically doubled. As a result, the present share of renewable energy in electricity capacity is one of the highest in EU15, falling only behind Austria and Sweden (Fig. 4.5).

In 13 years, Portugal's wind power has achieved a share in electricity production of about 17%, falling only behind the technological pioneer Denmark. Renewable electricity production goals were attained by 2010.

The Portuguese government plans to increase the share of renewable electricity to 60% in 2020[540]. It is a plan that follows from the new common energy policy of the European Union for 2020, which aims to increase the European share of renewables in final energy to 20% and reduce primary energy consumption and CO_2 emissions, in relation to 1990 levels, by 20%[541]. Portugal already had a share of 21% of renewables in 2005 and has been given a target of 31% in 2020, only lower than Sweden, Finland, Latvia and Austria[542]. To fulfill the goal, the country proposes to increase the share of biofuels in transportation to 10% and invest mainly in conventional hydropower, wind and solar energy[543]. Portugal has already initiated the construction of eight new large dams, aiming at doubling hydropower by 2020. These investments are probably the *Last cycle of large dams,* meaning that most of the available hydropower will be exploited after 2020[544]. Offshore wind production is also in the plans, as the viable onshore wind resources will be fully tapped in a few years´ time. Some challenges arise, however, from an increasing wind penetration in the grid. In relation to offshore resources, the nature of the Portuguese coast (deep waters) is unlikely to give the same returns as the exploitation of wind resources in the North Sea, where turbines can be put farther away from the coast, increasing the hours of wind use (the wind blows with more intensity farther from the coast)[545]. Secondly, the peripheral position of the country is an obstacle to the security of supply and gains from electricity exchange. Most of the wind power that is exported in off-peak hours is sold at marginal prices to Spain, close to zero,

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[540] Plano Novas Energias – Estratégia Nacional para a Energia (ENE2020).

[541] EC - European Commission (2010).

[542] OJ L140/16-59, 5.6.2009, 2009/28/EC Directive**.**

[543] *Plano Novas Energias – Estratégia Nacional para a Energia* (ENE2020).

[544] An expression which was used for the promotion of an international conference on the new hydropower projects, organized in Feb. 4-5 2010 and organized by FEUP. "Aproveitamentos Hidroeléctricos em Portugal – Um Novo Ciclo".

[545] Ferreira and Vieira (2010). Floating wind turbines are the most promising technological option for deep waters. The first offshore floating turbine (2 MW) is under construction in Póvoa do Varzim, in the North of the country, and will be tested in 2011.

while the country continues to import electricity (mostly nuclear) from Spain and France during peak hours at higher prices[546]**.** One idea of making wind-power penetration viable is then to construct dams with reverse pumping so that the wind can pump the water at night, allowing full advantage to be taken of the fact that the wind blows mostly at night, when there is less demand[547]. Another idea is to use the renewable features of the Portuguese electric system to allow the charging of a future fleet of electric cars, also in off-peak time. The program MOBI-E was launched in 2008 and more than 1350 battery chargers were to be installed by July 2011 in several cities of the country[548]. In December 2010, Nissan Leaf became the first electric car to be sold in the Portuguese market. As in many countries, there are tax deductions to make the price of the car more attractive to consumers, but it is still significantly more expensive than an internal combustion equivalent. The goal is to replace 10% of fossil fuel cars with electric ones around 2020[549]. While there are major doubts that Portuguese consumers will switch that quickly to electric cars (low income effect, absence of garages to charge the vehicles) it is undeniable that policy makers are trying to build a favourable institutional setting for the marketing of those cars.

Portugal has received the praise of international organizations and the international press for its bold policy on renewable electricity[550]. However, if the path to a carbon-zero society is a desirable goal in environmental terms, the issue of policy affecting electricity prices should nevertheless be addressed. In economic terms, the feed-in tariffs offered to most renewable electricity are generous and imply a financial cost, which can be large depending on the price of fossil fuels. In the last decade, the feed-in-tariffs have cost between 3% and 61% more than the fossil fuel reference price electricity. The lowest differential was during the oil crisis of 2008, but renewable electricity was already 32% more expensive in 2009[551].

At the moment, the costs are mostly passed on to household consumers and to tariff deficits that delay the increase of electricity prices for some years (case of 2008, for instance). For the consumer, the breakdown of the household tariff has become increasingly difficult to understand. The monthly bill is divided into three components: cost of access to the grid, production costs, and general cost of economic interest where the subsidies to renewables and tariff deficits, among

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[546] Portugal is a net importer of electric energy. From 2004 to 2008, imports of electricity represented 18% of consumption.

[547] Plano Novas Energias – Estratégia Nacional para a Energia (ENE2020).

[548] See MOBI.E; www.mobie.pt.

[549] Plano Novas Energias Renováveis.

[550] IEA (2009); Rosenthal (2010, Aug.9); Tariq (2010, Sep. 19).

[551] Ferreira (2010, May 5).

other components, are included[552]. This last item, the general cost of economic interest, represents 42% of the electricity bill and almost 40% of that is due to the extra-costs of feed-in-tariffs[553]. Some Portuguese households are starting to question the electricity bill, and many are blaming the feed-in-tariffs for the increase in their monthly payments. This feeling led to a recent online petition from DECO, the Portuguese consumer association, which asked for an end to the extra cost in the electricity bill[554]. It was able to collect about 170 000 signatures in two weeks, something that cannot be considered irrelevant for a country with low instances of civic participation. Even if Portuguese households still benefit from a low electricity price when compared with the European Union average, price increases can be significant in a scenario of low economic growth and loss of real income[555]. If the renewable energy policy is to be continued, it will have to become more transparent in the eyes of the consumer; otherwise it faces the risk of strong opposition.

After ten years of feed-in tariffs, the impact on costs of production of a kWh is starting to be noticeable, as Fig 4.6 shows. The difference between conventional electricity prices (large hydro + fossil fuels) and renewable electricity prices has actually increased, in order to promote the massive deployment of wind power. In 2009, the new wind-power contracts were set at 74 €/MWh, but average feed-in-tariffs were still paid at 97 €/MWh. The difference between conventional electricity and renewable electricity generation costs was more than double. As the share of subsidized electricity is increasing (right now almost 30%), electricity average generation costs are already substantially larger than conventional electricity costs.

While there is a general belief that additional wind-power capacity will reduce feed-in-tariffs in the future and the recovery of the world economy will increase conventional electricity prices, there is still a lot of uncertainty if this energy policy is the right path to follow. What will the impact of renewables on electricity prices be by 2020? Different compliance targets for renewables among member states can strongly affect competition in electricity prices.

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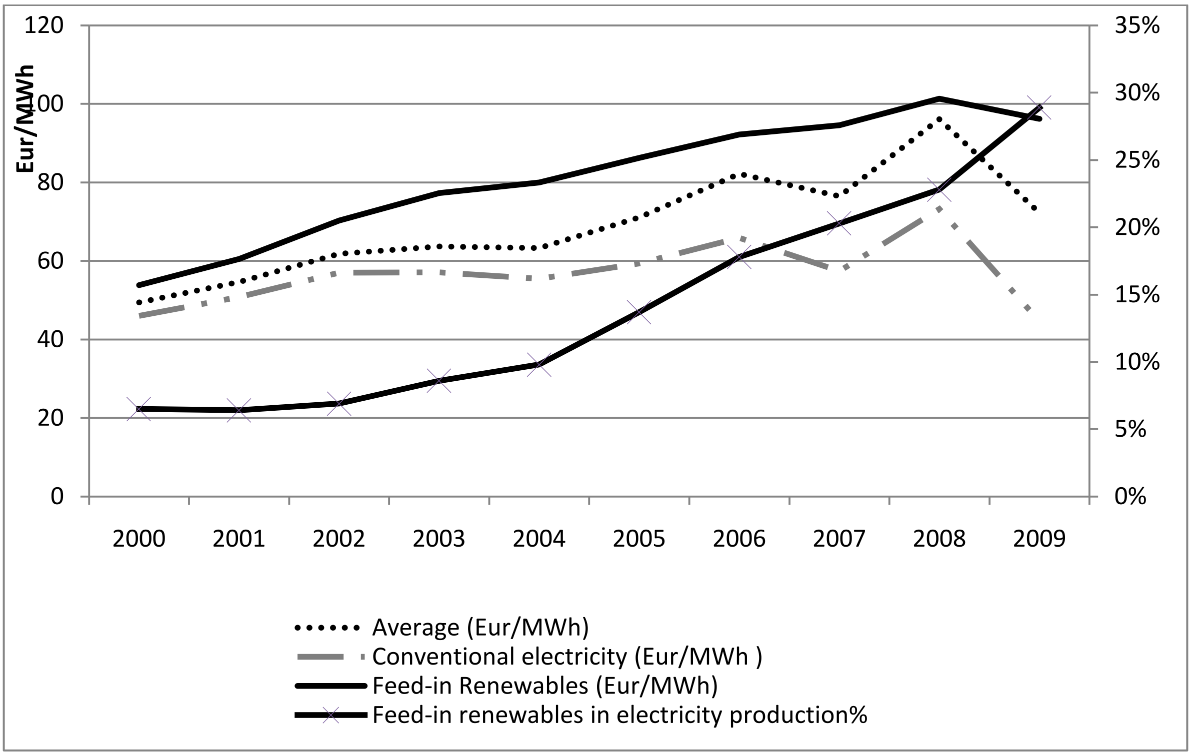
[552] Ferreira (2010, May 5)

[553] Ferreira (2010, May5)

[554] DECO (2010). Early in the year, a group of 33 academics, economists, engineers and former ministers severely criticized the renewable energy policy in the national press. See “Manifesto por uma nova política energética em Portugal”, *Expresso*, 31/03/2010 .

[555] Data from EUROSTAT (2010) shows that electricity prices were still below the EU-27 average by 2010, excluding taxes: 0.1093 EUR/ kWh for household consumers (0.1223 EUR/kWh for EU-27) and 0.0896 EUR/kWh for industrial consumers (0.0918 EUR/kWh for EU-27).

Figure 4.6 Renewable electricity and conventional generation electricity costs



Source: ERSE, 2010

A sustainable energy policy that does not harm Portuguese economic growth should be an important goal. From 1973 to the present, the Portuguese economy has converged only 10% with the wealthy nations of the world, although it has converged much more in many social and consumption indicators, including energy consumption, education, health and highway kilometres per capita[556]. Most of the economic growth convergence was during the first years of European Union membership, i.e., between 1986 and 1992, a period of cheap oil and significant EU subsidies. A strong currency and a low interest rate in the 1990s boosted consumption, but also caused a decline of competition in labour-intensive exports, the previous model of Portuguese economic growth. Economic growth has been practically zero during the last decade, long-term unemployment has risen and the economy is struggling to attract Foreign Direct Investment (FDI)[557]. While high energy prices might not have been the reason for the Portuguese divergence path, strong renewable subsidies need to be measured against the expected benefits.

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[556] Amaral (2010).
[557] Amaral (2010).

Table 4.18 Renewable electricity production 1997-2010

	GWh			
	1997	**2002**	**2005**	**Jun. 2010**
Big Hydro (>30 MW)	12 537	6 896	4 454	13 241
Small Hydro (<30 MW)	638	1 200	546	1 799
Wind	38	341	1 741	9 008
Biomass	1 036	1 208	1 350	1 952
Waste		518	545	485
Biogas		2.5	31	87
Photovoltaic		1.8	3.8	189.5
Concentrated Solar Panel				
Wave				
Total	**14 099**	**10 167**	**8 671**	**26 761**
Index of Rainfall (1=average year)	1.22	0.623	0.336	1.024
Total adjusted for rainfall		15066	18552	26409
% Renewables EProduction (Real)	39	21.8	16.8	49.6
% Renewables EP (Adjusted for rainfall)	39	32.3	35.9	48.9

Source: DGGE (2010)

Sometimes, being an early adopter can create opportunities for future economic growth. While it is too soon to measure the impacts of this energy policy on future economic growth, the fact that Portugal was early in adopting renewable electricity does not seem to have created many opportunities to ensure a strong renewable cluster or expand employment. R&D expenditure on new energy technologies is the lowest of all OECD countries. This has been pointed out by IEA as a major flaw in Portuguese energy policy.[558] Portuguese expansion of wind, solar and other renewable sources is strongly dependent on international technology, unlike that of Germany, Denmark and Spain, with their pioneering companies (ENERCOM, VESTAS, GAMESA). The turbine components that the domestic wind sector produces rely on international technology and are difficult to export due to their heaviness. So the early mover advantages are more connected with the management of a smart grid and project installation than with a strong development block associated with renewable energy. On the one hand, EDP Renováveis has won some projects for renewable systems installation and is one of the major players in Europe; on the other hand there are few spurring effects in the national economy. Therefore, it is reasonable to ask if Portugal should set different types of incentives in order not to compromise electricity prices too much. In a scenario of uncertainty about

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[558] IEA (2009).

fossil fuel prices and environmental pressures, it is hard to be critical of a renewable trajectory, but the economic efficiency of Portuguese energy policy can and should be discussed. Some studies show that feed-in-tariffs can be substantially reduced without harming the financial health of renewable companies[559].

Despite all efforts to increase the renewable share of electricity production to 39% by 2010, the fact is that along the path, and due to large irregularities in Portuguese rainfall, increments in renewable power capacity were not reflected in production, as Table 4.18 shows.

Portugal started from a position of 39% share of renewables in electricity production in 1997 (a humid year), but the extremely dry years in 2002 and 2005 lowered renewable contribution to 22% and 16%. Only a return to a good hydrological year in 2009-2010 enabled Portuguese energy policy to fully attain the goals proposed in the European Directive. It seems then that the goal of 60% of renewable electricity consumption by 2020 is extremely uncertain, especially since most of the capacity increases will be directed to new large dams. Also, the 31% of renewable energy in final consumption seems overly ambitious, given the fact that household transition to modern fuels will be practically over by 2020. While the results of household inquiries, which are being conducted during this year by INE, are still not available, they will probably show that household biomass consumption per capita has fallen significantly since 2000, as a result of urbanization trends and penetration of natural gas. Not even with a large renewable power capacity does Portugal have a considerable lead in environmental outcomes related to electricity production. IEA statistics for CO_2 emissions per unit of electricity and heat production show that Portugal is below the average for environmental efficiency in OECD Europe (see Figure 4.7). This suggests not only climatic differences (absence of district heating due to lower heating requirements), but also the role of nuclear power in reducing CO_2 emissions, especially evident in countries such as Sweden and France.

Some propose a serious debate on the introduction of nuclear power in Portugal[560]. The proponents argue that renewable electricity will be either too expensive or too irregular to make Portugal a carbon-free electricity country, and that natural gas prices are now indexed to the oil market, putting national security at stake[561]. Nuclear power has the advantages of being CO_2 free and probably cheaper than any fossil fuel electricity up to 2020, if we consider

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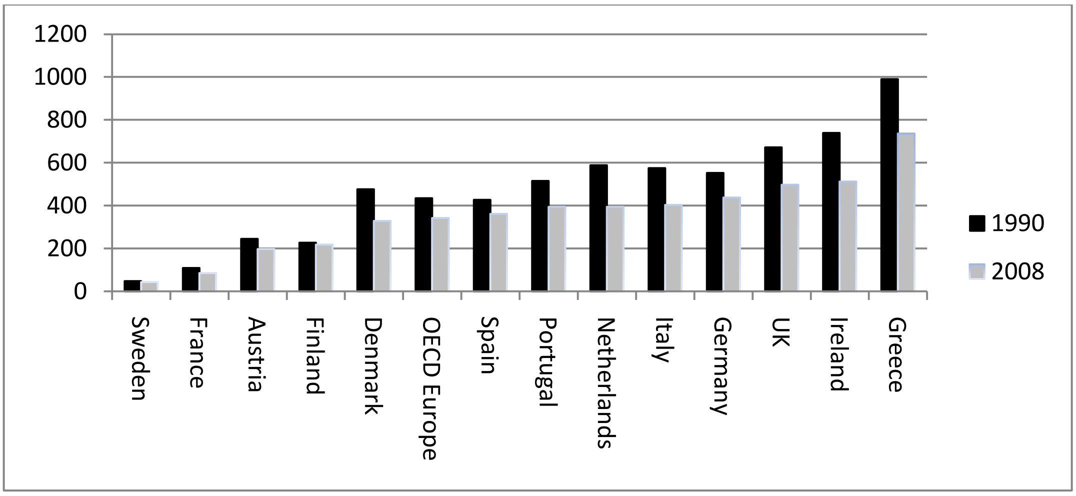
[559] Cardoso (2007); Amorim *et al*. (2010).

[560] Amaral (2009), Rodrigues and Azevedo (2006).

[561] Amaral (2009), Barros (2006).

carbon taxes at the level of 30 USD/ton and low discount rates[562]. The proponents argue that a nuclear power station of 1 600 MW could satisfy ¼ of Portuguese electricity needs by 2020[563]. But the challenges of a nuclear option are also huge. Even if the political will exists and public acceptance is obtained, there are also problems such as the risk of project delay and excessive costs, the lack of economies of scale (some argue that Portugal does not have enough scale for nuclear power) and lack of technical capabilities (no experience in nuclear projects)[564].

Figure 4.7 CO_2 emissions per unit of heat and electricity produced gCO_2/kWh



Source: IEA (2010a).

Whatever the path chosen by Portugal in the field of electricity production it will not be an easy one. At the current feed-in prices, the sole bet in carbon-free electricity runs the risk of being economically unsustainable in the future, while not solving the problems of dependence on fossil fuels at peak times and in dry seasons. But the nuclear option also seems a risky one given the lack of experience in such large-scale projects. Can the two alternatives complement each other? Or will the bet on renewable electricity also lock out the nuclear option for the future?[565] Does nuclear power have advantages over wind power in a future charging of a fleet of electric batteries?

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[562] IEA /NEA (2010). For high discount rates (10%) natural gas and coal become more attractive.

[563] The last proposal for the construction of a nuclear power central was made in 2005, see Barros, P. (2006).

[564] See Rodrigues and Azevedo (2006) for a discussion of the advantages and disadvantages of the introduction of nuclear power in Portugal.

[565] The non-complementarity between renewable energy and nuclear power has been raised by Peças Lopes (2008), for example. He argues that there is no capacity to integrate a nuclear power utility in

Lastly, electricity is not all, but only 25% of Portuguese final energy consumption. Even with a doubling of renewable power or the "help" of a sluggish economic growth, Portugal may fail to reach the Kyoto targets for 2010-2012. Portugal comes off worse in relation to many European Countries with apparently more stringent targets[566].

This suggests that a diversification of the energy mix might not be the only way, but should be complemented with improvements in energy efficiency. One clear problem is the poor insulation of buildings. Adequate insulation in the winter could save a significant amount of energy without the need to suffer from thermal discomfort. Recent policies point in that direction, such as new legislation in accordance with European Union directives, which requires new buildings to be energy certified [567]. Such measures will increase thermal comfort and avoid future emissions, but will not significantly decline present household emissions, which are still quite low by European standards. In fact, it is estimated that about 1/2 of the Portuguese households suffer from fuel poverty in the sense that they are unable to keep their houses warm enough without spending more than 10% of their monthly income on energy[568].

A second clear problem is transportation. Assuming that the electric car is not going to be around soon, the transportation sector needs action. The rise of personal incomes and strong investments in road infrastructure have led to an increasing number of passenger cars, from probably the lowest per 1000 inhabitants in Western Europe in 1970 to currently being only slightly behind the average for the European Union [569]. Recent investments in public transportation, especially in the urban centers, have not been able to significantly halt the growth of personal transportation. In relation to the European Union, the largest difference is in railway transportation. For each

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the Portuguese electric system given the decision to rely on renewable energy, and that nuclear power is not an interesting option for Portugal, either technically or economically, at least until 2030.

[566] See Chapter 3.

[567] See ADENE (2009), for a description of the new energy efficiency regulations for services and residential buildings. New residential buildings are obliged to have an energy efficiency label of A to B- in a scale of A (high efficiency) to G (poor efficiency). The legislation also obliges households to use solar collectors for hot water if the conditions are favourable.

[568] Healy (2004), pp. 192-193. Portugal has the highest rate of fuel poverty in the European Union according to the author. A heating paradox exists in all of southern Europe. Despite having a milder climate, southern European countries are the ones with the higher rates of fuel poverty. Southern Europeans are also the most prone to die due to cold-related diseases during the winter months. Portugal has an excess mortality of 28% in winter months, the highest in the Healy sample.

[569] In 1973 Portugal had only an average of 86 cars per 1000 inhabitants. Italy, the Netherlands, Sweden, the UK, France and Germany had an average of 220-300 passenger cars per 1000 people. See Mitchell (2003). EUROSTAT figures for 2006 give an average of 405 passenger cars per 1000 people in Portugal against an average of 466 passenger cars in EU-27 and 506 in EU-15.

euro invested in the railway sector, 3.3 euros have been invested in the road sector in the last 20 years. As a result, the sector failed to modernize, regional lines were closed, and railways lost 43% of their passengers between 1990 and 2008. In contrast, railway transportation increased during this time in all the other European countries: 30% in France or the Netherlands, 50% in the UK, and about 157% in Spain[570].

4.6 Conclusions

In a time when industrialization could only proceed with the aid of cheap energy, Portuguese natural endowments were very limited. The lack of development and low intensities of the industrial structure can be in part explained by the costly nature of energy resources.

During the First Industrial Revolution, Portugal missed out on most of the advantages of steam. With end-use coal prices clearly above coal-endowed countries, water-power or wood were only poor alternatives to inland regions where coal arrived at exorbitant prices. Unlike Scandinavian countries, water and wood did not make a difference. Despite the high proportion of wood in the energy system, any resemblance to any of those countries is pure speculation. In Portugal wood was mostly traditional, a second best choice. It could never sustain the needs of industrialization. The most salient aspect of the First Industrial Revolution is that, with poor coal and iron reserves, Portugal was unable to emulate European leaders´ economic growth based on iron and steel. That might (or not) have brought some multiplier effects to the rest of the economy, especially through supply of materials to railway construction efforts or to machinery-making or even to shipbuilding. Instead, relative high energy to labor costs directed Portuguese industry to a labor-intensive type of industrialization, which was hardly successful as a model of development at that time. Only products based in indigenous natural resources such as canned fish and cork were able to find a regular export market. The main problem of the Portuguese manufacturers was that a major part of the raw materials used by the industry was imported. Any advantage in labor costs did not normally compensate for the lower productivity of the labor force which was due to both lack of human and physical capital. I would leave to others to discuss weather another path could or not have been pursued with an effort to reduce illiteracy and promote education.

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[570] Cipriano (2011, Feb. 2).

During the Second Industrial Revolution Portugal also missed on most of the advantages of electricity. The idea that coal-poor countries had an opportunity to leapfrog cannot be applied to Portugal, despite its hydro resources. Production was mainly thermo and the difference in energy costs in relation to coal-endowed countries was maintained; electrification was poor. Why were hydro-resources unexploited during this time? The main argument is that due to the needs of water regulation and the absence of smaller-size resources, the full exploitation of hydro-resources required large amounts of capital as well as the guarantee of demand. I contend that a process of path-dependence from the First to the Second Industrial Revolution implied that neither of these elements (capital and demand) was present to guarantee the viability of hydro-electricity. The labor-intensive path chosen during the First Industrial Revolution implied low levels of energy demand and prevented capital accumulation. There was neither capital to attract demand nor demand to attract capital. Thermo-power stations were more adaptable to the small size of demand and had less capital requirements. It was an understandable choice, but created a vicious circle of high energy prices and labour intensive industrialization, or at worst – poor industrialization.

It seems that it was almost chance that provided Portugal with the capital to pursue industrialization. The accumulation of large gold reserves during the war allowed vast funds for a State-oriented industrialization based on hydropower and other indigenous natural resources. But if hydropower reduced energy dependence and acted in a first period as a catalyst for the expansion of industrial needs, it was soon obvious that it could not sustain *per se* the most energy intensive industries. Due to the limitation of natural resources and the emergence of a cheap high quality energy carrier –oil, electricity failed to be a sound alternative for the industries that the state sought to promote most. It was soon evident that the Scandinavian type of industrialization based on cheap electricity was not sustainable in the long-run as most of the intensive uses only survived due to subsidized prices. The fact that the leadership of hydropower was so soon questioned did not stop Portugal from industrializing and converging with other European countries precisely during the period when energy was finally cheap. Many countries that did succeed in catching up in this period were poorly endowed with natural resources. The fact that oil was such an important element (see for example the South Asian type of industrialization) reinforces the notion that a strong converge in energy prices was probably needed to democratize industrialization.

The last decade of the Portuguese energy system has been following a common European Energy Policy that aims to increase the share of renewable energy in Europe in order to mitigate climate change. The energy policy goals are aimed at attaining a renewable share of 60% in electricity consumption and 31% in final energy by 2020. This energy policy is one of the most ambitious in Europe Union, especially for a country that has the more economical renewable resources already fully exploited. If the path for a carbon-zero society is a desirable goal in environmental terms, the questions on how this policy might restrain or not economic growth should nevertheless be addressed. Different compliance goals for different state members can result in an excessive energy bill for only some at the expense of others and losses in competitiveness. Portuguese economic growth has been practically zero during the last decade. The general idea is that the economy is sick and faces innumerous structural problems related, among other things, with a past model of development based in low wages that is no longer valid. With difficulty in attracting foreign investment and facing structural problems in the traditional export sector, strong subsidies to renewables need also to be measured against the benefits that are creating. And if the environmental benefits are noteworthy, it seems that the leadership in renewable consumption is not fully accompanied by job creation. Nor there is a strong development of domestic renewable technologies that would allow Portugal to later reap the benefits from a considerable investment in technologies that are still uneconomical in relation to conventional energy.

Even with the “help” of a lost decade and strong investments in renewable energy, Portugal can fail to comply with the climate target of a 27% increase in CO_2 emissions by 2010-2012. This suggests that a diversification of the energy mix might not be the only way, but should be complemented with improvements in energy efficiency and measures of conservation.

The challenge seems huge to Portuguese economy. Most of the solutions that can guarantee a cleaner future are solutions that are capital intensive. For a country with a high public debt and negative growth some of these projects are at a high risk to become financial unsustainable.

Chapter 5

Energy intensity and the service transition[571]

5.1 Introduction

Currently, strong concerns about the energy basis for our economic welfare in society exist due to the risks of global warming and potentially increasing costs of energy production. Thus, there is a hope that future energy demands will be less than in the past. One possible solution that could bring about this less energy-intensive future, at least in theory, is the transition to a service economy, because service production is generally less energy-demanding than industrial production in relation to the value that is created.

It is beyond dispute that employment in the service sector has increased drastically over the last several decades and that services make up the lion's share of GDP these days. However, this trend bears little resemblance to what happens in actual production. Kander[572] raised the concern that the transition to a service economy was merely an illusion when it comes to what matters for energy: the real production structure. Kander's analysis confirmed this for Sweden's service economy production. Data of value added at the four-sector level (industry, agriculture, services and transport) were used to demonstrate that the real share of the service sector did not grow in the long run. Further, the share for transports grew slightly, whereas the manufacturing sector share declined.

This chapter expands the analysis to our set of countries. The aim is, first, to explore how the share of real service sector production develops over time and, second, to determine to which degree any decline of energy intensity can be attributed to a (possible) service transition. For that, we use a decomposition

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[571] With Astrid Kander. The bulk of this chapter is identical to the one published in *Ecological Economics, 70 (2),* 271-282, with the title "The modest environmental relief resulting from a transition to the Service Economy". The present version excludes some redundant information which was presented in the previous chapters, a Portuguese contextualization (see section 5.7), and some minor revisions.

[572] Kander (2005).

method, which separates energy intensity changes into structural changes (changes between sectors) and technological changes (changes within sectors). The analysis is mainly based in our dataset, but is subsequently widened by including some of the giant emerging economies: India, Brazil and Mexico. This expansion is motivated because of the widespread concern that developing countries today are taking over the role that England played during the first industrial revolution of being the "factory of the world". Thus, any transition to a service economy in the developed world may be due to a new division of labour on the global scale, accompanied by developing countries producing energy-intensive exports for the developed world. As Hermele says, "*while we live in the service economy our industrial goods are produced elsewhere*"[573]. Because global warming is a truly global phenomenon, as the atmosphere knows no national borders, there are no system gains from a service transition if this logically cannot be generalised over the globe. We will not be able to cover the trade issue in any depth here, but will look into the economic structures of the emerging economies and their energy intensity paths to see if we can find indications that they are being used as the new factories of the world.

5.2 Previous research

Kander used the concept of Baumol's cost disease to explain why both employment and the share of GDP in current prices have grown in Sweden since the 1970s[574], whereas the share of real service production has not grown. Furthermore, Kander discussed the environmental implications of these findings on energy intensity (energy/GDP). Baumol used a simple two-sector model of the economy that included the technically progressive sector (industry) and the stagnant sector (services)[575]. In the technically progressive sector, labour time is a means to achieve an end, so production can be rationalised by equipping workers with timesaving machines. In the stagnant sector, human time is often an indispensable part of the product itself, and labour productivity cannot rise as fast as in the manufacturing sector. Productivity gains in the progressive sector normally lead to an increase in industrial wages and, consequently, service workers will also demand higher salaries even though their productivity has not risen to the same degree. The result is higher costs for service production relative to manufacturing production. The higher costs in service production will

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[573] Hermele (2002).
[574] Kander (2005).
[575] Baumol (1967).

be passed on to consumers, and prices of services will tend to increase compared to manufactured goods. There is a "cost disease" in the service sector, and if people continue to buy services in roughly the same relative amounts as they buy manufactured goods, despite the relatively higher costs, employment will logically have to shift over gradually from manufacturing to services. Thus, the service sector will employ an increasing share of the labour force and, over time, services will become more expensive than industrial products. The increased employment, together with the increasing prices, creates an illusion that service production increased its share of GDP in recent decades more than it actually did. This fact becomes obvious from the evolution of the real production structure, which did not exhibit any growth of services, at least not in the Swedish economy[576] .

Ever since William Baumol wrote his stimulating 1967 article, the accuracy of his analysis regarding the stagnant nature of service production has been discussed. The doomsday prediction inferred from it was that overall productivity and growth rates would slow down substantially in the post-industrial societies. It is now widely acknowledged that not all services lag behind manufacturing in labour productivity; it is only those services that have human time as an indispensable ingredient, what we call personal services, that, by necessity, lag. In reality, the service sector consists of a diverse mixture of progressive and stagnant elements, so the generalisation that services are stagnant and manufacturing industries are progressive clearly is too rough[577]. Broadberry points out that certain market services have had high productivity increases, and what determines the level of productivity over the long run is the "industrialisation" of services, which involves both producer services (services provided to business) and the provision of some consumer services in a more mass-market fashion[578]. Large productivity increases have occurred, especially in the areas of transport and telecommunications, wholesale and retail distribution, and banking and finance. Van Ark and Piatkowski[579] compare the importance of ICT capital for productivity in manufacturing industries in the EU15 and former communist countries of East Europe. They find that ICT capital contributes decisively to labour productivity, which brings convergence. Still, even with this industrialisation of services, a large fraction of the sector consists of personal services, such as health care, education, child care, etc., so

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[576] Kander (2005).

[577] Baumol *et al.* (1985).

[578] Broadberry (2006).

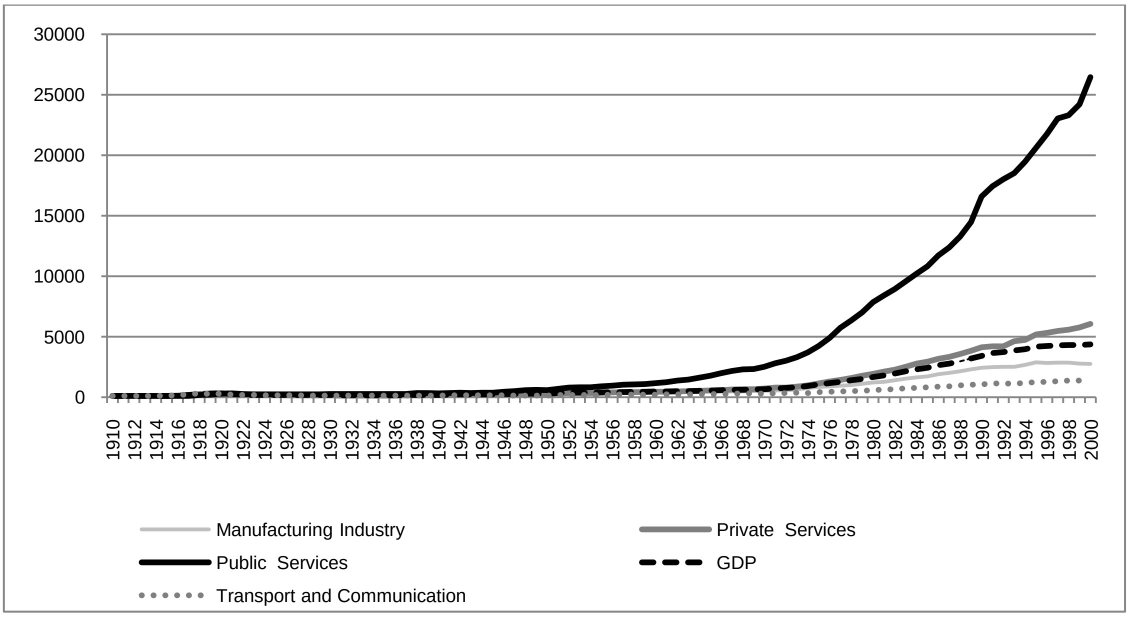
[579] Van Ark and Piatkowski (2004).

there is normally some difference between the productivity development of the service sector and that of the manufacturing sector.

All sensible researchers use sector values in constant prices, as opposed to current prices, when they calculate sectoral productivity. This is done to account for price inflation within the sector, which has nothing to do with actual productivity. For some reason, scholars who calculate the impacts of structural shifts on energy intensity do not always use this method correctly and consequently produce skewed results, as seen in Figure 5.1, which shows the long term price development (price deflators) for some main sectors of the Swedish economy, as well as GDP.

The price for public and private services rise more than the price of GDP does, whereas transport and communication are, on average, more technically progressive than GDP and even industry. Price deflators, such as the ones in Figure 5.1, are used in national accounts to recalculate values in current prices to constant prices to measure the sectoral productivity development. The simple procedure for converting numbers in current values into real production is to divide the values in current prices by the proper sector price deflator. Naturally, dividing the values in current prices with such different price deflators, as we do in Figure 5.1, means that sector shares in current prices and in constant prices will differ, as will their growth rates.

Figure 5.1 Price deflators for sectors and GDP in Sweden, 1910/12=100.



Source: Krantz and Schön (2007).

The more rapid increase of service prices over other prices, as shown in Figure 5.1, is an illustration of what Baumol in 1967 called the cost disease of services. Much discussion these days is devoted to the topic of proper price deflators and whether real service production is underrated due to the way we measure productivity in services, especially in public services, where most often a zero productivity increase is assumed. It is not the intention of this paper to engage in discussions of the quality of price deflators. If services were measured differently, taking better account of their productivity increase, then GDP would have grown faster, and energy intensity would have declined more, some of which would be explained by the service transition. However, that reality is in another world and far from our current situation. In this paper, we confine our argument and investigation to what impact the transition to the service economy has the way it is measured in national accounts today.

Researchers sometimes overlook these different price developments for sectors. For instance, Hamilton and Turton[580] find that energy intensity decline has taken place mainly in services and industry in the United States and within services in the European Union. Close scrutiny reveals that the value added by the sectors has been calculated in current prices, which exaggerates the decline in the service sector and underestimates it in industry. The results are as misleading as if energy/GDP was calculated based on current prices, which would show an immense decline over time due to inflation. Schäfer also uses GDP shares in current prices when he discusses structural change in energy use[581]. He divides the world into 11 regions and finds that for the period from 1971 to 1998, structural changes in the economy are accompanied with energy shifts. When economies move from agricultural to industrial, there is a shift in the final energy use from the former to the latter. More surprisingly, he also finds that the shift to the service sector is accompanied by a shift in final energy use. There are two reasons for this finding in Schäfer's study, and both of them have to do with unconventional methods. One shortcoming is that he uses shares of GDP in current prices to calculate energy intensity, a procedure that tends to overrate the value of the service sector over time, and thus underreports the values for service energy intensity in 1998. The other shortcoming is that the statistics he uses (International Energy Agency) do not enable any separation of energy for commercial transport (which constitutes part of GDP and should be allocated to services) and energy for household cars (this is final energy use, which should not be allocated to the service sector). Instead, he combines all this

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[580] Hamilton and Turton (2002).

[581] Schäfer (2005).

energy into the service sector. Thereby, levels of energy intensity in services are inflated, perhaps equal to those of the manufacturing industry, which means that if the energy for the household car fleet increases more than service production in general, the overestimation of service sector energy use will grow over time. These flaws in his method distort the results of energy intensity of the service sector in different directions, but mean that the service sector becomes “guilty” of far more energy use than it really is, and therefore there is no environmental relief from the transition to the service economy in his study. Although such a pessimistic conclusion is fairly accurate, as we will see later on in this paper, his results have not been obtained in a convincing manner.

5.3 Theory and hypothesis

Up until the 1980s, energy was believed to have an ironhand relationship with GDP and there was no talk of decoupling, or any growing gap between the energy and GDP curves over time. The couple was theorised to stick together over time. The view changed drastically in 1990 with an article in *Scientific American* by Reddy and Goldemberg that introduced long run estimates of energy intensity (energy/GDP) for several countries, suggesting a bell-shaped curve, or an inverted U-curve. According to this stylised graph, latecomers in the development process benefit from technical transference from their predecessors, so they peak at a lower point. This article served as a major input to what later became known as the environmental Kuznets curve. The idea behind the inverted U-curve is clearly related to structural change. During the industrialisation phase, energy intensity would increase, and after a peak, the curve would turn downwards, demonstrating the effect from the transition to a service economy**.** The idea that industrial societies would eventually see an end was presented in Marxist theory, where it was viewed in the negative terms of a collapse. However, Fourastié[582] introduced the more modern and positive view that declining industrial production would pave the way for a new kind of society based on increased service production.

In 1993, Panayotou[583] labelled the inverted U-curve in environmental relations as Environmental Kuznets Curve (EKC), after the famous Kuznets curve for income and equality relations[584]. He explicitly proposed that the

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[582] Fourastié (1949).

[583] Panayotou (1993).

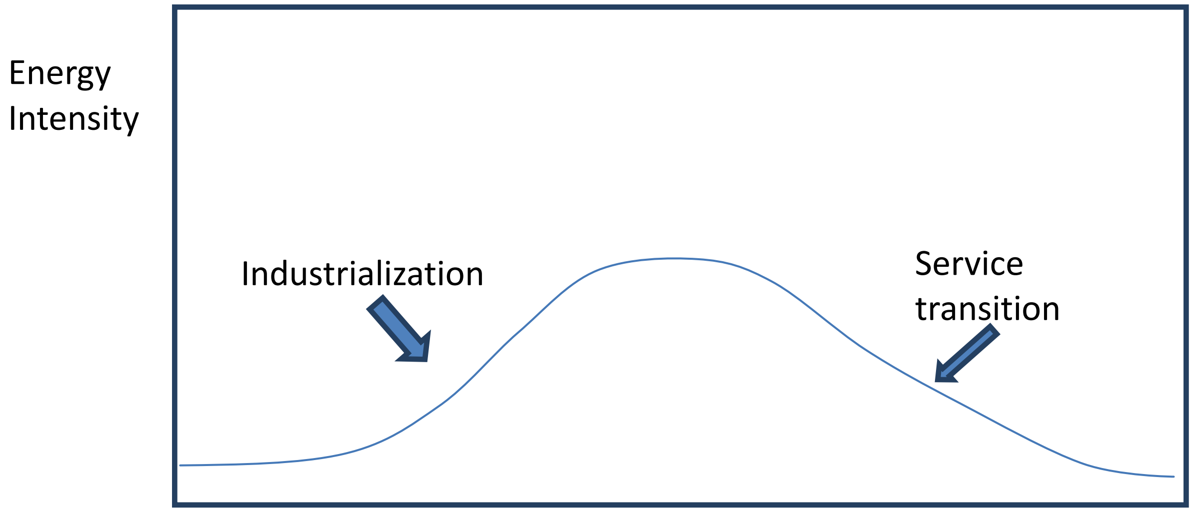
[584] Kuznets (1955).

transition to a service economy was one of the main reasons for the declining environmental impact of economic growth (see Figure 5.2).

The idea is quite intuitive; as a country industrialises, it uses more energy and machines, and when it de-industrialises, the process is reversed, resulting in less energy use. Because of its intuitive character, this idea has not met many objections, at least until Kander suggested that it was perhaps based on false beliefs of how a service transition functions[585].

This brings us to the issue of what drives a service transition and of what it consists. At the intermediate service production level (services used as inputs of firms), part of the transition is a statistical artifact, as manufacturing firms increasingly outsource some of their service production to consultancy firms[586]. Still, with the increasing complexity of goods, innovation and value creation take place more and more in the after-production stage, with companies providing maintenance services to their customers. Thus, there is reason to think that some actual increase in producer service production takes place, which is larger than the growth of manufacturing goods production per se[587].

Figure 5.2 Energy intensity and structural change



When it comes to services for final demand by households, there are two opposing forces. One demand side force is Engel's law, suggesting that when people climb up the income ladder, their basic needs, such as food and shelter, mainly produced in the primary sector (agriculture), are met first; second, they

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[585] Kander (2002); Kander (2005).
[586] Petit (1986).
[587] Perry (1990); Berggren *et al*. (2005).

meet their less pressing needs, such as refrigerators, televisions and telephones, produced in the secondary sector (manufacturing); lastly, their least pressing needs are met, such as opera visits, psychological therapy, etc. (services).[588] Another supply side force is Baumol's cost disease, which states that certain services tend to price themselves out of the market and thus stimulates the DIY (do-it-yourself) economy, where companies like IKEA have found a niche by concentrating on the technically progressive part of the process: providing flat parcels and leaving the final, time-consuming assembly to the costumers to complete. Engel's law is only applicable in one country at a specific point in time and can neither be used to infer expenditure patterns between countries, nor the consumption patterns over time for a country[589]. Simply put, when a country gets richer, this does not imply that everyone can afford to hire a cleaning lady or a gardener because the wages of these jobs follow the general income growth of the country.

Fourastié expressed these opposing forces as saturation on the demand side and technological progress on the supply side[590]. Krüger[591] places large emphasis on the theoretical insights provided by Fourastié and then draws the conclusion that "*viewed against the empirical pattern of sectoral development, these considerations imply that in the long run the changes of the demand structure dominate the supply-side forces*." It is possible to say that these researchers jumped to their conclusions, based on not paying attention to the fact that sector development looks very different when viewed as shares in current or constant prices. This possibility was addressed in 1978 by Gerschuny, who questioned the view that modern society is entering a post-industrial phase when it comes to actual production, but from the expenditure side of individuals[592].

Theoretical discussions give reasons to be cautious in expecting too grand of a service transition in actual production terms. We therefore propose the following double hypotheses, which will be examined in our paper:

1) A service transition means that services have increased their share of total employment and their share of GDP in current prices (see Figure 5.3).

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[588] After the German statistician Ernst Engel (1821-1896), not to be confused with Friedrich Engels, who collaborated with Marx.
[589] Ingelstam (1997).
[590] Fourastié (1949).
[591] Krüger (2008).
[592] Gerschuny (1978).

2) A service transition does not mean that services have increased their share of GDP in constant prices (or not as much as employment or shares in current prices) (see Figure 5.4).

Figure 5.3 The transition in employment and current prices

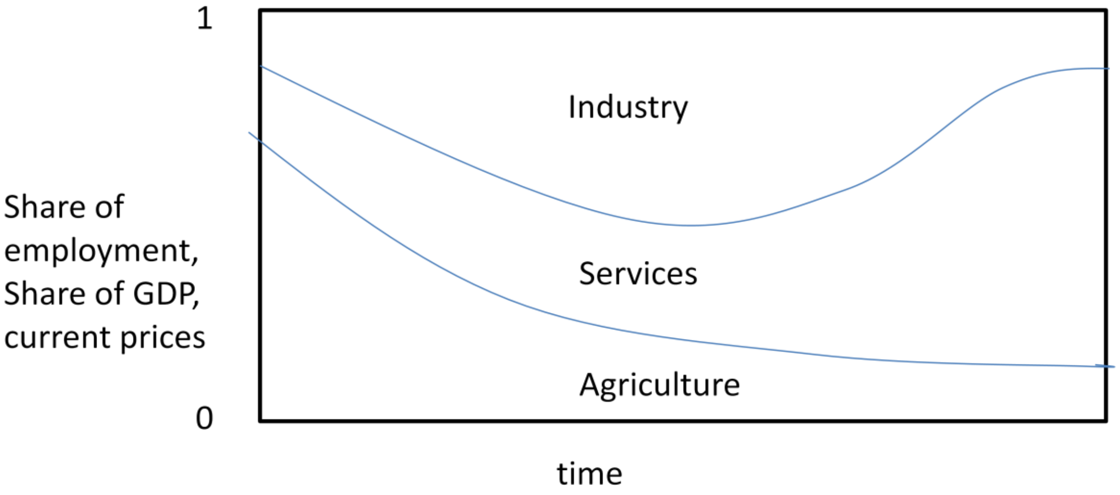
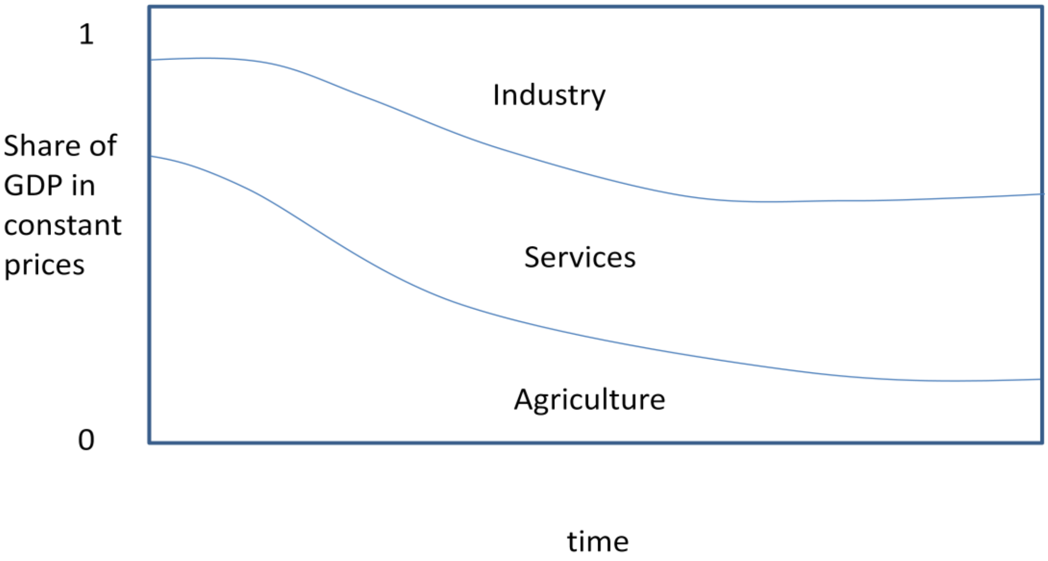


Figure 5.4 The transition in constant prices



Our main hypothesis is that the service transition is modest when it comes to actual production in the economy, and that it does not affect the energy intensities of developed countries. This hypothesis is based on the theoretical arguments above and on the previous study results for Sweden, which confirmed our hypothesis in an empirical test[593]. However, the results need not be as general as we expect; Sweden may be unique with its relatively large public service sector and large fraction of person-to-person services. Therefore, there is reason for investigating the issue across more countries.

5.4. Data

We present benchmarks on the share of employment and share of the services in constant and current prices for 1950, 1971, 1990 and 2005 to explore our hypothesis of completely different evolutions of the service sector depending on which indicator is used.[594] For all the developed countries, except the United States of America, we use the newly updated EU KLEMS November 2009 release for 32 industries[595]. In the case of the United States, we had to use the EU KLEMS 2008, SIC version that covers the period from 1970 to 2005 because the EU KLEMS 2009 release - NAICS version only goes back to 1977[596]. The reason why we prefer the EU KLEMS to other databases is that it separates postal services & communications from commercial transport in the service sector; these factors are very different from an environmental perspective. The benchmarks for 1950 are obtained by linking the EU KLEMS database to the 10-sector database of the Groningen Growth and Development Centre (GGDC)[597]. For Portugal in 1970, EUKLEM 2009 values for the employment share are linked with Pinheiro[598]. Data for India, Mexico and Brazil are based on the database in Timmer and de Vries[599] for Asia and Latin America, which covers the period from 1950 to 2005 and comprises 10 sectors.[600]

For the Divisia decomposition, the 32 sector data in 1995 constant prices for the 10 developed countries was reduced to 4 sectors for the years 1971 and 2005 as follows: 1) Agriculture (includes forestry and fishing); 2) Industry (Mining and Quarry; Manufacturing, Public Utilities and Construction); 3)

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[593] Kander (2005).

[594] There is detailed information at the sub-sectoral level in constant and current prices after 1970 for all the developed countries except for Japan, which starts in 1973.

[595] EU KLEMS (2009), O´Mahony and Timmer (2009)

[596] EU KLEMS, 2008; Timmer *et al*. (2007)

[597] van Ark (1995)

[598] Pinheiro (1997)

[599] Timmer and de Vries (2007)

[600] Constant prices for the emerging economies are expressed in 1993-1994 rupees, 1993 pesos and 2000 reais. Thus, there is a little difference between the price-level year for our developed countries (all 1995 price level) and these countries. However, for the analysis we perform, this is irrelevant.

Services (Wholesale, Retail Trade, Hotels and Restaurants; Finance, Insurance and Real Estate; Community, Social and Personal Services and Government Services; Post and Communications); and 4) Transportation. This division allows us to focus on the main issue of the paper: the effect from the transition to the service economy, where commercial transportation should be separated from the rest of the service sector because of its different energy intensity. We calculate real value added for the different sectors, by employing the Törnqvist aggregation procedure as described in the Data Sources and Methodological section of the 60-industry database[601]. This method has been shown to be the most accurate for aggregating sectors and can differ substantially from the method of adding up the sum of value added at constant prices from the lowest industry level to higher aggregates, particularly when industries have different growth rates. For Brazil, India and Mexico, we had to use the less accurate method of aggregating the 10 sectors to 4 sectors based on constant prices. Also, due to insufficient sector details, Transport and Communication are grouped together for these emerging economies. As a consequence, the results for the emerging economies are somewhat less reliable than the results for the developed countries, where we have used very careful and accurate methods.

Benchmarks for 1971 and 2005 energy consumption by end user on the formal economy side include Agriculture, Industry, Services and Commercial Transportation. On the household side, benchmarks for Residential and Personal Transportation were constructed[602]. The energy balances provided by the International Energy Agency (IEA) contain data on final energy use since 1960 for OECD countries and since 1971 for non-OECD countries. Despite being the most complete and internationally known database on energy, it has the disadvantage of reporting transportation only by modes (air, water, rail and road) and not by end users. Energy for personal transportation (mainly cars) should not be included in the commercial transport sector because individuals are not immediately contributing to GDP as a consequence of their driving a personal car, as opposed to taxi drivers.

The separation between private and commercial transportation is difficult to carry out due to missing data on road transportation by end users. There is generally better data available for 2005 than for 1971. For our early benchmark (1971), we find it reasonable to allocate all road gasoline to private consumers (cars) and all road diesel fuel to commercial transportation (trucks) because at that time diesel was not used frequently for private transportation. We use actual

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[601] GGDC (2006)

[602] IEA (2008 a, b).

data from Schipper on car fuel usage for the United States, France, Italy, West Germany, Sweden and the United Kingdom[603]. We assumed that for the countries not included in this reference, i.e., the Netherlands, Portugal and Spain, gasoline was a good proxy for personal transportation in 1971. For the 2005 benchmark, we were able to get a much better allocation of energy to sectors. There is actual data on fuel consumption by type of vehicle: cars, motorcycles, buses, light duty vehicles and trucks for a set of 7 out of our 8 European Countries (Portugal is the exception) for the period from 1980 to 2007[604]. We have used this data and treated car and motorcycle consumption as part of personal transportation and allocated the remaining fuel to commercial transport. We managed to fill in the gap for Portugal with an estimate of Seixas and Alves[605] on personal transportation for 2005 (U.S. Department of Transportation, 2009). Fortunately, Japanese official energy statistics separate road energy consumption between different types of vehicles as far back as 1953, so benchmarks for 1973 and 2005 could be obtained through this source[606]. For the United States, the Bureau of Transportation Statistics also reports information on fuel consumption by type of vehicle for 2005[607]. However, passenger cars and motorcycle energy consumption are not good proxies for personal consumption because in the US, a large proportion of SUVs and light duty vehicles are used for personal use instead of commercial transportation. The last household inquiry of fuel use dates from 2001 and indicates that personal fuel consumption represented around 88% of the total estimated fuel consumption for cars, motorcycles and other 2-axles 4-tire vehicles[608]. We use this percentage to estimate the total personal fuel consumption in 2005.It is harder to find information on personal fuel use for developing countries. Whereas for Brazil, gasoline and ethanol demand are believed to represent the personal transportation sector relatively well, energy allocation is more difficult to perform for India, where the share of commercial cars in the transport sector (taxis) is much higher. No attempt was thus made to separate personal and commercial transportation in developing countries.

For early periods, IEA underestimates residential biomass consumption in Portugal, Spain and Italy. For Portugal we have used the estimates produced in

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[603] Schipper *et al.* (1993).
[604] Odyssee (2009).
[605] Seixas and Alves (2006).
[606] EDMC (2009).
[607] U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, 2009. National Transportation Statistics,
[608] EIA (2005).

Chapter 2; for Italy we used the estimates of Malanima[609]. The Odyssee database traces biomass residential consumption for Spain back until 1980. We assumed that the per capita firewood values were the same in 1971 and 1980.

5.5 Methods

In order to investigate the proximate reasons behind changes in energy intensity, divided into between-sector and within-sector changes, we employ the decomposition method of LMDI (Logarithmic Mean Divisia Index) in the version described in Ang and Zhang and Ang[610]. This method distinguishes between structural factors (change in the shares of sectors, keeping energy intensities constant) and intensity factors (changes in sector energy intensities, keeping the structure of economy unchanged). The LMDI has been used in a large number of energy studies because of its attractive properties: easiness of interpretation, unity independence and perfect decomposition (i.e., leaving no residual).[611] The elements in the decomposition scheme are as follows:

E	Final energy consumption (= $\sum E_i + \sum E_k$)
E_i	Energy consumption in economic sector i (Agriculture, Industry, Transportation and Services)
E_k	Energy consumption in non-economic sector k (Residential, personal transportation)
Y	Total value added (constant prices)
Y_i	Gross value added of sector i (constant prices)
I	Final energy intensity (= E/Y)
I_i	Energy intensity of sector i (= E_i/Y_i)
S_i	Share of sector i in total value added (=Yi/Y)
D_{tot}	Total energy intensity change
D_{str}	Change of I due to structural effect (between-sector changes)
D_{int}	Change of I due to technological effect (within-sector changes)

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[609] Malanima (2006 a)

[610] Ang and Zhang (2000), Ang (2005)

[611] For a description of the properties of LMDI and comparisons with other methods, see the previous reference and also Ang and Liu (2007) and Choi and Ang (2003).

D_{pcons} Change of I due to personal consumption effect (non-economic sector changes)

D_{tot} I^T/I^0, where T is the year of comparison (here 2005) and 0 is the starting year (here 1971).

In the multiplicative version we decompose the total energy intensity change into structural effect, technological effect and personal consumption effects:

$$D_{tot} = D_{str} D_{int} D_{pcons}$$

D_{str}, D_{int}, and D_{pcons} can be computed as follows:

$$D_{str} = exp\left[\sum_i w'_i \ln\left(\frac{S_i^T}{S_i^0}\right)\right]$$

$$D_{int} = exp\left[\sum_i w'_i \ln\left(\frac{I_i^T}{I_i^0}\right)\right]$$

$$D_{pcons} = exp\left[\sum_k w'_k \ln\left(\frac{E_k^T}{Y^T} \Big/ \frac{E_k^0}{Y^0}\right)\right]$$

The weights of the economic and non-economic sectors i and k are calculated in a similar fashion using the logarithmic mean of the energy consumption of the sectors divided by total value added in the numerator and dividing it by the logarithmic mean of total energy intensities[612], so that:

$$w'_{i(k)} = \frac{L\left(\frac{E_{i(k)}^T}{Y^T}, \frac{E_{i(k)}^0}{Y^0}\right)}{L(I^T, I^0)}$$

where the logarithmic mean weight function of two positive numbers is given by: $L(x, y) = (x - y)/\ln(x/y)$.

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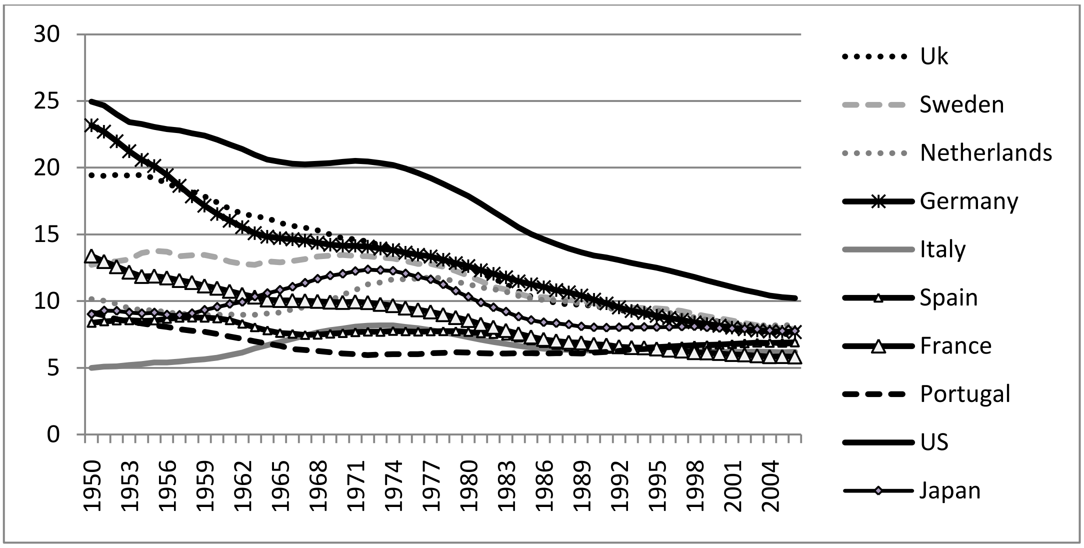
[612] Ang (2005).

5.6. Developed countries and late-comers

As already seen in Chapter 3, the long-run development of energy intensity in our sample of ten countries questions the stylized graph of Reddy and Goldemberg[613]. Here, we present only the evolution of primary energy intensities for the post-war period.

Figure 5.5 Energy intensities in 10 developed countries, 1950-2006 (7 year Moving Average), MJ/$1990



Source: Includes Modern Energy and Combustible, Renewables and Waste. For Japan, EDMC(2009). For remaining countries see Chapter 2.

The most eye-catching result is perhaps the strong convergence in energy intensity for all these countries over this period. From a large variation in energy intensities ranging from 25 to 5 MJ/dollar in 1950, most countries end up at levels of 6-8 MJ/dollar in 2006, with only the USA substantially above the other developed countries, at 10 MJ/dollar.

We find an accelerated decline in energy intensity around 1970 when the service transition is assumed to have taken off. This stronger rate of energy intensity decline is discernible for Sweden, the Netherlands, Germany, Italy, and France. For Spain and Portugal, latecomers to the industrialization process, there is more of a weak growth of energy intensity levels after 1970. What are the reasons for divergent patterns between late-comers and early-industrialized countries? And in which degree is this energy intensity decline in the period

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[613] Reddy and Goldemberg (1990)

after 1970 caused by a transition to the service economy? Let us first simply investigate the hypothesis that the real production structure has not shifted much in the direction of services.

Table 5.1 Service sector share (of GDP in current and constant prices, in employment), 1950, 1971, 1990 and 2005

	Employment (%)				Services current prices				Services constant prices 1995			
Countries	**1950**	**1971**	**1990**	**2005**	**1950**	**1971**	**1990**	**2005**	**1950**	**1971**	**1990**	**2005**
France	42	51	67	76	n.a.	57	69	77	68	64	71	73
Germany	34	45	59	72	n.a.	50	61	70	56	53	62	69
Italy[a]	27	42	60	67	n.a.	53	64	71	71	66	66	69
Japan[b]	31	46	58	68	44	52	59	69	55	60	61	66
Netherlands	50	60	72	79	n.a.	58	66	74	72	65	68	73
Portugal[c]	27	41	48	59	n.a.	61	62	73	n.a	58	64	69
Spain	33	42	59	65	n.a.	47	58	67	68	63	62	65
Sweden	39	56	69	75	n.a.	60	66	71	64	64	68	63
UK	49	56	70	80	n.a.	53	63	76	63	59	65	73
USA	58	67	76	81	54	63	70	74	63	65	72	72

Notes: [a] 1951; [b] 1953 and 1973 [c] 1953.
Source: See Section 5.4.

Table 5.1 reports the service sector shares of employment and GDP in current and constant 1995 prices[614] for the eight European countries, Japan, and the US.

The double hypothesis we presented in Figures 5.4 and 5.5 is largely, but not entirely, confirmed. Unsurprisingly, the first part of the hypothesis – that the service sector has grown since 1950 in its share of employment and its share of GDP in current prices – is fully confirmed for all countries. Service sector employment shares more than doubled between 1950 and 2005 in several countries (Germany, Italy, Japan, Portugal and Spain) and increased substantially in the others, too. Likewise, measured in current prices, the service sector increased its share of GDP. The second part of the hypothesis, which is more critical for our argument, and generally less known, is also largely

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[614] The choice of price base year for the comparison will not affect the sectoral growth rates, though it is true that the size of the sector shares will depend on the choice of base year. If we express the share of the service sector at the price level of 1950, when services were relatively cheaper than they are today, the sector will be smaller than if we express the share at the price level of 1995. What is important for our argument is that the real growth rates of the different subsectors will be the same, whether measured in 1950 or 1995 prices.

confirmed, but not unambiguously. Half of the countries see either no increase at all or no substantial increase in the share of services when measured in constant prices. If we set the criterion for qualifying as a case of "substantial increase" at 10 percentage points over the entire period 1950-2005, there are four countries that qualify: Portugal, Japan, Germany, and the UK. In addition, the USA nearly qualifies (9%). In the Portuguese case, this shift is quite impressive in comparative terms, given the late industrialization of the country. Unlike other countries about 1/3 of this shift can be explained by a movement from agriculture directly towards services. Nevertheless, an increase of 10 percentage points is still not much compared to the increase in service sector shares in current prices, where we find some examples of 30 percentage points increases. So it is apparent that the service transition, in real production terms, has been much less important than generally believed. Broadening the analysis beyond the Swedish case examined by Kander[615], we again find that a large part of the service transition is a price illusion caused by Baumol's disease.

To the degree that there still is some modest growth of the service sector, it is of interest to look into what part of the service sector has grown. If it is the sub-sector of commercial transportation, this growth may not bring about any decline in energy intensity whatsoever. It could even act in the other direction - to increase energy intensity - because of the high energy intensity of transportation. We have scrutinized the sub-sector growth within services, with the careful separation of the value added of the postal and communication sector from the transportation sector (see Table 5.2).

The separation between transport and communications shows that it is mainly communications that has grown disproportionally from 1-3% of GDP in 1971 to 4-8% in 2005. The share of the commercial transportation sector only increases in France, Italy, and Spain. These results show that there is some reason to believe that the structural changes within the service sector act to drive down energy intensities.

Another factor that seems to indicate a less energy intensive service sector is the reduction of the share of wholesale and retail trade, hotels and restaurants, and public services, which all use buildings and heating quite intensively, and the increase of finance, where large quantities of money circulate without any necessary equivalent energy consumption. After these initial tentative analyses of structural change and the role of the service sector in real terms, we turn to the results of the decomposition calculations. These calculations allow us to determine the role of structural change versus that of technical change in the

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[615] Kander (2005)

energy intensity decline. However, this analysis can only be carried out at the four-sector level of industry, agriculture, services, and transport, because energy use in the service sector is not reported at the sub-sector level in the statistics.

Table 5.2 Service sector composition, shares of total output in constant prices, in percent.

	1971					2005				
	Whs & RT, H&R (50-55)	Trpt (60-63)	P&C (64)	Fin. (65-74)	PS (75-99)	Whs & RT, H&R (50-55)	Trpt (60-63)	P&C (64)	Fin. (65-74)	PS (75-99)
France	20	5	1	37	37	17	6	5	40	31
Germany	25	5	3	30	37	18	5	4	41	31
Italy	26	5	2	33	35	24	8	5	35	29
Japan	25	10	2	28	34	24	6	5	37	28
Netherl.	22	8	2	25	43	23	7	7	35	29
Portugal	43	7	2	26	22	25	5	6	33	30
Spain	31	6	1	25	37	26	7	5	31	31
Sweden	18	9	2	41	29	17	9	6	42	26
UK	24	8	3	27	38	20	7	8	38	27
USA	16	5	2	32	46	20	4	4	41	32

Whs- Wholesale, RT- Retail trade, H&R- Hotels and restaurants; Trpt- Transport , P&C- Post and communications, Fin.- Finance, PS- Public Services

Notes: Numbers in parentheses correspond to ISIC – Rev3 values.
Source: EUKLEMS (2008) and EUKLEMS (2009).

Table 5.3 shows the data used for performing the LMDI decomposition for the years 1971 and 2005: sector shares of Gross Value Added (GVA) and energy consumption and relative sector energy intensities.

The most interesting result is the decreasing importance of industry compared to transport, both commercial and personal. Portugal is different in this respect as the increases in transportation and services were made at the cost of decreasing share of residential energy. The share of energy for personal consumption (residential energy and personal transportation) is quite significant in 2005, in the range of 29%-45%.

Table 5.3 Shares of GVA and energy consumption and sector energy intensities 1971-2005 for Western Europe, USA and Japan.

		FRA	GER	ITA	JAP[a]	NED	POR	SPA	SWE	UK	US
year	Share of Total GVA in 1995 K prices (%)										
1971	Agriculture	4	2	5	5	2	8	6	5	2	2
1971	Industry	32	45	30	34	32	34	31	31	39	33
1971	Services	61	50	62	54	60	54	60	59	54	62
1971	Transport	3	3	3	6	5	4	4	5	5	3
	Shares of Total GVA in 1995 K prices (%)										
2005	Agriculture	3	1	3	2	3	4	4	2	2	2
2005	Industry	24	29	27	32	24	27	30	35	26	26
2005	Services	68	66	64	62	68	65	61	58	67	69
2005	Transport	5	4	6	4	5	4	5	5	5	3
	Share of Energy (%)										
1971	Agriculture	2	1	2	1	1	5	5	2	1	1
1971	Industry	39	38	43	56	33	33	45	40	39	32
1971	Services	23	16	2	15	15	3	1	9	12	14
1971	Transport	7	8	10	9	9	16	18	8	12	13
1971	Residential	18	27	34	11	32	34	21	33	26	20
1971	Pers. Transp.	10	10	10	8	10	9	10	9	10	20
1971	Pers.cons.	28	37	44	19	42	43	31	42	36	40
	Share of Energy (%)										
2005	Agriculture	2	1	2	1	8	3	3	2	1	1
2005	Industry	20	25	27	34	28	30	31	36	21	20
2005	Services	18	17	14	23	15	12	9	13	12	15
2005	Transport	16	12	22	9	17	20	28	12	21	20
2005	Residential	28	29	25	17	20	17	16	22	29	19
2005	Pers. Transp.	15	15	10	16	13	18	13	13	16	25
2005	Pers.cons.	44	44	35	33	33	35	29	36	45	44
	Energy intensity 100= Total for 1971										
1971	***Total***	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
1971	Agriculture	45	50	48	27	32	62	89	32	72	84
1971	Industry	124	85	145	162	102	98	145	128	101	96
1971	Services	38	31	2	27	25	6	2	16	21	23
1971	Transport	233	299	279	153	172	397	504	162	250	433
	Energy intensity 100= Total for 1971										
2005	***Total***	**63**	**53**	**76**	**61**	**62**	**104**	**107**	**49**	**58**	**45**
2005	Agriculture	43	46	59	55	166	78	84	51	23	25
2005	Industry	54	46	74	65	71	117	111	52	49	35
2005	Services	16	14	17	23	13	19	16	11	11	10
2005	Transport	210	177	283	140	207	550	635	124	224	293

Source: See 5.4. Abbreviations : FRA-France, GER-Germany, ITA-Italy, JAP-Japan, NED-The Netherlands, POR-Portugal, SPA-Spain, SWE-Sweden [a] 1973

Most developed countries exhibit substantial decreases in their energy intensity over the last three decades, with the exception of Portugal and Spain. The countries with the most drastic decline were the USA, Sweden, and Germany (47%-55% decrease), followed by the UK, France, Japan, and the Netherlands with about a 40% reduction each. Italy had a more modest decrease in energy intensity of about 25%.

Table 5.4 shows the results of the decomposition of energy intensity for our developed countries dataset. The results clearly show that the impact of structural change was very small when compared with the technology effect, and even the personal consumption effect. The direction of impact from the structural change is furthermore ambiguous. Structural changes towards services tend to decrease energy intensity in 7 of our 10 countries (2% to 9%). Portugal and the United Kingdom were the countries where structural factors played the largest role, whereas France saw only a 2% contribution. In some other countries such as Italy, Spain and Sweden, the structural factors worked in the opposite direction; making energy intensity increase by 3-4%.

These countries are where the Baumol effects were strongest, with a zero or tiny increase in the real share of the service sector. In Italy and Spain, with fairly smooth transitions to services, this effect was offset by an increase in the transportation branch. This result confirms our hypothesis that the service transition does not constitute a postulate for energy intensity decrease per se, especially not if it is accompanied by an intensification of commercial transportation.

The technology (within-sector) effect had the strongest impact on energy intensity declines in all countries, with the exception of Portugal and Spain. Industry played this special role in all cases except for Portugal. The impact from what happened in industry was 34% for overall energy intensity reduction in Japan, 10% in the Netherlands and Spain and about 20% in the remaining countries.

The results from what happens within the service sector are somewhat mixed. Whereas internal changes within the service sector push down the energy intensities of the United States, France, Germany or the United Kingdom, the opposite is true for Portugal, Spain and Italy, where within-service sector changes contribute an 8-11% increase in overall intensity. This change could be related with an increase in air conditioning in these warm countries. Also interesting is the role of personal consumption for the decline in energy intensity. Whereas residential energy consumption contributes to a decline in energy intensity of about 10-15% in the majority of countries, personal transportation grows significantly slower than GDP only in the United States;

however, it started at high levels. In the more advanced European countries the impact from private transportation tends to drive energy intensity down, although not much (-3% to -1%). In some countries, private transportation increases faster than GDP. In Portugal, Spain and Japan, the present rates of contribution from personal transportation to the change in energy intensity are +10%, + 4% and +3%, respectively. The different results point to a possible saturation of final demand for transportation at higher levels of income.

Table 5.4 Divisia decomposition 1971-2005 for Western Europe, USA and Japan

	FRA	GER	ITA	JAP	NED	POR	SPA	SWE	UK	US
	71/05	71/05	71/05	73/05	71/05	71/05	71/05	71/05	71/05	71/05
Agriculture										
Intensity	1.00	1.00	1.00	1.01	1.05	1.01	1.00	1.01	0.99	0.98
Structure	0.99	1.00	0.99	0.98	1.01	0.97	0.98	0.99	1.00	1.00
Industry										
Intensity	0.78	0.82	0.79	0.66	0.89	1.06	0.90	0.71	0.80	0.77
Structure	0.92	0.87	0.98	0.97	0.92	0.93	0.99	1.04	0.88	0.93
Services										
Intensity	0.84	0.87	1.11	0.97	0.91	1.08	1.08	0.96	0.92	0.88
Structure	1.02	1.05	1.00	1.03	1.02	1.01	1.00	1.00	1.03	1.02
Transports										
Intensity	0.99	0.95	1.00	0.99	1.02	1.06	1.05	0.97	0.98	0.94
Structure	1.04	1.03	1.08	0.96	1.00	0.99	1.06	1.01	1.03	1.00
Productive Sector Total										
Intensity	0.65	0.68	0.89	0.64	0.87	1.22	1.03	0.67	0.72	0.63
Structure	0.98	0.93	1.04	0.94	0.94	0.91	1.04	1.03	0.92	0.95
Sub Total	0.63	0.64	0.92	0.60	0.82	1.11	1.07	0.69	0.66	0.60
Pers. Cons.										
Residential	0.99	0.85	0.84	0.99	0.78	0.86	0.96	0.73	0.89	0.84
Personal tr.	0.99	0.98	0.97	1.03	0.97	1.10	1.04	0.97	0.99	0.88
Total										
Intensity	0.65	0.68	0.89	0.64	0.87	1.22	1.03	0.67	0.72	0.63
Structure	0.98	0.93	1.04	0.94	0.94	0.91	1.04	1.03	0.92	0.95
Pers. Cons.	0.99	0.83	0.82	1.02	0.76	0.94	1.00	0.71	0.88	0.75
Total impact	**0.63**	**0.53**	**0.76**	**0.61**	**0.62**	**1.04**	**1.07**	**0.49**	**0.58**	**0.45**

Note: A value of 1 implies no change; 1.1 a 10% contribution for increasing total final energy intensity; 0.9 a 10% contribution for decrease on total final energy intensity.

5.7. Why is Portugal different?

Unlike Spain or Italy, Portugal suffered some deindustrialization of its economy after the 1970s, which may well have contributed to the overall productivity slowdown of the economy and recent economic divergence. The special feature about Portugal is that it is a country with intensive structural shifts towards services that have not meant a decrease in energy intensity. It shares with Spain the rise of personal transportation in relation to income, which is a characteristic of late-comers. It also shares with Spain and Italy an increase of service sector energy intensities, which is a characteristic of southern European countries. However, it is the only country where industrial energy intensity is increasing. Why is it so different from other European countries? As the industrial sector is heterogeneous, with both low- and high-energy intensity branches, we need to be careful about giving all the credit to technological innovation in industrialized countries. The level of aggregation can mask structural changes within the industry, i.e., the increase of lighter branches in early-industrialized countries. Mulder & Groot have decomposed manufacturing energy productivity (GVA/energy, the inverse of energy intensity) for 14 OECD countries[616]. Intensity effects are in general much more important, but structural factors also play a role. They find structural changes from iron and steel, non-ferrous metals and non-metallic minerals towards higher value added and low energy intensive industries such as machinery or transport equipment. Interestingly, most of the energy productivity gains within the sectors tend to be concentrated in a small number of industries, especially in the machinery and chemical sectors[617]. These are some of the sectors which are credited with the Third Industrial Revolution or knowledge economies.

In order to compare, Table 5.5 shows the changes in the structure of the industrial sector, the sectoral energy intensities and a decomposition of the changes in energy intensity in the industrial sector (excluding the electricity sector) for the period 1971-2006.

Industrial energy intensity increased by 35% from 1971 to 2006. Unlike many industrialized countries, Portuguese industry was dominated by light industries in the early 1970s. Construction, textiles and food comprised more than half of the industrial structure. Other non-metallic minerals (ceramics,

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[616] Mulder and Groot (2004)

[617] Mulder and Groot (2004)

cement & glass) were the most energy intensive branch of the economy followed by others and chemicals.

Table 5.5 Shares of GVA, energy intensities and LMDI decomposition in the industrial sector, Portugal

	1971	**2006**	**1971**	**2006**	**1971-2006**	**1971 - 2006**
Sectors	GVA 1995 K(%)		EY 100= Total 1971		Int.eff,	Str. Eff.
Mining	1	2	77	155	1.01	1.01
Food, beverages and tobacco	13	9	106	141	1.03	0.97
Textiles and Clothing	14	11	71	86	1.02	0.98
Wood, Cork	3	3	89	109	1.00	1.00
Pulp, paper and printing	6	7	91	397	1.19	1.02
Chemical, rubber and plastics	6	10	198	151	0.97	1.06
Other non metallic mineral	5	8	612	530	0.96	1.16
Basic metals and fabricated metal	8	8	103	67	0.98	1.00
Machinery and electrical	8	10	14	42	1.02	1.00
Transport equipment	2	6	42	27	1.00	1.01
Others	5	4	328	110	0.92	0.99
Construction	30	23	6	29	1.05	0.99
Total	**100**	**100**	**100**	**135**	**1.14**	**1.19**

Source: Own elaboration from IEA (2008) for energy and EUKLEUMS (2009).

The 35-year period witnessed a movement from the most traditional sectors towards chemicals and non-metallic minerals. Even if some light sectors, such as machinery and transport equipment, increased their share as well, they did so at the cost of a decreasing share of construction, the lightest branch of industry. As a result, the impact of structural changes in industry was positive. Still, structural changes were not the only explanation for the trends towards increasing industrial energy intensity.

Technological effects within the industries also worked to increase energy intensities. Most of the changes can be observed in pulp, paper & printing, which may have been due to an increase of more energy intensive branches (such as pulp). In other sectors, energy intensities either slightly increased or slightly declined, but there were no major energy intensities declines as in other industrialized countries.

The possible explanations for this are not necessarily exclusive. First, some technological convergence in the amount of capital per worker in the various industries might have occurred, offsetting possible gains in efficiency. Second, Portuguese industry might have been unable to move to high value added and knowledge intensive products. This seems to have been the case not only in sectors such as chemicals, rubber & plastics, characterized by a high diversity of products, but also machinery & others, where the ICT producing sector is normally included. This points to a probable difficulty in creating the cluster of industries which emerged from the Third Industrial Revolution. A last possibility is that the technical energy efficiency of industrial processes has improved less in Portugal than in other developed countries.

5.8. Emerging economies

We saw that energy intensities did not significantly decline for Spain and Portugal after 1970. On the contrary, Italy, which was earlier in its industrial development, had a clear decline in energy intensity after 1970. This leads us to inquire whether developing countries of the world today are similar to the European predecessors. Is the service transition a generalised phenomenon also taking place in developing countries? Or, are the developing countries of today taking on the role of being the factory of the world as England was during the first industrial revolution? India is well known for specialising in high-value service production such as ICT services and the film industry (Bollywood). Does this show up in their energy intensity figures and in their sector composition of GDP? Are Brazil and Mexico playing a greater role as industrial manufacturers for the world markets?

A related question is whether the developing countries are leapfrogging in terms of energy intensity (peaking at lower values than the old industrialisers), as suggested by the stylised inverted U-shape graphs of Reddy and Goldemberg[618]. Stern sums up the environmental Kuznets curve studies by saying that it is not higher income (different structure of demand) that will lead to a downward trend of the curve, but rather the transfer of energy-efficient technology from the developed world[619]. The mere existence of leapfrogging at the aggregate level of course does not explain the reasons for this. It may be that the developing countries are experiencing a faster transition to a service economy, or that they receive technology from abroad, or that the household sector reduces its share of energy consumption as the economy grows.

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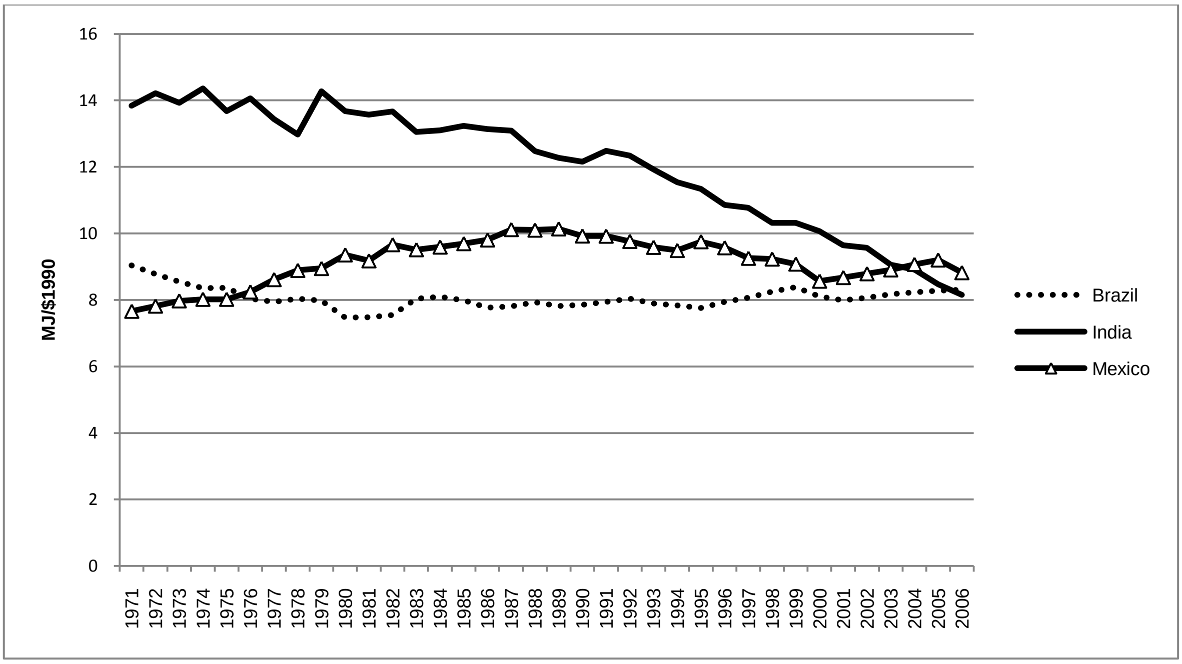
[618] Reddy and Goldemberg (1990).

[619] Stern (2004)

Figure 5.6 Energy intensity in Brazil, India and Mexico 1971-2006



Source: IEA, 2008 a,b.

Figure 5.6 shows energy intensities for Brazil, India and Mexico for 1971 through 2006. The most conspicuous feature of these graphs is that they end up at very similar levels to those of the more developed countries (7 to 10 MJ/dollar). So over time, there seems to be a strong convergence in global energy intensity. This does not support the idea that the developing countries take over the role of being the factory of the world, and that developed countries lower their energy intensity by passing over the problems of energy intensive production to less developed countries.

Table 5.6 Service sector shares of Brazil, India and Mexico.

	Employment (%)				Services current prices				Services K prices			
	1950	**1971**	**1990**	**2005**	**1950**	**1971**	**1990**	**2005**	**1950**	**1971**	**1990**	**2005**
Brazil	20	33	51	62	n.a.	n.a.	60	54	43	51	60	55
India	n.a.	16	21	22	23	29	38	50	23	29	39	51
Mexico	25	35	48	57	59	65	64	71	60	63	63	64

Note: Services in K prices 2000 price level for Brazil,1993 for India and Mexico.

Source: Timmer and de Vries (2007).

The country that reduces its energy intensity the most is India, starting out at the same levels as the United Kingdom and Germany in 1971. Brazil and Mexico do not change their energy intensity much over this period, and in that respect, they resemble Portugal and Spain.

Table 5.6 shows the service sector share for Brazil, India and Mexico. India is the country standing out from the rest of the developed and developing countries by showing a relatively modest service transition in terms of employment, but a substantial transition both in current and constant prices. The only possible explanation for this is that labour productivity in Indian services must have increased tremendously. Such an increase may be possible, judging by the structure of the service sector, because Finance was the sector with the most impressive growth – from 5% to 17%At the same time, public services declined from 38% to 28%. Finance is one example of industrialised services with high productivity, whereas public services consist mainly of person-to-person services, which are less technically progressive in Baumol´s terminology. Thereby, India is the only country that seems completely unaffected by Baumol’s cost disease. India also stands out in the importance of structural changes away from Agriculture over to more of both Industry and Services (see Table 5.8).

Table 5.7 Service sector composition of Brazil, India and Mexico

	1971				2005			
	Whs. and retail trade (50-55)	Trpt. and comm. (60-64)	Finance. (65-74)	Public services (75-99)	Whs. and retail trade (50-55)	Trpt. and comm. (60-64)	Fin. (65-74)	Public services (75-99)
Brazil	16	7	36	42	12	10	31	47
India	41	17	7	35	34	22	16	27
Mexico	41	11	5	43	37	23	8	32

Source: Timmer and de Vries (2007). Whs- wholesale; Trpt- Transport.

All three emerging economies exhibit a decline in the share of residential energy, which is very natural for growing economies, but only India starts from extremely high shares in 1971 (59%). Brazil and India’s energy structures differ from developed countries in the sense that both countries increase their industrial energy consumption. Mexico’s peculiarity is the decreasing share of services in favour of transports and communication. Expressed in constant national currencies, India shows the most significant decrease in its energy intensities (57%), followed by Brazil (21%) and Mexico (6%).

Table 5.8 Shares of GVA and energy consumption and sector energy intensities 1971-2005 for Brazil, India and Mexico

	Brazil		India		Mexico	
	Share of Total GVA(%)					
	1971	**2005**	**1971**	**2005**	**1971**	**2005**
Agriculture	9	8	47	21	10	6
Industry	38	36	23	29	27	30
Services	49	50	25	40	56	50
Transportation[a]	3	5	5	11	7	15
	Share of energy consumption (%)					
	1971	**2005**	**1971**	**2005**	**1971**	**2005**
Agriculture	9	5	1	4	4	3
Industry	29	42	24	31	37	28
Services	2	5	6	6	2	4
Transportation[b]	23	33	10	11	33	47
Residential	36	14	59	48	24	18
	Energy intensity 100 = Total for 1971					
	1971	**2005**	**1971**	**2005**	**1971**	**2005**
Total	100	79	100	43	100	*94*
Agriculture	92	48	2	9	35	50
Industry	76	93	106	46	138	88
Services	5	9	23	6	4	7
Transportation	687	487	207	44	480	304

Notes: [a] Includes Communications. [b] Includes personal transportation

The results for India, Mexico and Brazil show both similarities and differences to the results for the developed countries (see Table 5.9).

Technology effects contribute to a decline in energy intensity, but unlike the developed countries, structural effects work to increase energy intensity in all three emerging economies due to a move from agriculture to industry in India and Mexico, and due to an increase of the commercial transportation sector in all countries. So, even though there is a strong service transition taking place in India, this is accompanied by industrialisation, and the employment does not move from industry to services, but from agriculture to services directly. This is one kind of leapfrogging.

Table 5.9 Divisia decomposition for Brazil, India and Mexico

	Brazil	India	Mexico
	71/05	71/05	71/05
Agriculture			
Intensity	0.96	1.03	1.01
Structure	0.99	0.98	0.98
Industry			
Intensity	1.07	0.80	0.86
Structure	0.98	1.06	1.03
Services			
Intensity	1.02	0.93	1.02
Structure	1.00	1.03	1.00
Transports			
Intensity	0.91	0.85	0.83
Structure	1.14	1.09	1.36
Total Productive Sector			
Intensity	0.95	0.64	0.74
Structure	1.10	1.17	1.37
Sub Total	1.05	0.75	1.02
Personal Consumption			
Residential	0.75	0.57	0.93
Total			
Intensity	0.95	0.64	0.74
Structure	1.10	1.17	1.37
Personal Consumption	0.75	0.57	0.93
Total impact	0.79	0.43	0.94

Source: Own calculations

The structural changes offset technology gains in Brazil and Mexico, but not in India. However, it is not within the productive economy that the main energy intensity gains are achieved, but in the share of energy in the residential sector. Moving from traditional fuels to modern fuels leads to some savings, but more importantly, the residential sector declines radically in size in relation to the formal economy. This is also what took place in Europe some hundred years ago.

5.9 Concluding discussion

In conclusion, the service transition was far less impressive in real terms than is normally believed. Whereas employment and share of GDP in current prices have risen by approximately 30% in recent decades, the increase in the share for real service production is smaller. Over the last 50 years, Germany, the United States of America, the United Kingdom, Japan, Portugal, India and Brazil exhibited a rise in service shares by some 10%; countries such as Italy, the Netherlands, France, Spain and Sweden show negligible increases or even declining shares in the service sector. The decomposition analysis showed that, due to the very modest service transition and the increasing share of commercial transportation, structural shifts have not contributed at all to the decline in energy intensity that has taken place in recent decades in some of the countries such as Italy, Spain and Sweden. In the remaining developed countries, the structural changes toward the service sector have worked to modestly decrease energy intensity. Still, the impact from the transition to the service economy is always much smaller than from technical change.

For emerging economies, we find that the technical change (within-sector changes) is the main driver for declines in energy intensity, especially in manufacturing. Emerging economies converge with developed countries in energy intensities, a fact which does not lend support to the notion that they play the role of being the factory of the world, while the developed world lives in the service economy. On the contrary, India shows a substantial service share growth in real terms, which is not of the same cost-disease-kind as much of the developed world's service transition. Instead, it is the productive financial sector that grows, with India developing its industry and service sector at the same time. The combined structural effect from these two movements (fundamental service transition and industrialisation) does not act to drive India's energy intensity down. Instead, it is the technology effect in manufacturing that is responsible for India's rapid decline in energy intensity over the last decades, together with declining shares for the residential sector's energy consumption.

For less-developed European economies, such as Portugal and Spain, there used to be the same declining energy intensity effect from fuel switching, and a declining share of household energy as the economy grew, just as we find for the emerging economies of today. Lately, however, there has been a period where overall energy intensity actually increases as a result of structural changes towards transportation (both commercial and personal), structural change within the industry sector (in Portugal) and increasing demand for comfort in the service sector (e.g., air conditioners and heating systems). Will the emerging economies pass through the same stage of development, or can they leapfrog in any way?

In addition to exploring these ideas further, there is the need to deepen our understanding of the role of services and transportation for industrial energy intensity in a more dynamic sense. Nowadays, only 10-20% of service production is directed to final demand, with the remaining share of the sector's output being consumed as an intermediary input to the manufacturing industry[620]. How do services' inputs contribute to declining energy intensities in the industrial sector? Kander stresses a double environmental beneficent impact of microelectronics in manufacturing thus: 1) increasing efficient control of energy flow and waste through the use of process computers in the production process; and 2) inducing a structural change within the industry towards lighter branches[621]. However, the effects are not always unambiguous. One example is the development of the just-in-time production system that, while boosting industrial productivity and reducing the energy needs for storage, can decrease the energetic efficiency of the transport sector through an increasing reliance on road transportation instead of other more environmentally friendly modes such as railways. Also the DIY system, which is a natural consequence of an entrepreneurial response to Baumol's cost disease, has a similar effect on personal transportation, which may not be very efficient from an environmental cost point of view. So, the full environmental effects from the service transition need further study.

Policy makers need to be aware of what processes come naturally without policy measures being undertaken, and when there is a need for action. Even when economic growth processes involve partial solutions to problems, it is of utmost importance for policy makers to have a sound understanding of these processes. In the case of the transition to a service economy, we have shown that this process is not to be trusted when it comes to handling environmental problems because it does not entail much change in the real production structure of the economy i.e., it does not lead to much dematerialisation in its own right. What drives energy intensity down is mainly what takes place within the manufacturing sector, like the ICT revolution, and this should be further encouraged by policy measures in order to stimulate the much-needed delinking of energy and growth, more so than has occurred in the past. Our study shows that increasing needs of transportation (both personal and commercial) have a

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[620] O´Mahony (1999), Jespersen (1999)

[621] Kander (2005)

general and persistent negative impact on global energy efficiency. This is certainly an area where many improvements can be achieved by the implementation of policies that promote the use of public transportation and non-road modes. Emerging economies have an interesting challenge here, as successful urbanisation policies that concentrate living and working places within a short distance of each other, and provide a good public transportation network, could be one way of leapfrogging.

Historically, there is an ongoing process of formalisation of services performed as unpaid household work. When such services become part of the formal economy, this means that the economy grows without much changing in real terms. Energy consumption might go up in the cases when the services require new buildings like day care centres. It is the person-to-person services that are most afflicted by Baumol's cost disease, which mainly increases as a natural process of economic growth. However, when some person-to-person services are priced out of the market, we enter the DIY economy, where households do the time-consuming work tasks in their spare time, and only buy the services and products that are technically progressive and thus cheap. Therefore, the modest service transition, partly consisting of economic growth that takes place without much change in real production, only moves activities from the informal to the formal economy. Sometimes this is accompanied by increased energy consumption, but sometimes not. In other words, a modest transition to the service economy might be even more modest if this kind of economic growth does not take place. However, it is included in national accounts and our sole ambition in this paper is to analyse properly which effects the service transition actually has on energy consumption. And it is modest.

Chapter 6

Conclusions

This dissertation highlights the Portuguese long-run inter-relationships of energy, economic growth and the environment in an international comparative context. The aims are to characterize long-run energy transitions from organic to fossil fuels and the drivers of CO_2 emission changes associated with those shifts; to investigate the role that fossil fuels and renewable energy have had in determining the pace and intensity of industrialization in a fossil-poor country; and to understand how the relationship between energy and economic growth changes with the transition from an industrial to a service society. In order to address these aims, this thesis compares an original dataset on Portuguese energy consumption, fossil-fuel related CO_2 emissions and energy prices, for the period 1856-2006, with a long-run international energy database which includes France, England & Wales, Germany, Italy, the Netherlands, Spain, Sweden, Canada and the US.

The fulfillment of the aims allows us to conclude that Portuguese energy transition from traditional energy carriers towards fossil fuels and electricity was exceptionally late in comparison with early industrializers. Energy costs played an important role in constraining industrial growth, and determined Portugal's low energy intensive resource path. It only began to converge with industrialized countries when that problem was solved. The specificity of the low resource intensity path implies that although Portugal is today a post-industrial society, energy and CO_2 emissions are growing disproportionally faster than economic growth. This is due to technological convergence and structural changes in the industrial sector, the increase of private transportation and the growing levels of comfort in the service sector. Hence, Portugal is faced with significant challenges in a period when considerable reductions in carbon dioxide emissions need to be made in order to ensure sustainable growth.

The next sections contain a discussion of the main findings.

6.1 Energy transitions: Portugal in comparative perspective

The long-run assessment of energy transitions in seven European countries (France, England & Wales, Germany, Italy, the Netherlands, Portugal, Spain and Sweden) and two New World countries (Canada and the US) points to both common and distinct trends across pioneers and late-comers. Common patterns show that in the long-run all countries transformed their energy systems from a traditional energy basis towards fossil fuels, increased their share of electricity and shifted to higher energy quantities.

However, the pace and intensity of energy transitions was distinct; countries followed different energy pathways at least until World War II. At one extreme, pioneers and fossil-fuel rich countries had a type of energy transition that involved a fast increase in energy quantities and an early switch to coal. At the other extreme, southern European countries, coal-poor countries, had no major shift in the availability of energy per capita, had a high share of traditional energy carriers and a huge coal gap in relation to northern Europe, Canada and the US. Portugal still differed from Spain and Italy in the sense that equivalent levels of energy consumption were not a result of the same levels of modern energy. Portugal had half the level of coal and less than half the electricity consumption of the other two countries.

Oil significantly changed the pattern of energy transitions and the southern European countries switched to higher energy quantities. The characterization of energy transitions in the three southern European economies suggests a strong inter-relationship of oil, a rise in energy consumption per capita, a substantial reduction of the share of traditional energy carriers and post-war economic convergence. Since the 1970s, energy per capita has stabilized in all the high-consuming countries, while it is still increasing in Italy, Spain and Portugal.

This thesis compares the long-run relationship between energy and economic growth (energy intensity) across countries, taking the trend and level into account. The most accepted view in the literature, i.e., the Environmental Kuznets Curve theory, predicts that long-run energy intensity will increase with industrialization and decrease with the transition towards the service sector.

Comparing the trend, it is found that Portuguese modern energy intensity does not follow the typical inverted U-shaped or Environmental Kuznets Curve (EKC) of early industrializers, but shows a continuous increase with a break in trend during World War I. When traditional energy carriers are incorporated, Portuguese energy intensity seems to have followed an inverse pattern to what the EKC theory predicts for modern energy intensities; it decreased with industrialization and increased weakly with the transition to the service sector.

In relation to previous studies which incorporate traditional energy carriers, the decline during the industrialization phase is not surprising, as various countries exhibit this pattern. It is suggested that, in the Portuguese case, the decrease of the share of household energy in relation to the formal sectors of the economy might have been the most important factor accounting for the decline. Finally, the long-run tendency of decline in the various countries did not offset the fact that periods of coupling could occur depending on the intensity of industrialization at each growth phase.

Comparing levels of modern energy intensities, it is found that Portugal followed a low resource intensive path, along with Spain and Italy, never reaching the high modern energy intensities of the remaining countries. Despite the long-run tendency for energy intensities to decline when traditional energies are included, Portuguese energy intensities were still substantially lower than coal or wood-rich countries like Sweden, the US, Canada, Germany or England and Wales. In relation to the remaining countries, Portuguese long-run total energy intensity could be also considered low by international standards during the industrialization phase of the Portuguese economy, in the 1950s-1980s.

Despite the historical decoupling of energy and economic growth, energy intensity forces were not strong enough to counterbalance the increasing needs of energy as a result of population and economic growth. However, since the early 1970s, energy decoupling forces have accelerated substantially in many of the countries that followed energy intensive paths, thus contributing to the stabilization of energy consumption.

In sum, the long-run study of energy transitions in seven European countries and two New World Countries suggests a strong interconnection between natural resource endowments (especially coal), early industrialization and high historical levels of energy intensity as opposed to the lack of energy resources, late industrialization and low energy intensive path of southern economies. The convergence in energy intensities since the 1970s, as a result of sharp decreasing trends in early-industrializers and weak increasing trends in Portugal, suggests that natural resources are no longer factors of distinction across nations.

6.2 Natural Resources and Industrialization

In the mid-nineteenth century the prospects of industrialization were clearly distinct for those who had coal and for those who did not. Those who had affordable coal and iron could emulate the intensive energy pathway of pioneers; those who did not would have to find other ways to industrialize. Of those who lacked coal reserves, some managed to industrialize, some imported coal, some used water or wood with advantage, and many leapfrogged to hydropower, becoming emergent powers in the age of electricity. In Portugal, none of the alternatives were enough to create a sustained growth path. It failed to industrialize both in the age of coal and in the age of electricity, and missed the advantages of both the First and Second Industrial Revolution. To understand why Portugal industrialized at such a low pace, and lagged so much relative to the leaders and other fossil-poor countries, we have investigated how energy costs and relative prices affected the industrial structure in the different eras.

Until the late nineteenth century, imported coal arrived at the Portuguese harbors at a cost 3.5 times more than at the pithead of a coal-endowed country. Despite the international price gap, Portuguese harbor cities probably had the cheapest energy costs of the whole country at that time. But coal only brought hopes of some industrialization to the urban areas of Oporto and Lisbon. In other regions, transport costs made coal terribly expensive. Water and wood were only second best alternatives, and much more expensive than coal at the harbours. Hence, industrialization did not spread to other parts of the country, which represented a substantial difference in relation to some fossil-poor countries. For example, in Sweden, the steam engine was just as advantageous to the urban areas as to the sawmill industry in the countryside, as wood could be used with advantage, eliminating the dependence on water-power sources[622].

The lack of coal endowments and suitable iron reserves was an important constraint. The scarcity of these two raw materials prevented any multiplier effects in the economy that could have come from the existence of heavy industries. Consequently, Portuguese industry was pushed towards a labour-intensive type of industrialization with low chances of success at the time. The lack of a heavy industry was also an important difference in relation to other fossil-poor countries.

Despite the relatively high energy costs compared to coal-endowed countries, Portugal missed the advantages of the age of electricity.

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[622] Schön (2010).

Electrification was poor, there was an excessive reliance on thermo-power, and industrial electricity prices were 2-4 times higher than in Europe in the mid-1930s. In this thesis we investigate the reasons why the incentives to turn to hydropower did not arise in Portugal with the same intensity as in other coal-poor countries.

Coal-poor countries with an early electrification had at least one of the following factors in common: tradition in water-power use and small or medium water resources that could be used without any large capital investment; the existence of energy intensive industries that ensured a demand for power and the capital that large investments would require. I contend that in Portugal, due to the absence of smaller-size resources and large needs of water regulation, the full exploitation of hydro-resources would have required large amounts of capital and guaranteed demand; these conditions were not present in early 20th century Portugal. The choice of light industrialization during the late nineteenth century prevented any capital accumulation and implied low levels of demand for power. The thermo option was an understandable choice more adaptable to the size of demand, with lower capital requirements. This technical choice, while understandable, created a vicious circle of high energy prices and poor industrialization. Again, high energy prices kept all the industries with large energy costs out of the industrial structure. This meant that most of the raw materials were imported, and one of the problems of Portuguese industry was the absence of significant backward and forward linkages between the different branches. On the eve of World War II, Portugal was still one of the most backward countries in Europe, incapable of modernizing its energy system.

Governmental policies intended to break the vicious circle of high energy prices. A certain amount of capital accumulated during World War II provided the state with the funds to invest in a vast electrification plan. Hydropower would act as the main driver of the economy by ensuring cheap energy for new basic industries, manufacturing and households. This thesis studies the impact of energy policies on the industrialization of the country. A national grid of dams initially constituted an obvious advantage over coal; electricity prices declined and converged with those in other European countries in many user categories; consumption responded to the price signals and energy dependence was greatly reduced, allowing for important savings in the payments balance. The electrification of the country also saw the birth of a machinery sector consisting of industries such as electric cables, transformers and hydraulic equipment which had not existed before.

Still, hydropower failed to sustain the energy intensive industries that the state sought to promote most. Firstly, the irregularity of hydropower limited any attempts to emulate a Scandinavian type of industrialization. Secondly, the electricity policy intended to benefit a large number of consumers at the same time, which compromised cheap electricity prices in the basic industries. Thirdly, hydropower had come too late to make a big difference. Oil was also cheap, and soon became the fuel that could sustain the full modernization of the Portuguese energy system. It not only assured cheap energy essential for the needs of industrialization, it soon became the core element of the new development plans.

First with hydropower and later with oil, Portugal finally managed to catch up with the European Core.

The energy factor has received less acknowledgment in Portuguese Economic History than it deserves. In truth, Portugal has had growth facilitators which were not present in the interwar period or before. The European post-war reconstruction represented an important stimulus; markets opened up and the large wage gap which arose from years of economic stagnation led to the expansion of some traditional labour intensive exports such as textiles and clothing. But would industrialization have occurred without the modernization of the energy system and the sharp convergence in energy prices? This thesis argues that cheap energy was a necessary pre-condition for industrialization.

In a wider framework, the analysis of the role of energy in boosting industrialization in a comparative perspective allows us to gain some understanding of why some fossil-poor countries managed to industrialize and others did not. Coal mattered a lot, but the history of European economic growth cannot be restricted to the statement of no coal, no industrialization. Industrialization was possible as long as other natural resources could act as catalysts for industrial growth. As a result of distinct initial factor endowments, fossil-poor countries had different degrees of industrialization potential. The initial industrial structure of each country and the relative prices of capital, labour and energy produced different incentives for the adoption of energy technologies. The abundance and quality of renewable energy resources largely determined the relative success of industrialization based on indigenous natural resources.

6.3 Energy Intensity and the Service Transition

Energy intensity has been decreasing substantially in early industrialized countries since the 1970s. In late-comers Portugal and Spain, energy intensity is now increasing, after a long-term decline. One of the hypotheses tested in this thesis is whether the transition from an industrial towards a service society provided any relief for the environment. It is found that if services are measured in constant prices, the transition is far less impressive than is commonly believed. While employment and the share of GDP rose by around 30% in the last three decades of the period covered here, the increasing share of real service production was much smaller in all the countries in the study. An analysis of the contribution of structural and technological factors shows that, for developed countries, structural shifts towards the service sector were modest, and technological changes in manufacturing sector were the most important factors. Structural changes towards lighter industrial branches and the impact of the Third Industrial Revolution are proposed as reasons for the impressive decline in all the developed economies.

In Portugal, most of the long-run growth in energy occurred when the transition towards the service sector was on its way. What is interesting is that Portugal is the country with a larger impact of structural shifts towards the service sector, but that did not bring any sort of environmental relief. The only user category which is decoupling from economic growth is residential energy, due to a late transition from wood towards more efficient fuels such as oil, electricity and natural gas, and to a falling share of residential energy as a result of economic growth in the formal sectors. Portugal shares with Spain some elements typical of late-comers, such as the increase of personal transportation in relation to economic growth. In this respect Spain and Portugal are following in the footsteps of early-comers. Portugal also shares with Spain and Italy an increase of the service sector intensities. As most of the energy in the service sector is consumed by buildings, it is likely that southern European countries are catching up in thermal comfort with the northern Economies.

What is specific for Portugal is the increase in industrial energy intensities compared to industrialized nations. There are various possible reasons for the disparities in industrial energy intensities. In the first place, Portugal followed a low resource intensive path and sub-sectoral structural changes were of a different nature. For example, with the advent of globalization, construction, textiles and food industries, lost weight in the Portuguese industrial structure to much more intensive branches such as pulp, chemicals and cement. Secondly, there are reasons to believe in some technological convergence across industries in the various countries. As a result Portugal uses relatively more capital per worker today than back in the 1970s. But this could also work to decrease energy intensity as a rise in productivity should be expected with the adoption of modern technology. A more concerning factor is that Portuguese industry has probably not been able to move up in the value-added chain like other developed countries have done. In a time when knowledge is the important factor of production, producing low value-added products can be extremely energy inefficient and compromise the decoupling of energy from economic growth. Is Portugal also losing the advantages of the Third Industrial Revolution (knowledge intensive), after failing to industrialize during the First Industrial Revolution and a large part of the Second Industrial Revolution (both energy intensive)?

6.4. The drivers of historical fossil-fuel CO_2 emissions and the transition towards a low carbon future

This thesis explores the drivers behind the long-run CO_2 emissions across countries, by decomposing changes in CO_2 emissions into energy intensity, population, income and energy mix changes. In the long-run, income and population growth (scale effects) are the most important drivers of changes in CO_2 emissions. However, changes in the energy mix (fuel switching) are also quite important. At low levels of pollution per capita, the transition from traditional energies towards fossil fuels is a factor which has great significance for determining the rise of CO_2 emissions. At high levels of pollution per capita, substitution of natural gas for coal and oil and the expansion of nuclear power are also important forces, which, along with declines in energy intensity, reduce emissions in some early-industrializers.

The impact of energy policies in changing CO_2 emissions since 1990 has been quite limited in relation to the negotiated Kyoto targets in most countries. The contribution of energy savings and fuel switching to the decline in CO_2 emissions was smaller in the period 1990-2006 than in 1973-1990, pointing to a need to accelerate energy policies if the Kyoto commitments are to be fulfilled. Late-comers such as Portugal and Spain seem to have more difficulty reaching the targets, as a result of historically low energy consumption paths and low intensive industrialization.The different results of the fuel switching factor across countries cannot be explained only in terms of successful mitigation policies. Countries with a large historical proportion of renewable energy, no nuclear power or low coal usage can have more difficulties in reaching the targets.

In Portugal, the effects of transition from biomass towards fossil fuels contributed to a rise in CO_2 emissions in the whole period, offsetting the negative impact on CO_2 emissions of inter-fossil fuel substitution and carbon-free energy sources. CO_2 emissions have been increasing disproportionally faster in relation to economic growth in the last decades as a result of increasing energy intensities and a still ongoing transition away from biomass towards fossil fuels.

Portuguese environmental policies are a consequence of its membership in the European Union. As a result of a burden sharing agreement, Portugal is committed to limiting the increase of CO_2 emissions to 27% in relation to its 1990 levels, which is in practice a policy tunnel as Portugal is not expected to reach the past per capita CO_2 emissions of early-comers[623]. An increase of renewable energy is part of the package of environmental policies: Portugal agreed to maintain a forty percent share of renewable electricity in 2010 and recently embraced an even more ambitious goal of 60% of renewable electricity by 2020.

This dissertation does not discuss the present environmental policies in as much detail as the past energy development policies, but points to some bottlenecks which arise from the massive deployment of renewable energy. Firstly, large increases in the capacity of wind-power and hydropower do not mean proportional increases in electricity generation. Despite the growth in investment in renewable capacity, successive droughts have caused renewable electricity to oscillate between 17% and 50% of the total production. Secondly, generous feed-in-tariffs are presently affecting average electricity generation costs, which can compromise competition with other countries with less stringent targets. Thirdly, the early adoption of renewable technology does not seem to have created a stronger renewable cluster which could enhance further growth. Will some of these bottlenecks disappear in the near future?

Excluding the environmental component, which is an important element of present energy policies, it will be interesting to compare the future development of these policies with the hydropower policy of the post-war period. The latter promised much, but failed to reach the full potential in a period of cheap oil. How will the renewable policies of today succeed in a period of expensive fossil-fuels?

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[623] The expression of policy tunnel is used by Munasinghe (1999).

At the time of writing this conclusion, it seems that most of the European countries will be able to meet the Kyoto requirements. Portugal also seems to be on target. Unfortunately, and especially true in the Portuguese case, negative economic growth has been the best friend of the environment[624]. The challenge that remains is how to re-enter a period of convergence with the European core without substantially increasing energy needs, which are still far below the European Union average.

6.5. Future research

This thesis argues that natural resource endowments determined the mode of industrialization in each country and were among the main reasons for the past disparity of energy intensity pathways. Countries which industrialized early on had a much more energy intensive industrialization as the path of growth was biased towards the use of resources. Late-comers such as Portugal, Spain, or even Italy, never reached the same intensity patterns as the pioneers. Similar results are produced by comparing the historical experience of pioneers with other late-comers or developing countries. For example, Marcotullio & Schulz[625] contrasted the historically resource-intensive pathway of a pioneer, the US (1850-2000), and 29 developing and new industrialized countries (1960-2000). At the time late-comers attained the same levels of development as the US had done, they used less energy per capita, polluted less and combined more diversified forms of energy. This seems to confirm the idea of Reddy & Goldemberg[626], that developing countries would leapfrog the intensive steps of their predecessors, benefiting from a more efficient and cleaner stock of technology at the time of their industrialization. However, even if there is evidence that developing countries (China included) follow less resource intensive patterns than pioneers, many developing countries of today follow more resource intensive patterns than for example Portugal, Spain and Italy.

The study of energy structures from the production point of view does not say much about the impact of the improvement of technological efficiency on reducing the energy needs of developing countries. In the past, the production of energy intensive goods was much more concentrated in a few endowed countries than it is today.

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[625] Marcotullio & Schulz (2007). The energy dataset used by the authors included modern energy carriers and fuelwood.

[626] Reddy and Goldemberg (1990).

Therefore, in order to ascertain whether developing countries use less energy today than pioneers in the past, we have to account for the energy that is embodied in the external trade as well. The study of energy structures from the point of view of consumption would provide a valuable insight into whether technological efficiency has reduced the energy consumption needs of developing countries.

Appendix A

Aggregate Series, Portugal

Table A.1 Population, total and per capita energy consumption, GDP and Energy Intensity, 1856-2006

	Population	**Total energy consumption** PJ	**Per capita consumption** GJ	**GDP** million 1990$	**Energy intensity** MJ/1990$
1856	3,957,349	73	18.4	3,705	19.7
1857	3,986,231	73	18.2		
1858	4,015,114	73	18.2		
1859	4,043,997	74	18.4		
1860	4,072,879	74	18.1		
1861	4,101,762	74	18	3,903	18.9
1862	4,130,645	74	18		
1863	4,159,527	75	18.1		
1864	4,188,410	76	18.1		
1865	4,213,303	76	18.1	4,229	18
1866	4,238,344	78	18.5	4,169	18.8
1867	4,263,533	78	18.3	4,230	18.5
1868	4,288,873	80	18.7	4,199	19.1
1869	4,314,363	79	18.2	4,205	18.7
1870	4,340,004	81	18.6	4,325	18.6
1871	4,365,798	80	18.3	4,120	19.4
1872	4,391,745	81	18.4	4,280	18.9
1873	4,417,847	84	18.9	4,373	19.1
1874	4,444,103	82	18.5	4,408	18.7
1875	4,470,516	84	18.7	4,453	18.8
1876	4,497,085	84	18.6	4,395	19.1
1877	4,523,813	85	18.8	4,494	19
1878	4,550,699	86	18.9	4,393	19.5
1879	4,590,330	86	18.8	4,442	19.5
1880	4,630,307	89	19.2	4,583	19.4
1881	4,670,631	89	19.2	4,726	18.9
1882	4,711,307	92	19.4	4,674	19.6
1883	4,752,337	92	19.4	4,684	19.7
1884	4,793,725	94	19.5	5,290	17.7
1885	4,835,473	93	19.2	5,096	18.2
1886	4,877,584	95	19.6	5,323	17.9
1887	4,920,062	97	19.8	5,624	17.3

	Population	**Total energy consumption** PJ	**Per capita consumption** GJ	**GDP** million 1990$	**Energy intensity** MJ/1990$
1888	4,962,910	99	19.9	5,581	17.7
1889	5,006,131	102	20.3	5,538	18.3
1890	5,049,729	103	20.3	5,656	18.1
1891	5,085,882	104	20.4	5,734	18.1
1892	5,122,294	103	20.2	5,829	17.7
1893	5,158,966	102	19.7	5,440	18.7
1894	5,195,902	105	20.3	5,538	19
1895	5,233,101	105	20	5,747	18.2
1896	5,270,567	105	20	5,813	18.1
1897	5,308,301	106	20	6,028	17.6
1898	5,346,305	110	20.5	6,548	16.7
1899	5,384,582	110	20.3	6,365	17.2
1900	5,423,132	111	20.5	6,406	17.4
1901	5,469,876	112	20.4	6,787	16.5
1902	5,517,022	115	20.8	6,932	16.6
1903	5,564,575	116	20.9	6,707	17.3
1904	5,612,538	119	21.2	6,788	17.5
1905	5,660,915	119	21	6,633	17.9
1906	5,709,708	123	21.5	6,533	18.8
1907	5,758,922	126	21.8	6,546	19.2
1908	5,808,560	127	21.9	7,016	18.1
1909	5,858,626	128	21.8	6,932	18.4
1910	5,909,123	130	22	6,879	18.9
1911	5,960,056	131	22	7,114	18.5
1912	5,968,116	135	22.5	7,236	18.6
1913	5,976,187	137	22.9	7,212	18.9
1914	5,984,269	134	22.3	7,266	18.4
1915	5,992,362	132	22	7,109	18.5
1916	6,000,466	130	21.6	7,153	18.2
1917	6,008,581	118	19.6	7,047	16.7
1918	6,016,706	116	19.2	6,320	18.3
1919	6,024,843	125	20.8	6,840	18.3
1920	6,032,991	127	21.1	7,166	17.7
1921	6,107,947	121	19.8	7,569	15.9
1922	6,183,835	129	20.9	8,481	15.2
1923	6,260,666	127	20.3	8,844	14.3
1924	6,338,451	133	20.9	8,523	15.6
1925	6,417,203	135	21.1	8,896	15.2
1926	6,496,933	135	20.8	8,840	15.3
1927	6,577,653	142	21.6	10,363	13.7

	Population	**Total energy consumption** PJ	**Per capita consumption** GJ	**GDP** million 1990$	**Energy intensity** MJ/1990$
1928	6,659,377	149	22.4	9,378	15.9
1929	6,742,116	149	22.1	10,382	14.4
1930	6,825,883	154	22.6	10,255	15
1931	6,910,616	153	22.1	10,778	14.2
1932	6,996,402	148	21.2	10,988	13.5
1933	7,083,252	156	22	11,719	13.3
1934	7,171,180	157	21.9	12,213	12.9
1935	7,260,200	161	22.1	11,576	13.9
1936	7,350,325	159	21.7	10,713	14.9
1937	7,441,589	171	23	12,490	13.7
1938	7,533,945	167	22.1	12,574	13.2
1939	7,627,468	173	22.7	12,743	13.6
1940	7,722,152	167	21.6	11,926	14
1941	7,791,221	169	21.7	13,022	13
1942	7,860,907	167	21.2	12,850	13
1943	7,931,217	173	21.8	13,695	12.6
1944	8,002,156	186	23.3	14,708	12.7
1945	8,073,729	183	22.6	13,915	13.1
1946	8,145,942	192	23.6	14,990	12.8
1947	8,218,801	208	25.3	16,224	12.8
1948	8,292,312	196	23.6	16,176	12.1
1949	8,366,480	199	23.7	16,400	12.1
1950	8,441,312	199	23.6	16,862	11.8
1951	8,481,440	201	23.7	18,128	11.1
1952	8,521,759	199	23.4	17,742	11.2
1953	8,562,270	208	24.3	19,299	10.8
1954	8,602,973	211	24.5	20,280	10.4
1955	8,643,870	220	25.4	20,869	10.5
1956	8,684,961	224	25.8	21,588	10.4
1957	8,726,248	228	26.1	22,551	10.1
1958	8,767,731	227	25.9	23,972	9.5
1959	8,809,411	232	26.3	24,924	9.3
1960	8,851,289	241	27.2	26,056	9.2
1961	8,822,616	251	28.5	26,807	9.4
1962	8,794,036	254	28.9	29,854	8.5
1963	8,765,548	261	29.8	30,841	8.5
1964	8,737,153	261	29.9	32,545	8
1965	8,708,850	273	31.3	35,629	7.7
1966	8,680,638	275	31.7	37,195	7.4
1967	8,652,518	288	33.3	38,605	7.5

	Population	**Total energy consumption** PJ	**Per capita consumption** GJ	**GDP** million 1990$	**Energy intensity** MJ/1990$
1968	8,624,489	294	34.1	40368	7.3
1969	8,596,551	313	36.4	41,399	7.6
1970	8,568,703	335	39.1	45,134	7.4
1971	8,689,199	346	39.8	50,325	6.9
1972	8,811,389	364	41.3	55,710	6.5
1973	8,935,297	386	43.2	58,626	6.6
1974	9,060,948	397	43.9	60,397	6.6
1975	9,188,366	418	45.5	56,882	7.3
1976	9,317,576	429	46	57,898	7.4
1977	9,448,602	437	46.3	62,151	7
1978	9,581,471	447	46.6	65,993	6.8
1979	9,716,209	471	48.5	70,340	6.7
1980	9,852,841	493	50	73,801	6.7
1981	9,853,810	507	51.5	75,850	6.7
1982	9,854,780	528	53.6	77,701	6.8
1983	9,855,750	538	54.6	78,966	6.8
1984	9,856,719	532	54	78,510	6.8
1985	9,857,689	531	53.9	79,917	6.6
1986	9,858,659	562	57	82,639	6.8
1987	9,859,629	586	59.4	88,952	6.6
1988	9,860,599	608	61.7	93,489	6.5
1989	9,861,570	688	69.7	99,730	6.9
1990	9,862,540	718	72.8	107,427	6.7
1991	9,863,510	742	75.2	112,120	6.6
1992	9,867,768	786	79.7	113,341	6.9
1993	9,885,593	774	78.3	111,025	7
1994	9,915,301	793	80	112,096	7.1
1995	9,938,671	837	84.2	116,897	7.2
1996	9,961,843	842	84.6	121,143	7
1997	9,994,621	893	89.4	126,210	7.1
1998	10,031,459	939	93.6	132,300	7.1
1999	10,079,090	1,013	100.5	137,341	7.4
2000	10,150,092	1,032	101.7	142,770	7.2
2001	10,329,340	1,035	100.2	145,636	7.1
2002	10,407,470	1,081	103.9	146,782	7.4
2003	10,474,685	1,053	100.5	145,636	7.2
2004	10,529,255	1,077	102.3	147,841	7.3
2005	10,569,592	1,100	104.1	148,905	7.4
2006	10,599,095	1,071	101	150,708	7.1

Appendix B

Energy Carriers, Portugal

Table B.1 Energy consumption in Portugal 1856-2006

	1	2	3	4	5	6	7	8	9	
	Food for men	**Animals**	**Fire-wood**	**Wind & Water**	**Coal**	**Oil**	**Natural Gas**	**Primary electricity**	**Others**	**Total**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1856	13.7	12.9	41.8	0.9	3.6					73
1857	13.8	12.9	42.1	0.9	2.8					73
1858	13.9	13.0	41.7	0.9	3.3					73
1859	14.0	13.1	42.2	1.0	4.0					74
1860	14.1	13.2	42.2	1.0	3.2					74
1861	14.2	13.3	42.5	1.0	2.7	0.0				74
1862	14.3	13.4	42.9	1.0	2.8	0.0				74
1863	14.4	13.4	43.4	1.0	2.9	0.0				75
1864	14.5	13.5	43.5	1.0	3.0	0.0				76
1865	14.6	13.6	43.8	1.0	3.1	0.0				76
1866	14.7	13.7	44.2	1.0	4.8	0.0				78
1867	14.8	13.8	44.4	1.0	4.2	0.1				78
1868	14.9	13.9	44.5	1.0	5.7	0.1				80
1869	15.0	13.9	44.8	1.0	3.9	0.2				79
1870	15.0	14.0	45.2	1.0	5.2	0.2				81
1871	15.1	14.1	45.3	1.0	4.1	0.1				80
1872	15.2	14.1	45.9	1.0	4.5	0.1				81
1873	15.3	14.2	46.4	1.0	6.5	0.2				84
1874	15.4	14.2	46.6	1.0	4.8	0.2				82
1875	15.5	14.3	47.0	1.0	5.8	0.1				84
1876	15.6	14.3	47.0	1.0	5.7	0.2				84
1877	15.7	14.4	47.6	1.0	6.4	0.2				85
1878	15.8	14.4	47.6	1.0	6.7	0.2				86
1879	15.9	14.5	48.1	1.0	6.6	0.3				86
1880	16.1	14.5	48.3	1.0	8.4	0.3				89
1881	16.2	14.6	48.8	1.0	8.5	0.4				89
1882	16.4	14.6	49.5	1.0	9.7	0.3				92
1883	16.6	14.7	49.5	1.0	10.3	0.2				92
1884	16.7	14.7	49.8	1.0	11.0	0.4				94
1885	16.9	14.8	49.8	1.0	10.0	0.4				93
1886	17.1	14.8	50.9	1.0	11.2	0.4				95

	Food for men PJ	Animals PJ	Fire-wood PJ	Wind & Water PJ	Coal PJ	Oil PJ	Natural Gas PJ	Primary electricity PJ	Others PJ	Total PJ
1887	17.2	14.9	51.3	1.1	12.4	0.4				97
1888	17.4	14.9	51.8	1.1	13.2	0.5				99
1889	17.6	15.0	51.9	1.1	15.5	0.5				102
1890	17.8	15.0	51.9	1.1	16.3	0.5				103
1891	17.9	15.1	52.4	1.1	16.7	0.5				104
1892	18.0	15.1	52.6	1.2	15.8	0.6				103
1893	18.1	15.2	53.0	1.2	13.6	0.6				102
1894	18.2	15.2	53.6	1.2	16.6	0.6		0.001		105
1895	18.3	15.3	53.8	1.2	15.6	0.6		0.001		105
1896	18.4	15.3	54.0	1.3	15.6	0.6		0.001		105
1897	18.5	15.4	54.5	1.3	16.0	0.6		0.002		106
1898	18.6	15.4	54.9	1.3	18.6	0.6		0.002		110
1899	18.7	15.5	55.4	1.4	17.9	0.6		0.002		110
1900	18.9	15.5	55.8	1.3	19.1	0.6		0.002		111
1901	19.0	15.6	56.2	1.3	18.9	0.7		0.002		112
1902	19.2	15.6	57.1	1.3	20.9	0.6		0.003		115
1903	19.3	15.7	57.3	1.3	21.8	0.7		0.003		116
1904	19.5	15.7	57.9	1.3	23.9	0.6		0.004		119
1905	19.7	15.8	57.9	1.2	23.4	0.7		0.005		119
1906	19.8	15.9	58.3	1.2	26.6	0.7		0.007		123
1907	20.0	15.9	58.7	1.2	29.3	0.7		0.007		126
1908	20.1	15.9	59.3	1.2	29.7	0.7		0.008		127
1909	20.3	16.0	59.6	1.2	29.7	0.8		0.011		128
1910	20.5	16.0	60.2	1.2	30.7	1.1		0.011		130
1911	20.6	16.0	60.6	1.2	31.7	1.1		0.014		131
1912	20.6	16.0	61.1	1.2	34.7	0.8		0.016		135
1913	20.6	16.0	61.1	1.2	36.7	1.0		0.019		137
1914	20.6	16.0	62.0	1.2	33.2	0.7		0.022		134
1915	20.6	16.0	63.0	1.1	30.2	0.7		0.025		132
1916	20.6	16.0	64.4	1.1	26.7	1.0		0.026		130
1917	20.6	16.0	68.1	1.1	11.1	1.0		0.027		118
1918	20.6	16.0	70.9	1.1	6.9	0.3		0.028		116
1919	20.5	16.0	69.9	1.1	16.4	1.4		0.030		125
1920	20.5	16.0	71.3	1.1	16.4	1.7		0.037		127
1921	20.8	16.0	64.2	1.1	16.9	1.6		0.039		121
1922	21.0	16.0	63.9	1.1	25.1	1.9		0.081		129
1923	21.3	16.0	64.7	1.1	21.4	2.1		0.103		127
1924	21.6	16.0	65.8	1.1	25.7	2.3		0.119		133
1925	21.8	16.0	66.8	1.1	27.2	2.2		0.151		135
1926	22.1	16.0	67.5	1.1	25.2	2.7		0.173		135

	Food for men	Animals	Fire-wood	Wind & Water	Coal	Oil	Natural Gas	Primary electricity	Others	Total
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1927	22.4	16.0	68.1	1.1	31.2	3.1		0.210		142
1928	22.6	16.0	70.3	1.1	34.3	4.3		0.260		149
1929	22.9	16.1	71.3	1.1	33.3	4.2		0.286		149
1930	23.2	16.1	72.0	1.1	36.7	4.9		0.347		154
1931	23.4	16.1	72.6	1.1	34.1	4.9		0.360		153
1932	23.7	16.1	73.4	1.1	29.0	4.9		0.392		148
1933	24.0	16.1	74.1	1.1	34.6	5.5		0.370		156
1934	24.2	16.1	74.1	1.1	34.7	6.5		0.390		157
1935	24.5	16.0	75.0	1.0	36.7	7.0		0.442		161
1936	24.8	16.0	76.4	1.0	33.8	6.8		0.499		159
1937	25.1	15.9	77.4	1.0	43.3	7.9		0.524		171
1938	25.4	15.8	78.2	1.0	37.5	8.2		0.474		167
1939	25.9	15.8	81.4	1.0	39.9	8.8		0.688		173
1940	26.4	15.7	84.6	0.9	28.9	9.3		0.671		167
1941	26.9	15.7	87.5	1.0	28.7	8.3		0.718		169
1942	27.3	15.7	94.6	1.0	24.9	2.7		0.812		167
1943	27.8	15.8	98.5	1.0	24.6	4.9		0.764		173
1944	28.2	15.8	104.2	1.0	26.3	10.2		0.742		186
1945	28.7	15.8	102.5	1.0	25.0	9.1		0.729		183
1946	29.2	15.8	102.7	1.0	26.8	15.8		1.173		192
1947	29.7	15.8	98.4	0.9	36.9	24.7		1.210		208
1948	30.1	15.9	88.3	1.0	32.3	26.9		1.306		196
1949	30.0	15.9	88.5	0.9	35.7	26.5		1.017		199
1950	32.3	15.9	88.3	0.9	30.7	29.6		1.609		199
1951	32.1	15.9	87.6	0.9	27.2	34.2		2.959		201
1952	30.6	15.9	87.4	0.9	22.6	37.5		4.338		199
1953	32.2	15.9	88.8	0.9	26.4	40.6		3.649		208
1954	32.4	16.0	89.4	0.9	22.2	44.6		5.307		211
1955	32.2	16.0	89.5	0.8	23.4	50.9		6.332	0.8	220
1956	33.3	15.6	90.1	0.8	23.6	52.7		7.465	0.8	224
1957	33.1	15.2	90.7	0.8	28.0	52.3		6.777	0.8	228
1958	31.9	14.8	90.0	0.8	24.0	55.4		9.160	0.7	227
1959	32.9	14.4	90.4	0.8	21.4	60.9		10.4	0.9	232
1960	34.2	13.9	91.7	0.8	21.6	66.1		11.3	1.0	241
1961	33.3	13.5	90.2	0.8	27.0	72.5		12.5	1.1	251
1962	34.4	13.1	89.3	0.8	25.4	77.3		12.9	1.1	254
1963	35.6	12.7	87.1	0.7	28.9	80.1		14.8	1.2	261
1964	33.7	12.3	86.5	0.7	28.2	82.9		15.3	1.5	261
1965	37.3	11.9	85.4	0.7	27.5	91.7		16.0	2.3	273
1966	36.4	11.5	83.8	0.6	30.0	91.3		19.2	2.7	275

	Food for men	Animals	Fire-wood	Wind & Water	Coal	Oil	Natural Gas	Primary electricity	Others	Total
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1967	38.6	11.1	83.9	0.6	28.1	103.3		19.8	3.1	288
1968	39.0	10.7	83.5	0.5	25.3	112.7		19.2	3.5	294
1969	40.0	10.3	82.1	0.5	28.3	124.2		23.1	4.3	313
1970	39.3	9.9	80.8	0.5	26.0	153.1		21.1	4.7	335
1971	40.2	9.4	78.9	0.5	19.8	170.5		23.0	3.2	346
1972	40.6	9.0	78.0	0.5	17.5	191.0		25.9	1.5	364
1973	41.1	8.8	77.2	0.5	20.4	209.2		26.4	2.3	386
1974	42.6	8.6	76.6	0.4	16.1	222.6		28.6	1.9	397
1975	42.9	8.4	76.3	0.4	16.7	246.5		23.9	2.6	418
1976	43.2	8.1	75.2	0.4	16.4	259.1		23.8	2.5	429
1977	43.3	7.9	75.9	0.4	16.8	256.4		34.1	2.6	437
1978	41.5	7.7	75.0	0.4	18.1	263.1		38.3	2.5	447
1979	41.1	7.4	73.6	0.4	18.2	287.9		39.8	2.9	471
1980	41.9	7.3	73.4	0.4	17.7	313.4		35.7	3.1	493
1981	42.0	7.2	73.1	0.4	15.5	336.2		29.9	3.2	507
1982	42.5	7.1	73.8	0.1	13.5	352.0		35.8	3.6	528
1983	42.5	7.0	73.4	0.1	16.3	356.5		37.7	4.2	538
1984	43.1	6.8	72.7	0.1	17.8	349.1		38.2	4.1	532
1985	45.2	6.7	76.5	0.1	32.6	318.7		47.2	4.1	531
1986	47.4	6.6	76.6	0.1	60.8	328.6		37.6	4.4	562
1987	49.7	6.5	80.0	0.0	79.2	321.8		44.0	4.8	586
1988	49.9	6.4	79.7	0.0	87.4	326.6		52.9	5.0	608
1989	50.4	6.3	77.8	0.0	107.5	414.8		26.0	4.8	688
1990	51.9	5.9	77.9	0.0	115.6	413.6		33.6	19.7	718
1991	51.9	5.5	76.0	0.0	121.7	428.6		33.4	24.9	742
1992	52.2	5.2	75.3	0.0	123.5	482.0		23.1	24.7	786
1993	53.0	4.8	74.4	0.0	131.6	454.3		32.1	24.1	774
1994	53.6	4.5	72.9	0.0	139.3	455.9		41.9	25.1	793
1995	53.8	4.1	73.8	0.0	150.9	493.7		33.9	27.1	837
1996	54.2	3.7	74.8	0.0	143.6	482.4		57.8	25.9	842
1997	52.7	3.4	75.5	0.0	147.1	523.4	3.6	58.2	29.3	893
1998	55.3	3.0	75.0	0.8	135.3	563.1	29.3	48.5	29.0	939
1999	57.5	2.7	75.6	0.8	156.9	580.2	81.9	25.1	32.6	1013
2000	58.2	2.4	74.5	0.8	159.6	562.4	89.6	46.4	38.5	1032
2001	59.3	2.2	74.7	0.8	134.0	577.2	94.9	53.9	37.8	1035
2002	59.5	2.1	75.4	0.8	146.6	603.6	114.8	38.2	40.2	1081
2003	59.9	1.9	77.1	0.8	140.5	551.7	110.9	70.0	40.4	1053
2004	60.2	1.8	80.1	0.9	141.3	552.5	138.9	63.1	38.6	1077
2005	60.4	1.7	80.3	1.0	140.2	569.4	157.5	49.6	40.0	1100
2006	60.6	1.5	81.3	1.4	138.6	524.4	150.5	71.7	40.6	1071

Table B.2 Animals, 1856-2006

	Work Cows 10^3	Work Oxen 10^3	Work Horses 10^3	Work Mules 10^3	Work Donk 10^3	Cows PJ	Oxen PJ	Horses PJ	Mules PJ	Donk. PJ	Total PJ
1856	127	283	63	46	115	1.0	6.8	1.8	1.1	2.1	12.9
1857	127	283	64	47	115	1.0	6.8	1.8	1.1	2.1	12.9
1858	126	283	64	48	116	1.0	6.9	1.8	1.2	2.2	13.0
1859	126	283	65	49	117	1.0	6.9	1.8	1.2	2.2	13.1
1860	126	283	65	50	117	1.0	6.9	1.9	1.2	2.2	13.2
1861	125	284	66	51	118	1.0	7.0	1.9	1.2	2.2	13.3
1862	125	284	66	52	118	1.0	7.0	1.9	1.3	2.2	13.4
1863	125	284	67	54	119	1.0	7.0	1.9	1.3	2.2	13.4
1864	124	284	67	55	120	1.0	7.0	1.9	1.3	2.2	13.5
1865	124	284	68	56	120	1.0	7.1	1.9	1.3	2.2	13.6
1866	124	284	68	57	121	1.0	7.1	1.9	1.4	2.2	13.7
1867	124	285	69	58	121	1.0	7.1	1.9	1.4	2.3	13.8
1868	123	285	69	59	122	1.0	7.2	2.0	1.4	2.3	13.9
1869	123	285	70	60	123	1.0	7.2	2.0	1.5	2.3	13.9
1870	123	285	70	61	123	1.0	7.2	2.0	1.5	2.3	14.0
1871	124	285	70	61	123	1.1	7.2	2.0	1.5	2.3	14.1
1872	126	285	70	61	124	1.1	7.3	2.0	1.5	2.3	14.1
1873	128	285	71	61	124	1.1	7.3	2.0	1.5	2.3	14.2
1874	129	285	71	61	124	1.1	7.3	2.0	1.5	2.3	14.2
1875	131	285	71	61	124	1.1	7.3	2.0	1.5	2.3	14.3
1876	132	285	71	61	124	1.1	7.4	2.0	1.5	2.3	14.3
1877	134	285	71	61	124	1.2	7.4	2.0	1.5	2.3	14.4
1878	135	285	72	61	125	1.2	7.4	2.0	1.5	2.3	14.4
1879	137	285	72	61	125	1.2	7.4	2.0	1.5	2.3	14.5
1880	139	285	72	61	125	1.2	7.5	2.0	1.5	2.3	14.5
1881	140	285	72	61	125	1.2	7.5	2.1	1.5	2.3	14.6
1882	142	285	72	61	125	1.2	7.5	2.1	1.5	2.3	14.6
1883	143	285	73	60	125	1.3	7.5	2.1	1.5	2.3	14.7
1884	145	285	73	60	126	1.3	7.6	2.1	1.5	2.3	14.7
1885	147	285	73	60	126	1.3	7.6	2.1	1.5	2.3	14.8
1886	148	285	73	60	126	1.3	7.6	2.1	1.5	2.3	14.8
1887	150	285	74	60	126	1.3	7.6	2.1	1.5	2.3	14.9
1888	151	285	74	60	126	1.4	7.7	2.1	1.5	2.3	14.9
1889	153	285	74	60	126	1.4	7.7	2.1	1.4	2.3	15.0
1890	155	285	74	60	126	1.4	7.7	2.1	1.4	2.3	15.0
1891	156	285	74	60	127	1.4	7.8	2.1	1.4	2.4	15.1
1892	158	285	75	60	127	1.4	7.8	2.1	1.4	2.4	15.1
1893	159	285	75	60	127	1.5	7.8	2.1	1.4	2.4	15.2

	Work Cows 10^3	Work Oxen 10^3	Work Horses 10^3	Work Mules 10^3	Work Donk 10^3	Cows PJ	Oxen PJ	Horses PJ	Mules PJ	Donk. PJ	Total PJ
1894	161	285	75	60	127	1.5	7.8	2.1	1.4	2.4	15.2
1895	163	285	75	60	127	1.5	7.9	2.1	1.4	2.4	15.3
1896	164	285	75	60	127	1.5	7.9	2.1	1.4	2.4	15.3
1897	166	285	76	59	128	1.5	7.9	2.1	1.4	2.4	15.4
1898	167	285	76	59	128	1.6	7.9	2.2	1.4	2.4	15.4
1899	169	285	76	59	128	1.6	8.0	2.2	1.4	2.4	15.5
1900	171	285	76	59	128	1.6	8.0	2.2	1.4	2.4	15.5
1901	172	285	76	59	128	1.6	8.0	2.2	1.4	2.4	15.6
1902	174	285	77	59	128	1.6	8.0	2.2	1.4	2.4	15.6
1903	175	285	77	59	129	1.7	8.1	2.2	1.4	2.4	15.7
1904	177	285	77	59	129	1.7	8.1	2.2	1.4	2.4	15.7
1905	178	285	77	59	129	1.7	8.1	2.2	1.4	2.4	15.8
1906	180	285	77	59	129	1.7	8.1	2.2	1.4	2.4	15.9
1907	182	281	77	60	133	1.7	8.0	2.2	1.5	2.5	15.9
1908	184	277	77	62	137	1.8	7.9	2.2	1.5	2.6	15.9
1909	185	272	76	64	142	1.8	7.8	2.2	1.5	2.6	16.0
1910	187	268	76	65	146	1.8	7.7	2.2	1.6	2.7	16.0
1911	189	264	76	67	150	1.8	7.6	2.2	1.6	2.8	16.0
1912	191	259	76	69	154	1.8	7.5	2.1	1.7	2.9	16.0
1913	193	255	75	70	158	1.9	7.4	2.1	1.7	2.9	16.0
1914	195	251	75	72	162	1.9	7.2	2.1	1.7	3.0	16.0
1915	196	247	75	74	167	1.9	7.1	2.1	1.8	3.1	16.0
1916	198	242	74	75	171	1.9	7.0	2.1	1.8	3.2	16.0
1917	200	238	74	77	175	1.9	6.9	2.1	1.9	3.2	16.0
1918	202	234	74	79	179	1.9	6.7	2.1	1.9	3.3	16.0
1919	204	229	73	80	183	2.0	6.6	2.1	1.9	3.4	16.0
1920	205	225	73	82	188	2.0	6.5	2.1	2.0	3.5	16.0
1921	207	221	73	84	192	2.0	6.4	2.1	2.0	3.6	16.0
1922	209	217	72	85	196	2.0	6.3	2.1	2.1	3.6	16.0
1923	211	212	72	87	200	2.0	6.1	2.1	2.1	3.7	16.0
1924	213	208	72	89	204	2.0	6.0	2.0	2.1	3.8	16.0
1925	214	204	72	90	209	2.1	5.9	2.0	2.2	3.9	16.0
1926	215	198	72	94	211	2.1	5.7	2.0	2.3	3.9	16.0
1927	216	193	73	97	214	2.1	5.6	2.1	2.4	4.0	16.0
1928	216	188	73	101	217	2.1	5.4	2.1	2.4	4.0	16.0
1929	217	183	74	104	220	2.1	5.3	2.1	2.5	4.1	16.1
1930	218	177	74	108	223	2.1	5.1	2.1	2.6	4.1	16.1
1931	218	172	75	111	225	2.1	5.0	2.1	2.7	4.2	16.1
1932	219	167	76	115	228	2.1	4.8	2.1	2.8	4.2	16.1
1933	220	162	76	118	231	2.1	4.7	2.2	2.9	4.3	16.1
1934	220	156	77	122	234	2.1	4.5	2.2	2.9	4.3	16.1

	Work Cows 10^3	Work Oxen 10^3	Work Horses 10^3	Work Mules 10^3	Work Donk 10^3	Cows PJ	Oxen PJ	Horses PJ	Mules PJ	Donk. PJ	Total PJ
1935	224	156	76	122	230	2.2	4.5	2.2	2.9	4.3	16.0
1936	227	156	75	122	225	2.2	4.5	2.1	2.9	4.2	16.0
1937	230	156	75	122	221	2.2	4.5	2.1	3.0	4.1	15.9
1938	234	156	74	122	217	2.2	4.5	2.1	3.0	4.0	15.8
1939	237	156	73	123	213	2.3	4.5	2.1	3.0	3.9	15.8
1940	240	156	72	123	209	2.3	4.5	2.1	3.0	3.9	15.7
1941	240	157	72	123	208	2.3	4.5	2.0	3.0	3.9	15.7
1942	240	159	71	123	208	2.3	4.6	2.0	3.0	3.9	15.7
1943	240	160	70	124	207	2.3	4.6	2.0	3.0	3.8	15.8
1944	240	161	70	124	207	2.3	4.7	2.0	3.0	3.8	15.8
1945	240	163	69	124	206	2.3	4.7	2.0	3.0	3.8	15.8
1946	240	164	68	125	206	2.3	4.7	1.9	3.0	3.8	15.8
1947	240	166	68	125	205	2.3	4.8	1.9	3.0	3.8	15.8
1948	240	167	67	125	205	2.3	4.8	1.9	3.0	3.8	15.9
1949	240	168	67	126	204	2.3	4.9	1.9	3.0	3.8	15.9
1950	240	170	66	126	204	2.3	4.9	1.9	3.0	3.8	15.9
1951	240	171	65	126	203	2.3	4.9	1.9	3.0	3.8	15.9
1952	240	172	65	126	203	2.3	5.0	1.8	3.1	3.8	15.9
1953	240	174	64	127	202	2.3	5.0	1.8	3.1	3.8	15.9
1954	240	175	63	127	202	2.3	5.0	1.8	3.1	3.7	16.0
1955	240	176	63	127	201	2.3	5.1	1.8	3.1	3.7	16.0
1956	234	171	61	125	196	2.3	4.9	1.7	3.0	3.6	15.6
1957	229	167	59	123	190	2.2	4.8	1.7	3.0	3.5	15.2
1958	223	162	57	120	184	2.1	4.7	1.6	2.9	3.4	14.8
1959	218	157	55	118	178	2.1	4.5	1.6	2.9	3.3	14.4
1960	212	152	53	116	172	2.0	4.4	1.5	2.8	3.2	13.9
1961	207	147	51	113	167	2.0	4.3	1.5	2.7	3.1	13.5
1962	202	143	49	111	161	1.9	4.1	1.4	2.7	3.0	13.1
1963	196	138	47	109	155	1.9	4.0	1.3	2.6	2.9	12.7
1964	191	133	46	106	149	1.8	3.8	1.3	2.6	2.8	12.3
1965	185	128	44	104	143	1.8	3.7	1.2	2.5	2.7	11.9
1966	180	123	42	102	138	1.7	3.6	1.2	2.5	2.6	11.5
1967	174	118	40	100	132	1.7	3.4	1.1	2.4	2.4	11.1
1968	169	114	38	97	126	1.6	3.3	1.1	2.3	2.3	10.7
1969	163	109	36	95	120	1.6	3.1	1.0	2.3	2.2	10.3
1970	158	104	34	93	114	1.5	3.0	1.0	2.2	2.1	9.9
1971	153	99	32	90	109	1.5	2.9	0.9	2.2	2.0	9.4
1972	147	94	30	88	103	1.4	2.7	0.9	2.1	1.9	9.0
1973	142	92	30	86	103	1.4	2.7	0.8	2.1	1.9	8.8
1974	136	89	29	82	102	1.3	2.6	0.8	2.0	1.9	8.6

	Work Cows 10^3	**Work Oxen** 10^3	**Work Horses** 10^3	**Work Mules** 10^3	**Work Donk** 10^3	**Cows** PJ	**Oxen** PJ	**Horses** PJ	**Mules** PJ	**Donk.** PJ	**Total** PJ
1975	131	87	28	79	102	1.3	2.5	0.8	1.9	1.9	8.4
1976	125	84	28	75	102	1.2	2.4	0.8	1.8	1.9	8.1
1977	120	82	27	72	101	1.2	2.4	0.8	1.7	1.9	7.9
1978	114	79	26	68	101	1.1	2.3	0.7	1.7	1.9	7.7
1979	109	77	25	65	101	1.0	2.2	0.7	1.6	1.9	7.4
1980	104	78	26	63	97	1.0	2.3	0.7	1.5	1.8	7.3
1981	98	80	26	60	93	0.9	2.3	0.8	1.5	1.7	7.2
1982	93	82	27	58	89	0.9	2.4	0.8	1.4	1.7	7.1
1983	87	83	28	55	86	0.8	2.4	0.8	1.3	1.6	7.0
1984	82	85	28	53	82	0.8	2.5	0.8	1.3	1.5	6.8
1985	76	87	29	51	78	0.7	2.5	0.8	1.2	1.5	6.7
1986	71	88	29	48	75	0.7	2.6	0.8	1.2	1.4	6.6
1987	65	90	30	46	71	0.6	2.6	0.8	1.1	1.3	6.5
1988	60	92	30	44	67	0.6	2.6	0.9	1.1	1.2	6.4
1989	54	93	31	41	63	0.5	2.7	0.9	1.0	1.2	6.3
1990	49	86	31	39	60	0.5	2.5	0.9	1.0	1.1	5.9
1991	44	79	31	37	57	0.4	2.3	0.9	0.9	1.1	5.5
1992	38	72	31	36	54	0.4	2.1	0.9	0.9	1.0	5.2
1993	33	65	31	34	51	0.3	1.9	0.9	0.8	1.0	4.8
1994	27	58	31	32	48	0.3	1.7	0.9	0.8	0.9	4.5
1995	22	51	31	30	45	0.2	1.5	0.9	0.7	0.8	4.1
1996	16	43	31	28	42	0.2	1.3	0.9	0.7	0.8	3.7
1997	11	36	31	26	39	0.1	1.0	0.9	0.6	0.7	3.4
1998	5	29	31	24	36	0.1	0.8	0.9	0.6	0.7	3.0
1999	0	22	31	22	33	0.0	0.6	0.9	0.5	0.6	2.7
2000	0	15	31	20	30	0.0	0.4	0.9	0.5	0.6	2.4

Table B.3 Firewood

	Firewood urban households PJ	**Firewood rural households** PJ	**Firewood households** PJ	**Firewood industry** PJ	**Firewood transports** PJ	**Firewood power** PJ	**Total** PJ
1856	3.2	37.6	40.8	1.0	0.0	0.0	41.8
1857	3.3	37.9	41.1	0.9	0.0	0.0	42.1
1858	2.6	38.1	40.8	0.9	0.0	0.0	41.7
1859	2.8	38.4	41.2	0.9	0.0	0.0	42.2
1860	2.6	38.7	41.3	0.9	0.0	0.0	42.2
1861	2.6	39.0	41.6	0.9	0.0	0.0	42.5
1862	2.8	39.2	42.0	0.9	0.0	0.0	42.9
1863	2.9	39.5	42.4	1.0	0.0	0.0	43.4
1864	2.7	39.8	42.5	1.0	0.0	0.0	43.5
1865	2.7	40.0	42.7	1.0	0.0	0.0	43.8
1866	2.9	40.2	43.1	1.1	0.0	0.0	44.2
1867	2.9	40.4	43.3	1.1	0.0	0.0	44.4
1868	2.8	40.7	43.5	1.1	0.0	0.0	44.5
1869	2.8	40.9	43.7	1.1	0.0	0.0	44.8
1870	2.8	41.1	43.9	1.2	0.0	0.0	45.2
1871	2.9	41.3	44.2	1.1	0.0	0.0	45.3
1872	3.1	41.5	44.6	1.3	0.0	0.0	45.9
1873	3.1	41.8	44.9	1.5	0.0	0.0	46.4
1874	3.2	42.0	45.2	1.5	0.0	0.0	46.6
1875	3.3	42.2	45.5	1.4	0.0	0.0	47.0
1876	3.2	42.4	45.6	1.3	0.0	0.0	47.0
1877	3.4	42.7	46.1	1.5	0.0	0.0	47.6
1878	3.3	42.9	46.2	1.5	0.0	0.0	47.6
1879	3.5	43.2	46.7	1.4	0.0	0.0	48.1
1880	3.5	43.4	47.0	1.4	0.0	0.0	48.3
1881	3.6	43.7	47.3	1.5	0.0	0.0	48.8
1882	3.9	44.0	47.9	1.6	0.0	0.0	49.5
1883	3.6	44.3	47.9	1.6	0.0	0.0	49.5
1884	3.7	44.6	48.2	1.6	0.0	0.0	49.8
1885	3.4	44.8	48.3	1.6	0.0	0.0	49.8
1886	3.9	45.1	49.1	1.9	0.0	0.0	50.9
1887	3.9	45.4	49.3	2.0	0.0	0.0	51.3
1888	4.1	45.7	49.8	2.0	0.0	0.0	51.8
1889	4.0	46.0	50.0	1.9	0.0	0.0	51.9
1890	3.5	46.3	49.7	2.2	0.0	0.0	51.9

	Firewood urban households PJ	**Firewood rural households** PJ	**Firewood households** PJ	**Firewood industry** PJ	**Firewood transports** PJ	**Firewood power** PJ	**Total** PJ
1891	3.8	46.5	50.4	2.0	0.0	0.0	52.4
1892	3.8	46.8	50.6	2.0	0.0	0.0	52.6
1893	3.8	47.1	50.9	2.1	0.0	0.0	53.0
1894	4.2	47.4	51.6	2.0	0.0	0.0	53.6
1895	4.0	47.7	51.7	2.1	0.0	0.0	53.8
1896	3.9	48.0	51.9	2.1	0.0	0.0	54.0
1897	3.9	48.2	52.2	2.4	0.0	0.0	54.5
1898	3.9	48.5	52.4	2.4	0.0	0.0	54.9
1899	4.0	48.8	52.9	2.5	0.0	0.0	55.4
1900	3.9	49.1	53.0	2.7	0.0	0.0	55.8
1901	4.2	49.4	53.6	2.6	0.0	0.0	56.2
1902	4.7	49.7	54.4	2.7	0.0	0.0	57.1
1903	4.5	49.9	54.4	2.9	0.0	0.0	57.3
1904	4.7	50.2	54.9	3.0	0.0	0.0	57.9
1905	4.6	50.5	55.1	2.8	0.0	0.0	57.9
1906	4.7	50.7	55.4	2.9	0.0	0.0	58.3
1907	4.6	51.0	55.6	3.1	0.0	0.0	58.7
1908	5.0	51.3	56.3	3.0	0.0	0.0	59.3
1909	5.1	51.5	56.6	3.0	0.0	0.0	59.6
1910	5.1	51.8	57.0	3.3	0.0	0.0	60.2
1911	5.2	52.1	57.3	3.4	0.0	0.0	60.6
1912	5.6	52.1	57.7	3.5	0.0	0.0	61.1
1913	5.5	52.1	57.5	3.6	0.0	0.0	61.1
1914	5.5	52.1	57.5	4.5	0.0	0.0	62.0
1915	5.6	52.0	57.7	5.4	0.0	0.0	63.0
1916	5.2	52.0	57.2	7.2	0.0	0.0	64.4
1917	6.8	52.0	58.8	8.9	0.0	0.4	68.1
1918	7.3	52.0	59.3	10.7	0.0	0.9	70.9
1919	10.5	52.0	62.5	7.2	0.0	0.2	69.9
1920	15.0	52.0	67.0	4.1	0.0	0.1	71.3
1921	7.3	52.5	59.8	4.4	0.0	0.1	64.2
1922	6.0	53.0	59.0	4.8	0.0	0.1	63.9
1923	6.4	53.6	59.9	4.7	0.0	0.1	64.7
1924	6.8	54.1	60.9	4.8	0.0	0.1	65.8
1925	7.2	54.6	61.8	4.8	0.0	0.2	66.8
1926	7.1	55.2	62.3	5.0	0.0	0.2	67.5
1927	7.0	55.7	62.7	5.1	0.0	0.3	68.1
1928	8.6	56.3	64.9	5.1	0.0	0.3	70.3
1929	8.5	56.8	65.3	5.6	0.0	0.3	71.3

	Firewood urban households PJ	**Firewood rural households** PJ	**Firewood households** PJ	**Firewood industry** PJ	**Firewood transports** PJ	**Firewood power** PJ	**Total** PJ
1930	8.7	57.4	66.1	5.5	0.0	0.4	72.0
1931	8.4	58.1	66.5	5.7	0.0	0.4	72.6
1932	8.4	58.8	67.2	5.7	0.0	0.4	73.4
1933	8.4	59.5	68.0	5.8	0.0	0.3	74.1
1934	8.0	60.2	68.3	5.4	0.0	0.5	74.1
1935	8.2	61.0	69.1	5.4	0.0	0.4	75.0
1936	8.3	61.7	70.0	6.0	0.0	0.4	76.4
1937	8.2	62.5	70.7	6.2	0.0	0.5	77.4
1938	8.2	63.2	71.5	6.2	0.0	0.5	78.2
1939	8.4	64.0	72.4	8.5	0.0	0.6	81.4
1940	8.3	64.8	73.0	10.7	0.0	0.8	84.6
1941	8.1	65.3	73.5	13.0	0.0	1.1	87.5
1942	8.0	65.9	73.9	15.2	4.0	1.5	94.6
1943	7.9	66.4	74.3	15.2	6.6	2.4	98.5
1944	7.8	67.0	74.7	16.0	11.1	2.3	104.2
1945	7.6	67.5	75.2	16.6	8.4	2.3	102.5
1946	7.5	68.1	75.6	16.2	9.2	1.7	102.7
1947	7.3	68.7	76.0	13.4	8.0	1.0	98.4
1948	7.2	69.3	76.4	10.5	0.4	1.0	88.3
1949	7.3	69.8	77.1	9.8	0.3	1.4	88.5
1950	7.4	70.4	77.8	9.6	0.1	0.9	88.3
1951	n.d.	n.d.	77.9	9.1	0.0	0.5	87.6
1952	n.d.	n.d.	78.1	8.9	0.0	0.4	87.4
1953	n.d.	n.d.	78.3	10.1	0.0	0.4	88.8
1954	n.d.	n.d.	78.5	10.4	0.0	0.5	89.4
1955	n.d.	n.d.	78.6	10.4	0.0	0.4	89.5
1956	n.d.	n.d.	78.8	11.0	0.0	0.3	90.1
1957	n.d	n.d	79.0	11.4	0.0	0.3	90.7
1958	n.d	n.d	79.2	10.6	0.0	0.3	90.0
1959	n.d	n.d	79.3	10.9	0.0	0.2	90.4
1960	n.d	n.d	79.5	12.0	0.0	0.1	91.7
1961	n.d	n.d	78.0	12.0	0.0	0.1	90.2
1962	n.d	n.d	76.5	12.7	0.0	0.2	89.3
1963	n.d	n.d	75.0	12.0	0.0	0.1	87.1
1964	n.d	n.d	73.5	12.9	0.0	0.1	86.5
1965	n.d	n.d	72.0	13.2	0.0	0.2	85.4
1966	n.d	n.d	70.5	13.2	0.0	0.1	83.8
1967	n.d	n.d	69.0	14.8	0.0	0.1	83.9
1968	n.d	n.d	67.6	15.9	0.0	0.1	83.5
1969	n.d	n.d	66.1	15.9	0.0	0.1	82.1

	Firewood urban households PJ	Firewood rural households PJ	Firewood households PJ	Firewood industry PJ	Firewood transports PJ	Firewood power PJ	Total PJ
1971	n.d	n.d	64.3	14.3	0.0	0.2	78.9
1972	n.d	n.d	64.0	14.0	0.0	0.0	78.0
1973	n.d	n.d	63.6	13.4	0.0	0.2	77.2
1974	n.d	n.d	63.2	13.4	0.0	0.0	76.7
1975	n.d	n.d	62.8	13.2	0.0	0.3	76.3
1976	n.d	n.d	62.3	12.9	0.0	0.0	75.2
1977	n.d	n.d	61.8	13.9	0.0	0.1	75.9
1978	n.d	n.d	61.3	13.6	0.0	0.0	75.0
1979	n.d	n.d	60.8	12.6	0.0	0.3	73.6
1980	n.d	n.d	60.2	12.8	0.0	0.3	73.4
1981	n.d	n.d	59.6	13.2	0.0	0.4	73.1
1982	n.d	n.d	58.9	14.5	0.0	0.4	73.8
1983	n.d	n.d	58.3	14.7	0.0	0.4	73.4
1984	n.d	n.d	57.7	14.7	0.0	0.3	72.7
1985	n.d	n.d	57.0	19.1	0.0	0.4	76.5
1986	n.d	n.d	56.4	19.2	0.0	1.0	76.6
1987	n.d	n.d	55.7	23.3	0.0	1.0	80.0
1988	n.d	n.d	55.1	23.6	0.0	1.0	79.7
1989	n.d	n.d	54.4	22.5	0.0	0.9	77.8
1990	n.d	n.d	53.8	19.8	0.0	4.2	77.9
1991	n.d	n.d	51.4	19.8	0.0	4.8	76.0
1992	n.d	n.d	49.8	19.3	0.0	6.1	75.3
1993	n.d	n.d	48.5	18.9	0.0	7.0	74.4
1994	n.d	n.d	48.0	18.7	0.0	6.3	72.9
1995	n.d	n.d	48.1	18.8	0.0	6.9	73.8
1996	n.d	n.d	48.2	20.0	0.0	6.6	74.8
1997	n.d	n.d	48.4	20.1	0.0	7.0	75.5
1998	n.d	n.d	47.9	20.3	0.0	6.8	75.0
1999	n.d	n.d	47.3	21.1	0.0	7.1	75.6
2000	n.d	n.d	47.1	21.3	0.0	6.1	74.5
2001	n.d	n.d	47.3	22.5	0.0	4.9	74.7
2002	n.d	n.d	47.3	21.3	0.0	6.8	75.4
2003	n.d	n.d	48.2	22.5	0.0	6.4	77.1
2004	n.d	n.d	48.5	22.8	0.0	8.8	80.1
2005	n.d	n.d	48.8	23.3	0.0	8.3	80.3
2006	n.d	n.d	48.6	23.7	0.0	9.0	81.3

Table B.4 Wind and water; solar and geothermal heat

	Wind: sailing ships	**Wind: fishery boats**	**Wind & Water: Cereal mills**	**Wind & Water: Industrial Mills**	**Solar heat**	**Geothermal heat**	**Total**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1856	0.173	0.063	0.531	0.14			0.907
1857	0.184	0.064	0.535	0.14			0.922
1858	0.194	0.064	0.538	0.14			0.937
1859	0.204	0.065	0.542	0.14			0.951
1860	0.215	0.066	0.546	0.14			0.966
1861	0.225	0.066	0.549	0.14			0.981
1862	0.235	0.067	0.553	0.14			0.996
1863	0.246	0.068	0.557	0.14			1.01
1864	0.256	0.068	0.56	0.14			1.025
1865	0.253	0.069	0.564	0.14			1.026
1866	0.25	0.07	0.568	0.14			1.027
1867	0.247	0.07	0.571	0.14			1.029
1868	0.244	0.071	0.575	0.14			1.03
1869	0.241	0.072	0.579	0.14			1.031
1870	0.237	0.072	0.582	0.14			1.032
1871	0.234	0.073	0.586	0.14			1.034
1872	0.231	0.074	0.59	0.14			1.035
1873	0.228	0.074	0.593	0.14			1.036
1874	0.225	0.075	0.597	0.14			1.037
1875	0.222	0.076	0.601	0.14			1.038
1876	0.219	0.076	0.604	0.14			1.04
1877	0.216	0.077	0.608	0.14			1.041
1878	0.212	0.078	0.612	0.14			1.042
1879	0.209	0.078	0.615	0.14			1.043
1880	0.206	0.079	0.619	0.14			1.044
1881	0.198	0.08	0.623	0.14			1.041
1882	0.191	0.08	0.626	0.14			1.038
1883	0.183	0.081	0.63	0.14			1.034
1884	0.175	0.082	0.634	0.14			1.031
1885	0.181	0.083	0.637	0.14			1.041
1886	0.184	0.083	0.641	0.14			1.049
1887	0.193	0.084	0.645	0.14			1.062
1888	0.202	0.085	0.648	0.14			1.075
1889	0.212	0.085	0.652	0.14			1.089
1890	0.221	0.089	0.656	0.14			1.105

	Wind: sailing ships	Wind: fishery boats	Wind & Water: Cereal mills	Wind & Water: Industrial Mills	Solar heat	Geothermal heat	Total
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1891	0.248	0.093	0.654	0.138			1.133
1892	0.275	0.097	0.653	0.136			1.162
1893	0.303	0.1	0.652	0.135			1.19
1894	0.33	0.104	0.651	0.133			1.218
1895	0.358	0.108	0.649	0.131			1.246
1896	0.385	0.112	0.648	0.129			1.274
1897	0.413	0.111	0.647	0.127			1.298
1898	0.44	0.119	0.646	0.125			1.33
1899	0.468	0.118	0.645	0.123			1.354
1900	0.453	0.114	0.643	0.121			1.331
1901	0.439	0.118	0.641	0.12			1.317
1902	0.424	0.14	0.638	0.118			1.32
1903	0.41	0.131	0.636	0.116			1.292
1904	0.386	0.138	0.633	0.114			1.272
1905	0.363	0.13	0.631	0.112			1.236
1906	0.353	0.134	0.628	0.11			1.226
1907	0.343	0.13	0.626	0.108			1.207
1908	0.334	0.13	0.623	0.106			1.193
1909	0.324	0.177	0.621	0.105			1.226
1910	0.314	0.181	0.618	0.103			1.216
1911	0.304	0.212	0.615	0.101			1.232
1912	0.294	0.212	0.611	0.099			1.215
1913	0.284	0.209	0.606	0.097			1.196
1914	0.274	0.208	0.602	0.095			1.179
1915	0.264	0.172	0.597	0.093			1.127
1916	0.268	0.177	0.592	0.091			1.128
1917	0.271	0.132	0.588	0.09			1.08
1918	0.274	0.136	0.583	0.09			1.084
1919	0.277	0.152	0.579	0.092			1.1
1920	0.281	0.153	0.574	0.091			1.099
1921	0.284	0.15	0.569	0.092			1.094
1922	0.287	0.176	0.565	0.092			1.119
1923	0.29	0.166	0.56	0.092			1.109
1924	0.293	0.178	0.555	0.093			1.119
1925	0.297	0.15	0.551	0.093			1.09
1926	0.3	0.169	0.546	0.094			1.109
1927	0.303	0.163	0.542	0.094			1.102
1928	0.346	0.143	0.537	0.094			1.12
1929	0.326	0.172	0.532	0.094			1.124

	Wind: sailing ships	**Wind: fishery boats**	**Wind &Water: Cereal mills**	**Wind & Water: Industrial Mills**	**Solar heat**	**Geothermal heat**	**Total**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1930	0.327	0.145	0.528	0.095			1.095
1931	0.332	0.172	0.536	0.095			1.135
1932	0.312	0.127	0.544	0.095			1.077
1933	0.31	0.118	0.552	0.095			1.074
1934	0.308	0.121	0.56	0.095			1.084
1935	0.234	0.115	0.568	0.096			1.013
1936	0.232	0.128	0.576	0.098			1.033
1937	0.186	0.128	0.584	0.099			0.996
1938	0.14	0.137	0.592	0.1			0.968
1939	0.135	0.122	0.6	0.101			0.957
1940	0.129	0.107	0.607	0.102			0.946
1941	0.124	0.112	0.612	0.103			0.952
1942	0.119	0.114	0.616	0.104			0.953
1943	0.114	0.123	0.62	0.106			0.962
1944	0.109	0.122	0.624	0.107			0.961
1945	0.103	0.118	0.629	0.108			0.958
1946	0.098	0.117	0.633	0.109			0.957
1947	0.052	0.112	0.637	0.11			0.911
1948	0.084	0.114	0.641	0.111			0.951
1949	0.051	0.11	0.646	0.113			0.919
1950	0.043	0.114	0.65	0.114			0.92
1951	0.04	0.11	0.645	0.114			0.908
1952	0.035	0.108	0.639	0.115			0.896
1953	0.008	0.103	0.634	0.115			0.861
1954	0.006	0.104	0.629	0.115			0.854
1955	0.006	0.103	0.623	0.116			0.848
1956	0.008	0.101	0.618	0.116			0.844
1957	0.006	0.097	0.613	0.117			0.832
1958	0.001	0.093	0.607	0.116			0.817
1959	0.001	0.093	0.602	0.113			0.809
1960	0.001	0.092	0.597	0.11			0.8
1961	0.001	0.094	0.578	0.107			0.781
1962	0.001	0.093	0.56	0.104			0.758
1963	0.001	0.091	0.541	0.101			0.735
1964	0.001	0.093	0.523	0.098			0.715
1965	0.001	0.092	0.504	0.093			0.69
1966	0.001	0.089	0.486				0.576
1967	0.001	0.089	0.467				0.557
1968	0.001	0.085	0.449				0.535

	Wind: sailing ships	Wind: fishery boats	Wind &Water: Cereal mills	Wind & Water: Industrial Mills	Solar heat	Geothermal heat	Total
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1971		0.081	0.402				0.483
1972		0.075	0.392				0.467
1973		0.073	0.382				0.455
1974		0.069	0.372				0.44
1975		0.064	0.362				0.426
1976		0.061	0.351				0.412
1977		0.062	0.341				0.404
1978		0.063	0.331				0.394
1979		0.065	0.321				0.386
1980		0.066	0.311				0.377
1981		0.061	0.301				0.362
1982		0.066					0.066
1983		0.064					0.064
1984		0.066					0.066
1985		0.064					0.064
1986		0.062					0.062
1987		0.041					0.041
1988		0.039					0.039
1989		0.036					0.036
1990		0.032					0.032
1991		0.028					0.028
1992		0.026					0.026
1993		0.023					0.023
1994		0.013					0.013
1995		0.012					0.012
1996		0.011					0.011
1997		0.011					0.011
1998		0.01			0.703	0.042	0.756
1999		0.01			0.724	0.042	0.776
2000		0.01			0.745	0.042	0.797
2001					0.766	0.042	0.808
2002					0.787	0.042	0.829
2003					0.808	0.042	0.85
2004					0.846	0.042	0.888
2005					0.917	0.042	0.959
2006					0.963	0.419	1.382

Table B.5 Coal

	Production PJ	**Imports** PJ	**Foreign navigation, exports** PJ	**Net imports** PJ	**Stock variation** PJ	**Total** PJ
1856	0.23	3.56	0.22	3.33	n.a.	3.56
1857	0.23	2.58	0.00	2.58	n.a.	2.81
1858	0.23	3.09	0.00	3.09	n.a.	3.32
1859	0.23	3.79	0.00	3.79	n.a.	4.02
1860	0.22	3.00	0.00	3.00	n.a.	3.22
1861	0.20	2.65	0.11	2.54	n.a.	2.74
1862	0.19	2.80	0.17	2.63	n.a.	2.81
1863	0.19	2.95	0.23	2.72	n.a.	2.91
1864	0.19	3.09	0.29	2.81	n.a.	3.00
1865	0.19	3.24	0.35	2.90	n.a.	3.09
1866	0.19	4.86	0.29	4.57	n.a.	4.77
1867	0.19	4.27	0.30	3.97	n.a.	4.17
1868	0.20	5.78	0.30	5.48	n.a.	5.69
1869	0.20	4.18	0.50	3.68	n.a.	3.89
1870	0.21	5.48	0.50	4.99	n.a.	5.20
1871	0.18	4.88	0.94	3.94	n.a.	4.11
1872	0.19	5.29	0.98	4.31	n.a.	4.50
1873	0.21	7.63	1.30	6.33	n.a.	6.54
1874	0.20	5.44	0.85	4.59	n.a.	4.79
1875	0.21	6.63	1.06	5.57	n.a.	5.78
1876	0.27	6.38	0.90	5.48	n.a.	5.75
1877	0.22	7.00	0.84	6.15	n.a.	6.37
1878	0.22	6.68	0.17	6.51	n.a.	6.73
1879	0.41	7.42	1.26	6.16	n.a.	6.57
1880	0.24	9.31	1.11	8.20	n.a.	8.44
1881	0.28	9.57	1.38	8.19	n.a.	8.47
1882	0.28	11.31	1.87	9.44	n.a.	9.71
1883	0.31	11.86	1.88	9.97	n.a.	10.28
1884	0.21	12.70	1.93	10.77	n.a.	10.98
1885	0.26	11.74	1.97	9.77	n.a.	10.03
1886	0.28	12.95	2.07	10.88	n.a.	11.16
1887	0.31	14.05	1.91	12.13	n.a.	12.44
1888	0.33	15.15	2.29	12.86	n.a.	13.18
1889	0.26	17.88	2.61	15.27	n.a.	15.52
1890	0.29	18.39	2.37	16.03	n.a.	16.31
1891	0.30	18.79	2.35	16.44	n.a.	16.74

	Production	**Imports**	**Foreign navigation, exports**	**Net imports**	**Stock variation**	**Total**
	PJ	PJ	PJ	PJ	PJ	PJ
1892	0.29	18.06	2.50	15.56	n.a.	15.85
1893	0.39	15.80	2.58	13.22	n.a.	13.61
1894	0.37	18.77	2.53	16.24	n.a.	16.61
1895	0.33	18.07	2.85	15.22	n.a.	15.55
1896	0.29	18.37	3.07	15.30	n.a.	15.59
1897	0.30	19.41	3.71	15.70	n.a.	16.00
1898	0.39	22.22	3.99	18.23	n.a.	18.61
1899	0.38	22.71	5.17	17.54	n.a.	17.92
1900	0.41	26.12	7.44	18.68	n.a.	19.10
1901	0.28	25.50	6.93	18.57	n.a.	18.85
1902	0.29	28.35	7.79	20.56	n.a.	20.85
1903	0.22	27.38	5.78	21.60	n.a.	21.81
1904	0.22	28.85	5.18	23.68	n.a.	23.90
1905	0.19	28.01	4.80	23.21	n.a.	23.40
1906	0.09	31.79	5.28	26.51	n.a.	26.60
1907	0.11	34.76	5.61	29.15	n.a.	29.26
1908	0.10	34.74	5.12	29.61	n.a.	29.71
1909	0.15	35.21	5.69	29.53	n.a.	29.68
1910	0.14	35.93	5.38	30.55	n.a.	30.69
1911	0.18	34.60	3.05	31.55	n.a.	31.73
1912	0.26	40.23	5.77	34.45	n.a.	34.72
1913	0.43	40.75	4.51	36.24	n.a.	36.67
1914	0.51	35.46	2.74	32.72	n.a.	33.22
1915	1.14	31.37	2.30	29.07	n.a.	30.20
1916	2.60	27.83	3.71	24.12	n.a.	26.72
1917	3.53	11.79	4.19	7.60	n.a.	11.13
1918	3.41	6.30	2.85	3.45	n.a.	6.86
1919	2.54	19.12	5.21	13.91	n.a.	16.45
1920	3.10	17.86	4.61	13.25	n.a.	16.35
1921	2.91	19.17	5.15	14.02	n.a.	16.92
1922	2.43	27.36	4.72	22.64	n.a.	25.08
1923	2.76	23.24	4.56	18.69	n.a.	21.45
1924	2.47	27.57	4.34	23.23	n.a.	25.70
1925	2.41	29.23	4.45	24.78	n.a.	27.20
1926	3.99	25.98	4.76	21.22	n.a.	25.21
1927	3.51	31.96	4.31	27.64	n.a.	31.16
1928	3.92	34.14	3.76	30.38	n.a.	34.30
1929	3.89	33.57	4.19	29.38	n.a.	33.27

	Production	**Imports**	**Foreign navigation, exports**	**Net imports**	**Stock variation**	**Total**
	PJ	PJ	PJ	PJ	PJ	PJ
1930	4.24	36.19	3.75	32.44	n.a.	36.68
1931	3.90	32.51	2.26	30.25	n.a.	34.15
1932	3.57	26.83	1.38	25.44	n.a.	29.01
1933	3.72	32.44	1.54	30.91	n.a.	34.63
1934	3.77	32.67	1.74	30.93	n.a.	34.70
1935	4.10	34.25	1.67	32.58	n.a.	36.68
1936	4.05	32.17	2.43	29.73	n.a.	33.78
1937	4.90	42.08	3.67	38.41	n.a.	43.31
1938	5.60	34.54	2.65	31.88	n.a.	37.48
1939	5.63	36.83	2.56	34.27	n.a.	39.90
1940	7.43	23.58	2.11	21.47	n.a.	28.90
1941	8.91	21.03	1.28	19.75	n.a.	28.66
1942	10.41	15.15	0.69	14.45	n.a.	24.87
1943	8.57	16.52	0.49	16.03	n.a.	24.60
1944	9.22	17.91	0.83	17.08	n.a.	26.30
1945	10.33	15.27	0.64	14.63	n.a.	24.95
1946	8.98	18.62	0.84	17.78	n.a.	26.75
1947	8.21	29.23	0.55	28.68	n.a.	36.89
1948	8.42	24.55	0.65	23.91	n.a.	32.33
1949	9.59	26.62	0.49	26.12	n.a.	35.71
1950	8.80	22.14	0.25	21.89	n.a.	30.69
1951	8.62	18.79	0.22	18.57	n.a.	27.19
1952	8.91	13.75	0.10	13.65	n.a.	22.56
1953	9.44	16.99	0.07	16.92	n.a.	26.36
1954	8.54	13.71	0.08	13.63	n.a.	22.17
1955	8.45	14.97	0.07	14.90	n.a.	23.36
1956	9.61	14.06	0.07	13.99	n.a.	23.60
1957	11.72	16.33	0.07	16.26	n.a.	27.98
1958	12.43	11.68	0.06	11.62	n.a.	24.04
1959	11.79	9.68	0.05	9.62	n.a.	21.42
1960	10.15	11.43	0.01	11.42	n.a.	21.57
1961	10.79	16.35	0.09	16.26	n.a.	27.05
1962	9.58	15.85	0.05	15.80	n.a.	25.38
1963	9.59	19.30	0.03	19.27	n.a.	28.86
1964	9.36	18.80	0.01	18.80	n.a.	28.16
1965	8.88	18.62	0.01	18.61	n.a.	27.49
1966	8.09	21.91	0.00	21.90	n.a.	29.99
1967	8.27	19.80	0.00	19.80	n.a.	28.06
1968	7.34	17.95	0.01	17.95	n.a.	25.29
1969	8.61	19.69	0.00	19.69	n.a.	28.30

	Production PJ	Imports PJ	Foreign navigation, exports PJ	Net imports PJ	Stock variation PJ	Total PJ
1970	4.65	21.33	0.02	21.32	n.a.	25.97
1971	4.34	11.73	0.00	11.73	-3.73	19.81
1972	4.87	14.76	0.00	14.76	2.15	17.47
1973	3.79	13.68	0.00	13.68	-2.93	20.40
1974	3.95	12.15	0.00	12.15	-0.01	16.11
1975	3.80	12.52	0.00	12.52	-0.35	16.67
1976	3.32	12.42	0.00	12.42	-0.65	16.39
1977	3.35	14.47	0.00	14.47	1.03	16.79
1978	3.09	15.15	0.00	15.15	0.15	18.10
1979	3.07	14.13	0.00	14.13	-0.97	18.18
1980	3.05	14.31	0.00	14.31	-0.32	17.67
1981	3.15	10.65	0.00	10.65	-1.68	15.49
1982	3.07	11.18	0.00	11.18	0.72	13.53
1983	3.18	15.34	0.00	15.34	2.19	16.33
1984	3.33	17.10	0.00	17.10	2.60	17.83
1985	4.07	43.88	0.00	43.88	15.38	32.56
1986	4.05	54.79	0.00	54.79	-1.95	60.79
1987	4.47	78.53	0.00	78.53	3.79	79.22
1988	3.95	80.50	0.00	80.50	-2.95	87.39
1989	4.43	97.82	0.00	97.82	-5.25	107.50
1990	4.83	125.54	0.22	125.32	14.48	115.57
1991	4.64	114.74	0.56	114.18	-3.10	121.68
1992	3.79	120.08	0.81	119.26	-0.79	123.49
1993	3.39	128.60	0.38	128.22	-0.12	131.56
1994	2.53	135.15	0.24	134.91	-2.01	139.35
1995	0.00	161.71	1.45	160.27	8.76	150.88
1996	0.00	141.93	0.96	140.97	-3.07	143.63
1997	0.00	156.43	1.30	155.14	7.52	147.06
1998	0.00	139.05	1.56	137.49	1.51	135.32
1999	0.00	159.00	1.57	157.43	-0.13	156.89
2000	0.00	166.51	1.57	164.94	4.61	159.65
2001	0.00	123.87	0.00	123.87	-10.15	134.02
2002	0.00	146.46	0.00	146.46	-0.10	146.56
2003	0.00	140.16	0.00	140.16	-0.31	140.47
2004	0.00	134.53	0.00	134.53	-6.78	141.31
2005	0.00	135.05	0.00	135.05	-5.16	140.21
2006	0.00	146.45	0.12	146.34	7.69	138.60

B.6 Oil (energy uses)

	Crude Oil	Feed-stocks	Kero-sene	Gas-olines	Jet	Gas oil Diesel Fuel oil	Gasoil Diesel	Fuel oil	Petrol coke	LPG	Total
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1861			0.0								0.0
1862			0.0								0.0
1863			0.0								0.0
1864			0.0								0.0
1865			0.0								0.0
1866			0.0								0.0
1867			0.1								0.1
1868			0.1								0.1
1869			0.2								0.2
1870			0.2								0.2
1871			0.1								0.1
1872			0.1								0.1
1873			0.2								0.2
1874			0.2								0.2
1875			0.1								0.1
1876			0.2								0.2
1877			0.2								0.2
1878			0.2								0.2
1879			0.3								0.3
1880			0.3								0.3
1881			0.4								0.4
1882			0.3								0.3
1883			0.2								0.2
1884			0.4								0.4
1885			0.4								0.4
1886			0.4								0.4
1887			0.4								0.4
1888			0.5								0.5
1889			0.5								0.5

	Crude Oil	Feed-stocks	Kero-sene	Gas-olines	Jets	Gasoil Diesel Fuel oil	Gasoil Diesel	Fuel oil	Petrol coke	LPG	Total
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1890			0.5								0.5
1891			0.5								0.5
1892			0.6								0.6
1893			0.6								0.6
1894			0.6								0.6
1895			0.6								0.6
1896			0.6								0.6
1897			0.6								0.6
1898			0.6								0.6
1899			0.6								0.6
1900			0.6								0.6
1901			0.7								0.7
1902			0.6								0.6
1903			0.7								0.7
1904			0.6								0.6
1905			0.7								0.7
1906			0.7								0.7
1907			0.7								0.7
1908			0.7								0.7
1909			0.8								0.8
1910			1.1								1.1
1911			1.1								1.1
1912			0.8								0.8
1913			1.0								1.0
1914			0.7								0.7
1915			0.7								0.7
1916			0.7	0.3							1.0
1917			0.8	0.3							1.0
1918			0.3	0.1							0.3
1919			1.0	0.4		0.0					1.4
1920			0.8	0.4		0.5					1.7
1921			0.7	0.4		0.5					1.6
1922			0.9	0.5		0.4					1.9
1923			0.9	0.4		0.9					2.1
1924			0.9	0.5		1.0					2.3
1925			1.1	0.6		0.5					2.2
1926			1.3	0.9		0.5					2.7
1927			1.3	1.2		0.5					3.1
1928			1.7	1.8		0.9					4.3

	Crude Oil PJ	Feedstocks PJ	Kerosene PJ	Gasolines PJ	Jets PJ	Gasoil Diesel Fuel oil PJ	Gasoil diesel PJ	Fuel oil PJ	Petrol coke PJ	LPG PJ	Total PJ
1929			1.5	1.8		0.9					4.2
1930			1.8	2.1		1.0					4.9
1931			1.8	2.1		1.0					4.9
1932			1.8	2.1		1.0					4.9
1933			2.1	2.3		1.2					5.5
1934			2.6	2.6		1.3					6.5
1935			2.3	3.1		1.6					7.0
1936			2.2	3.0		1.6					6.8
1937			2.2	3.3		2.4					7.9
1938			2.2	3.3		2.7					8.2
1939			2.2	3.3		3.4				0.0	8.8
1940	4.9		1.0	1.6		1.8				0.0	9.3
1941	4.6		0.6	1.5		1.5				0.0	8.3
1942	0.9		0.8	0.6		0.4				0.0	2.7
1943	0.0		0.8	1.4		2.7				0.0	4.9
1944	4.4		1.2	1.7		2.9				0.0	10.2
1945	1.2		1.5	2.0		4.4				0.0	9.1
1946	4.3		2.0	2.8		6.7				0.0	15.8
1947	11.1		1.9	3.2		8.4				0.0	24.7
1948	12.5		2.5	3.8		8.1				0.0	26.9
1949	11.8		2.2	3.6		9.0				0.0	26.5
1950	11.9		2.3	2.8		12.5				0.0	29.6
1951	14.8		2.8	3.5		13.0				0.0	34.2
1952	20.0		2.7	2.3		12.4				0.1	37.5
1953	5.6		5.1	5.8	0.1	23.9				0.1	40.6
1954	31.0		2.0	-0.4	0.1	11.7				0.1	44.6
1955	37.7		1.8	-2.3	0.0	13.6				0.1	50.9
1956	40.6		1.8	-2.3	0.0	12.5				0.0	52.7
1957	39.2		1.3	-1.6	0.0	13.5				0.0	52.3
1958	46.6		0.5	-3.9	0.0	12.1				0.0	55.4
1959	51.6		0.1	-3.0	0.0	12.2				0.0	60.9
1960	53.7		0.8	-3.2	0.0	14.3			0.5	0.1	66.1
1961	55.6		-0.7	-2.5	0.0	19.0			0.6	0.5	72.5
1962	55.1		0.5	-1.1	0.0	21.2	11.2	10.0	0.7	0.9	77.3
1963	59.6		-1.1	-1.2	-0.3	21.1	11.8	9.3	0.6	1.3	80.1
1964	62.4		0.1	-0.3	-2.8	20.3	11.2	9.1	0.4	2.8	82.9
1965	65.5		0.5	2.1	-4.2	23.6	12.2	11.3	0.0	4.2	91.7
1966	66.9		0.8	2.4	-5.6	21.8	10.9	10.9	0.0	5.0	91.3
1967	69.4		0.7	4.7	-6.3	27.3	14.3	13.0	0.0	7.4	103.3

	Crude Oil	Feed-stocks	Ke-ro-sene	Gas-olines	Jets	Gasoil diesel	Fuel oil	Petrol coke	LPG	Total
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1968	68		0.2	7.8	-4.8	17.3	15.9	0.0	7.9	113
1969	79		0.2	11.8	-4.2	15.4	13.2	0.1	8.7	124
1970	145		-5.1	0.8	-2.0	7.6	-3.4	0.0	10.1	153
1971	154	2.0	-3.9	1.3	-3.4	4.5	5.2	0.0	10.3	170
1972	170	0.5	-3.9	3.5	-2.8	3.8	8.6	0.0	11.5	191
1973	164	2.4	-3.2	7.7	-0.9	9.8	16.2	0.0	12.9	209
1974	224	3.6	-0.4	-0.7	-1.5	-3.2	-10.4	0.0	11.7	223
1975	221	1.8	0.0	2.4	-4.1	-0.5	13.1	0.0	12.6	246
1976	228	-0.7	0.2	-0.5	-6.2	3.0	20.9	0.0	14.6	259
1977	226	2.5	0.2	0.5	-7.8	5.9	14.1	0.0	14.8	256
1978	255	-15.6	0.1	-0.8	-5.4	10.4	3.4	0.0	15.6	263
1979	330	-1.3	-2.0	-12.7	-9.0	-9.5	-22.8	0.0	14.9	288
1980	303	1.6	-0.2	-10.0	-9.5	1.4	13.8	0.0	13.4	313
1981	323	2.8	-0.1	-15.1	-15.2	-2.0	30.5	0.0	12.6	336
1982	315	-2.3	-0.3	-3.3	-9.3	7.8	29.3	0.0	14.6	352
1983	322	5.0	0.1	-2.0	-12.1	-8.6	39.0	0.0	13.3	356
1984	294	-0.1	0.1	1.2	-15.3	4.1	50.5	0.0	14.1	349
1985	270	11.5	0.2	0.6	-13.8	1.9	34.5	0.0	13.7	319
1986	317	3.5	0.1	-5.1	-18.5	-10.1	29.0	0.0	13.2	329
1987	288	4.5	-0.1	2.2	-14.1	12.5	12.2	0.0	16.7	322
1988	300	29.4	0.1	-10.0	-17.1	9.0	-2.7	0.0	17.8	327
1989	388	20.4	0.0	-12.5	-19.3	-16.6	39.4	0.0	15.9	415
1990	407	33.8	0.0	-14.6	-28.1	-16.2	12.2	0.0	20.0	414
1991	373	14.6	0.1	-5.2	-21.0	16.3	26.1	0.0	24.6	429
1992	439	29.3	-0.1	-7.5	-24.8	-5.0	26.2	0.0	25.0	482
1993	417	32.1	0.4	5.2	-18.2	-15.6	4.3	0.0	28.7	454
1994	527	27.1	-0.1	-23.6	-34.2	-49.5	-17.4	0.0	26.8	456
1995	494	43.4	0.0	-38.4	-31.7	-33.6	26.6	3.1	30.7	494
1996	449	43.9	0.1	-27.7	-25.1	-12.0	12.3	4.8	37.3	482
1997	477	63.8	0.0	-38.8	-29.1	-11.6	15.7	10.0	36.6	523
1998	512	40.6	-0.1	-34.2	-27.8	-13.3	44.7	15.2	26.2	563
1999	482	42.3	0.1	-25.4	-22.5	3.0	45.4	20.6	34.8	580
2000	432	35.8	0.2	-9.3	-14.6	45.1	21.7	16.5	34.8	562
2001	458	39.5	0.2	-27.2	-8.4	28.8	33.8	21.1	31.1	577
2002	426	62.1	0.2	-20.9	-3.3	22.7	57.8	26.2	33.1	604
2003	462	51.8	0.2	-32.9	-11.3	21.4	10.0	24.5	25.9	552
2004	461	45.1	0.1	-28.7	-14.1	38.1	-4.4	28.9	26.8	553
2005	481	43.2	0.0	-31.3	-14.9	24.4	10.8	33.5	22.6	569
2006	494	70.8	0.1	-48.8	-15.9	10.8	-39.8	32.1	21.4	524

Table B. 7 Oil (non-energy uses)

	Crude oil (non energy uses) PJ	Naphtha PJ	Asphalts PJ	Lubricants PJ	Paraffins PJ	Solvents PJ	Propylen PJ	Total non-energy uses PJ
1892				0.056				0.056
1893				0.055				0.055
1894				0.052				0.052
1895				0.072	0.007			0.079
1896				0.078	0.003			0.081
1897				0.082	0.004			0.086
1898				0.071	0.017			0.088
1899				0.097	0.006			0.102
1900				0.108	0.008			0.116
1901				0.099	0.019			0.118
1902				0.107	0.013			0.12
1903				0.147	0.015			0.163
1904				0.111	0.02			0.131
1905				0.171	0.022			0.193
1906				0.186	0.016			0.202
1907				0.21	0.004			0.213
1908				0.165	0.017			0.182
1909				0.176	0.012			0.187
1910				0.175	0.022			0.196
1911				0.237	0.013			0.25
1912				0.286	0.012			0.298
1913				0.274	0.018			0.292
1914				0.289	0.014			0.304
1915				0.27	0.039			0.309
1916				0.372	0.012			0.384
1917				0.257	0.016			0.273
1918				0.097	0.03			0.127
1919				0.447	0.013			0.46
1920				0.322	0.049			0.371
1921				0.153	0.009			0.162
1922				0.329	0.015			0.345
1923				0.401	0.055			0.456
1924				0.302	0.022			0.324
1925				0.327	0.018			0.345
1926				0.366	0.048			0.415
1927				0.469	0.047			0.516
1928				0.784	0.046			0.831

	Crude oil (non energy uses) PJ	**Naphtha** PJ	**Asphalts** PJ	**Lubricants** PJ	**Paraffins** PJ	**Solvents** PJ	**Propylen** PJ	**Total non-energy uses** PJ
1931			0.22	0.64	0.04			0.90
1932			0.14	0.60	0.03			0.78
1933			0.10	0.76	0.05			0.91
1934			0.09	0.77	0.04			0.90
1935			0.28	1.05	0.06			1.39
1936			0.14	0.73	0.04			0.91
1937			0.04	0.69	0.04			0.77
1938			0.02	0.57	0.05			0.63
1939			0.07	0.63	0.05			0.75
1940			0.00	0.33	0.00			0.33
1941			0.00	0.09	0.03			0.12
1942			0.00	0.07	0.01			0.08
1943			0.00	0.24	0.03			0.27
1944			0.00	0.28	0.01			0.29
1945			0.00	0.31	0.03			0.35
1946			0.00	0.59	0.08			0.67
1947			0.00	0.65	0.04			0.69
1948			0.00	0.85	0.08			0.93
1949			0.00	0.57	0.08			0.65
1950			0.00	0.48	0.06			0.55
1951			0.01	0.87	0.09			0.96
1952			0.01	0.68	0.06			0.74
1953			0.01	0.59	0.06			0.65
1954			0.01	0.71	0.08			0.80
1955			0.02	0.79	0.09			0.90
1956	0.05		0.02	0.98	0.09			1.14
1957	0.05		0.03	0.05	0.11			0.22
1958	1.97		0.04	0.01	0.09			2.11
1959	0.55		0.03	1.04	0.09			1.71
1960	0.68	0.00	0.63	0.05	0.12			1.49
1961	0.63	0.00	0.79	0.06	0.15			1.62
1962	0.77	0.00	0.93	0.05	0.12			1.88
1963	4.74	0.00	0.78	0.06	0.12			5.71
1964	6.12	0.00	1.13	0.07	0.16			7.47
1965	6.48	0.00	1.03	0.08	0.14			7.72
1966	6.39	0.00	1.68	0.08	0.15			8.30
1967	7.40	0.00	1.43	0.09	0.22			9.13
1968	7.35	0.00	1.27	0.09	0.17			8.87
1969	11.12	0.00	1.59	0.10	0.16			12.96

	Crude oil (non energy uses)	**Naphtha**	**Asphalts**	**Lubricants**	**Paraffins**	**Solvents**	**Propylen**	**Total non-energy uses**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1970	14.70	-0.97	1.92	0.11	0.28			16.03
1971	15.70	0.63	1.89	-0.46	0.10	0.54		18.40
1972	14.71	2.33	1.78	-0.98	-0.03	0.70		18.51
1973	13.07	4.01	1.79	-0.68	0.03	0.94		19.16
1974	17.10	0.01	1.54	-0.89	-0.12	0.72		18.35
1975	16.12	-0.21	1.31	0.12	-0.13	0.74		17.95
1976	14.97	0.64	1.60	-0.20	-0.01	0.91		17.91
1977	17.94	0.31	2.28	-0.12	-0.05	1.00		21.36
1978	18.88	-1.61	3.02	0.57	-0.03	0.98		21.81
1979	19.40	-1.40	1.63	1.08	-0.03	1.18		21.87
1980	15.48	3.75	0.45	1.13	0.03	1.02		21.86
1981	10.41	6.62	2.15	0.35	-0.12	0.90		20.31
1982	9.24	24.66	2.43	0.58	-0.06	-1.44		35.42
1983	18.01	11.25	1.68	0.01	-0.08	-2.38		28.49
1984	18.12	16.78	2.32	0.47	0.01	-1.24		36.46
1985	33.13	5.08	1.51	-0.39	-0.01	0.55		39.87
1986	39.41	16.74	2.48	-0.60	-0.07	0.22		58.19
1987	32.69	19.71	3.17	-0.35	0.03	0.19		55.44
1988	39.79	26.45	6.11	-0.26	-0.04	-0.10		71.94
1989	43.18	26.37	6.87	-0.40	0.03	0.18		76.22
1990	42.63	28.10	7.04	-0.16	0.05	-0.16	0.00	77.50
1991	37.14	15.69	11.79	-0.42	-0.02	-0.12	0.00	64.06
1992	42.20	16.88	9.70	-0.54	0.04	0.20	0.00	68.48
1993	44.01	14.84	10.88	-1.31	0.07	-0.26	0.00	68.23
1994	53.03	14.07	7.81	-1.63	-0.05	-0.03	0.00	73.20
1995	57.38	16.29	8.97	-1.43	0.02	-0.21	-3.26	77.77
1996	53.14	9.49	8.77	-0.55	-0.06	-0.04	-2.77	67.99
1997	50.21	21.71	13.02	1.26	0.02	-0.43	-4.45	81.33
1998	65.69	16.12	12.22	0.46	-0.15	-0.41	-2.41	91.53
1999	70.16	15.13	9.74	-0.80	-0.14	-1.01	-3.71	89.37
2000	66.84	17.20	11.56	-1.43	-0.25	-1.24	-3.24	89.44
2001	72.82	1.68	15.18	-0.62	-0.27	-0.54	-4.01	84.24
2002	78.31	2.27	10.98	-2.78	-0.43	-0.81	-3.78	83.76
2003	78.26	6.70	8.03	-1.19	-0.32	-0.97	-3.40	87.12
2004	81.63	9.31	7.80	-2.26	-0.31	-1.00	-2.44	92.72
2005	80.17	8.29	12.81	-1.69	-0.17	-1.14	-2.99	95.29
2006	72.04	5.86	7.66	-2.41	-0.28	-1.05	-3.14	78.68

Note: non-energy uses of oil are not included in the totals

Table B.8 Electricity

	Hydro (1) GWh	Geo, eolic, solar (2) GWh	Imports (3) GWh	Exports (4) GWh	Primary[1] Elec-tricity (5) GWh	Thermo[2] (6) GWh	Total (7) GWh	Thermo[3] efficiency (8) %
1894	0.2				0.2	n.a.		
1895	0.3				0.3	n.a.		
1896	0.3				0.3	n.a.		
1897	0.4				0.4	n.a.		
1898	0.5				0.5	n.a.		
1899	0.5				0.5	n.a.		
1900	0.6				0.6	n.a.		
1901	0.6				0.6	n.a.		
1902	0.8				0.8	n.a.		
1903	0.8				0.8	n.a.		
1904	1.2				1.2	n.a.		

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[1] Primary electricity (5) = Hydro Production (1)+ Geo, wind, photovoltaic production (2)+ Imports (3) –Exports (4). From 1971-1989 geo production is included in hydro production.

[2] Thermoelectricity is a secondary form of energy and does not appear on primary energy consumption figures. Column 6 represents the produced electricity by mean of fuels and it is comparable with column 1.Termoelectricity in primary equivalents can be deducted from 1931 dividing column 6 (Thermo) by column 8 (thermo efficiency). Some estimations were performed for the period prior to official statistics. For 1918 thermo figures were estimated with basis on consumption figures for Lisbon (CRGE,1918) ((transformed in production figures assuming 15% of losses in transmission) and Oporto production figures (SMGEP,1918). The installed power of the two main companies in the country represented 79% of the power installed in public service in 1918, and was assumed that the production proportion was the same. For 1923 I assumed 1385 hours of use for the power installed in the public service (Revista Obras Públicas e Minas, 1923), equal to the one reported for 1927 by official statistics (DGSE, 1927). On 1927 autoproduction of electricity was 50% of the electricity produced by the public service. The same proportion was assumed to 1918 and 1923. Benchmark years were connected assuming a constant rate of growth. Until 1969 data reports to Mainland Portugal.

[3] Data on thermo power efficiency is reported here for 1931-2006.For 1931-1970 efficiency is taken from Madureira and Teives (2005) and reports on efficiency in conventional coal and oil power plants (excluding firewood and residuals). For 1971- 1989 data is taken from energy balances and all fuels and electricity are included in order to determine efficiency. After 1990, efficency is taken from all the fuels consumed for producing all thermo power other than used for cogeneration utilities. The differences are not significant due to the small portion of non-conventional electricity. Dividing hydro, geo, photovoltaic production in this appendix by thermo-efficiency allows hydro-production to be expressed in terms of fuel equivalents. For earlier dates than 1931 lower efficiencies need to be applied, i.e, in 1917 the efficiency of the Lisbon plant was around 5% (CRGE,1917) and during 1918-1920 Oporto plant had efficiencies of 3-4% (SMEGP,1918-1920).

	Hydro (1) GWh	**Geo, eolic, solar (2)** GWh	**Imports (3)** GWh	**Exports (4)** GWh	**Primary Elec-tricity (5)** GWh	**Thermo (6)** GWh	**Total (7)** GWh	**Thermo efficiency (8)** %
1905	1.3				1.3	n.a.		
1906	1.9				1.9	n.a.		
1907	2.0				2.0	n.a.		
1908	2.3				2.3	n.a.		
1909	3.0				3.0	n.a.		
1910	3.1				3.1	n.a.		
1911	3.9				3.9	n.a.		
1912	4.5				4.5	n.a.		
1913	5.2				5.2	n.a.		
1914	6.1				6.1	n.a.		
1915	7.0				7.0	n.a.		
1916	7.2				7.2	n.a.		
1917	7.6				7.6	n.a.		
1918	7.7				7.7	23.7	31.4	
1919	8.2				8.2	28.3	36.5	
1920	10.3				10.3	33.8	44.0	
1921	10.9				10.9	40.3	51.1	
1922	22.6				22.6	48.1	70.7	
1923	28.7				28.7	57.3	86.0	
1924	33.1				33.1	70.7	103.7	
1925	41.8				41.8	87.1	128.9	
1926	48.2				48.2	107.3	155.5	
1927	58.2		0.1		58.3	132.3	190.6	
1928	72.3		0.0		72.3	148.8	221.1	
1929	79.3		0.0		79.3	167.0	246.3	
1930	96.4		0.0		96.4	170.7	267.1	
1931	100.0		0.0		100.0	174.9	274.9	12
1932	108.9		0.0		108.9	183.4	292.3	13
1933	102.8		0.0		102.8	204.5	307.3	13
1934	108.2		0.0		108.2	222.2	330.4	14
1935	122.5		0.2		122.6	239.2	361.8	14
1936	138.4		0.2		138.6	238.1	376.7	14
1937	145.4		0.2		145.7	267.1	412.7	15
1938	131.5		0.2		131.8	299.6	431.4	16
1939	190.7		0.3		191.0	264.8	455.8	16
1940	186.0		0.3		186.3	281.3	467.6	15

	Hydro (1) GWh	**Geo, eolic, solar (2)** GWh	**Imports (3)** GWh	**Exports (4)** GWh	**Primary Elec-tricity (5)** GWh	**Thermo (6)** GWh	**Total (7)** GWh	**Thermo efficiency (8)** %
1941	199.2		0.3		199.5	288.1	487.6	14
1942	225.3		0.4		225.6	248.4	474.1	14
1943	211.8		0.3		212.2	272.4	484.6	14
1944	205.7		0.3		206.0	306.1	512.1	13
1945	202.1		0.2		202.3	349.9	552.3	14
1946	325.3		0.3		325.6	321.7	647.3	14
1947	335.8		0.3		336.1	394.2	730.3	15
1948	362.5		0.3		362.8	457.2	820.0	15
1949	282.0		0.4		282.4	560.6	843.0	16
1950	446.4		0.4		446.9	504.8	951.7	16
1951	821.3		0.6		821.9	230.5	1052.4	16
1952	1203.9		0.7		1204.7	147.7	1352.4	17
1953	1011.6		1.7		1013.3	380.7	1394.0	18
1954	1473.3		0.6		1473.9	207.8	1681.7	17
1955	1750.8		7.8		1758.6	164.7	1923.3	17
1956	2063.2		10.1		2073.3	140.3	2213.6	17
1957	1868.7		13.4		1882.1	328.1	2210.2	14
1958	2539.3		4.7		2544.0	158.2	2702.1	14
1959	2897.2		0.8		2898.0	130.2	3028.2	15
1960	3139.7		0.8		3140.5	158.6	3299.2	15
1961	3457.3		10.8		3468.1	189.2	3657.3	18
1962	3548.7		26.9		3575.5	321.9	3897.4	20
1963	4043.1		55.2		4098.3	300.1	4398.4	20
1964	4261.2		43.2	55.0	4249.3	540.4	4789.7	21
1965	4023.0		441.8	11.1	4453.7	651.6	5105.4	22
1966	5355.8		3.5	14.5	5344.7	285.1	5629.8	16
1967	5550.2		26.9	80.8	5496.3	439.5	5935.8	19
1968	5269.6		91.4	25.2	5335.8	998.0	6333.9	24
1969	6385.2		57.7	34.7	6408.1	511.9	6920.0	21
1970	5853.5		60.7	43.2	5871.1	1634.3	7505.4	27
1971	6206.6		204.8	26.5	6384.9	1726.2	8111.1	28
1972	7151.3		150.5	111.7	7190.2	1753.4	8943.6	32
1973	7353.9		67.5	78.2	7343.3	2467.3	9810.6	32
1974	7888.2		339.0	295.2	7932.0	2857.1	10789.2	34
1975	6436.8		465.7	266.5	6636.0	4290.9	10927.0	34

	Hydro (1) GWh	**Geo, eolic, solar (2)** GWh	**Imports (3)** GWh	**Exports (4)** GWh	**Primary Elec-tricity (5)** GWh	**Thermo (6)** GWh	**Total (7)** GWh	**Thermo efficiency (8)** %
1976	4887.4		1845.3	120.5	6612.1	5258.4	11870.5	35
1977	10009.9		381.7	927.3	9464.3	3808.5	13272.9	37
1978	10864.9		871.6	1089.5	10647.0	3788.1	14435.1	35
1979	11251.5		931.2	1133.9	11048.8	4901.7	15950.5	36
1980	8072.1	0.7	2346.0	518.4	9900.4	7190.6	17091.0	37
1981	5094.7	0.3	3344.8	139.8	8300.0	8804.5	17104.5	37
1982	6982.1	0.0	3369.4	400.3	9951.3	8435.9	18387.1	37
1983	8131.2	0.3	2372.9	26.5	10477.9	10026.9	20504.8	39
1984	9882.0	3.1	2077.0	1365.0	10597.1	9602.2	20199.3	40
1985	10848.7	4.1	3529.7	1283.9	13098.6	8260.0	21358.6	38
1986	8543.1	2.0	2873.9	988.7	10430.2	11814.4	22244.6	38
1987	9186	1.4	3699.0	675.0	12211.4	10949.0	23160.4	37
1988	12303		3417.1	1027.0	14693.1	10185.0	24878.1	38
1989	6049		2436	1270	7215	19727.0	26942.0	38
1990	9302	5	1733	1696	9344	19195.6	28539.6	38
1991	9176	6	1712	1620	9274	20649.7	29923.7	39
1992	5074	9	2538	1197	6424	24951.1	31375.1	40
1993	8737	15	2077	1902	8927	22443.2	31370.2	39
1994	10702	51	2257	1369	11641	20658.8	32299.8	38
1995	8454	59	2655	1741	9427	24740.6	34167.6	38
1996	14857	71	4116	3005	16039	19582.7	35621.7	37
1997	13175	90	5376	2477	16164	20827.5	36991.5	37
1998	13054	148	3974	3700	13476	25736.4	39212.4	37
1999	7631	204	3628	4488	6975	35385.9	42360.9	40
2000	11715	249	4698	3767	12895	31737	44632	41
2001	14375	362	3741	3502	14976	31772	46748	42
2002	8257	460	5329	3430	10616	37334	47950	42
2003	16054	589	5898	3104	19437	30209	49646	41
2004	10147	903	8612	2131	17531	34048	51579	44
2005	5118	1847	9626	2802	13789	38859	52648	41
2006	11467	3015	8624	3183	19923	34559	54482	42

Table B.9 Others

	Sulphite liquor and bleachs	**Urban Solid Wastes**	**Biogas**	**Total**
	PJ	PJ	PJ	PJ
1955	0.796			0.796
1956	0.835			0.835
1957	0.81			0.81
1958	0.651			0.651
1959	0.858			0.858
1960	0.961			0.961
1961	1.12			1.12
1962	1.137			1.137
1963	1.231			1.231
1964	1.474			1.474
1965	2.308			2.308
1966	2.699			2.699
1967	3.089			3.089
1968	3.499			3.499
1969	4.257			4.257
1970	4.743			4.743
1971	3.219			3.219
1972	1.529			1.529
1973	2.251			2.251
1974	1.888			1.888
1975	2.567			2.567
1976	2.517			2.517
1977	2.582			2.582
1978	2.536			2.536
1979	2.876			2.876
1980	3.119			3.119
1981	3.216			3.216
1982	3.641			3.641
1983	4.225			4.225
1984	4.08			4.08

	Sulphite liquor and bleachs	Urban Solid Wastes	Biogas	Total
	PJ	PJ	PJ	PJ
1985	4.1			4.1
1986	4.44			4.44
1987	4.799			4.799
1988	5.029			5.029
1989	4.836			4.836
1990	19.731	0	0	19.731
1991	24.927	0	0	24.927
1992	24.686	0	0	24.686
1993	24.106	0	0	24.106
1994	25.11	0	0	25.11
1995	27.142	0	0	27.142
1996	25.927	0	0	25.927
1997	29.266	0	0	29.266
1998	28.976	0	0	28.976
1999	30.191	2.384	0.017	32.592
2000	31.129	7.296	0.057	38.483
2001	30.477	7.309	0.051	37.836
2002	32.536	7.633	0.053	40.223
2003	32.38	7.927	0.049	40.356
2004	30.62	7.921	0.079	38.62
2005	30.905	8.667	0.45	40.021
2006	31.81	8.404	0.411	40.624

Appendix C

CO_2 emissions from fossil fuels, Portugal

Table C.1 CO_2 emissions from fossil fuels 1856-2006

	CO_2 fossil fuels thousand tonnes	**CO_2 coal** thousand tonnes	**CO_2 oil** thousand tonnes	**CO_2 natural gas** thousand tonnes	**CO_2** per capita ton
1856	338	338	0		0.1
1857	266	266	0		0.1
1858	315	315	0		0.1
1859	381	381	0		0.1
1860	305	305	0		0.1
1861	260	260	0		0.1
1862	267	267	0		0.1
1863	276	276	0		0.1
1864	285	285	0		0.1
1865	295	293	2		0.1
1866	455	452	3		0.1
1867	399	395	4		0.1
1868	544	539	6		0.1
1869	379	369	11		0.1
1870	504	492	12		0.1
1871	398	389	9		0.1
1872	436	426	10		0.1
1873	631	620	12		0.1
1874	467	454	14		0.1
1875	557	548	9		0.1
1876	556	545	12		0.1
1877	619	603	16		0.1
1878	655	638	18		0.1
1879	645	623	22		0.1
1880	821	799	22		0.2
1881	828	802	26		0.2
1882	944	920	24		0.2
1883	991	974	17		0.2
1884	1,069	1,039	30		0.2
1885	978	949	29		0.2
1886	1,086	1,056	30		0.2

	CO_2 fossil fuels thousand tonnes	**CO_2 coal** thousand tonnes	**CO_2 oil** thousand tonnes	**CO_2 natural gas** thousand tonnes	**CO_2** per capita ton
1887	1,209	1,178	31		0.2
1888	1,281	1,248	33		0.3
1889	1,504	1,469	35		0.3
1890	1,583	1,544	38		0.3
1891	1,624	1,585	39		0.3
1892	1,545	1,500	45		0.3
1893	1,332	1,289	43		0.3
1894	1,619	1,572	46		0.3
1895	1,515	1,472	43		0.3
1896	1,517	1,476	41		0.3
1897	1,560	1,515	45		0.3
1898	1,807	1,762	44		0.3
1899	1,743	1,696	46		0.3
1900	1,851	1,808	43		0.3
1901	1,835	1,784	51		0.3
1902	2,020	1,974	47		0.4
1903	2,117	2,064	53		0.4
1904	2,307	2,262	45		0.4
1905	2,263	2,215	49		0.4
1906	2,567	2,517	50		0.4
1907	2,822	2,768	53		0.5
1908	2,865	2,811	53		0.5
1909	2,863	2,808	54		0.5
1910	2,982	2,904	78		0.5
1911	3,080	3,002	78		0.5
1912	3,344	3,285	59		0.6
1913	3,540	3,471	70		0.6
1914	3,196	3,145	51		0.5
1915	2,911	2,861	50		0.5
1916	2,608	2,537	71		0.4
1917	1,139	1,066	73		0.2
1918	686	661	25		0.1
1919	1,665	1,565	100		0.3
1920	1,682	1,559	123		0.3
1921	1,726	1,612	115		0.3
1922	2,514	2,381	133		0.4
1923	2,194	2,039	155		0.4
1924	2,610	2,440	170		0.4
1925	2,741	2,582	160		0.4
1926	2,593	2,400	193		0.4

	CO_2 fossil fuels thousand tonnes	**CO_2 coal** thousand tonnes	**CO_2 oil** thousand tonnes	**CO_2 natural gas** thousand tonnes	**CO_2** per capita ton
1927	3,181	2,960	221		0.5
1928	3,566	3,259	307		0.5
1929	3,464	3,162	302		0.5
1930	3,832	3,486	347		0.6
1931	3,595	3,245	351		0.5
1932	3,105	2,758	348		0.4
1933	3,685	3,290	396		0.5
1934	3,758	3,296	462		0.5
1935	3,984	3,485	500		0.5
1936	3,700	3,211	489		0.5
1937	4,682	4,115	567		0.6
1938	4,159	3,567	592		0.6
1939	4,432	3,796	636		0.6
1940	3,438	2,762	676		0.4
1941	3,346	2,745	602		0.4
1942	2,584	2,391	193		0.3
1943	2,714	2,359	355		0.3
1944	3,270	2,522	748		0.4
1945	3,065	2,399	666		0.4
1946	3,726	2,564	1,162		0.5
1947	5,337	3,520	1,817		0.6
1948	5,065	3,089	1,976		0.6
1949	5,367	3,414	1,953		0.6
1950	5,122	2,936	2,186		0.6
1951	5,126	2,604	2,522		0.6
1952	4,936	2,168	2,769		0.6
1953	5,534	2,529	3,005		0.6
1954	5,425	2,129	3,296		0.6
1955	6,004	2,241	3,763		0.7
1956	6,162	2,268	3,895		0.7
1957	6,559	2,690	3,869		0.8
1958	6,425	2,321	4,104		0.7
1959	6,571	2,070	4,501		0.7
1960	6,978	2,078	4,900		0.8
1961	7,979	2,598	5,381		0.9
1962	8,168	2,436	5,733		0.9
1963	8,693	2,766	5,927		1.0
1964	8,807	2,698	6,109		1.0
1965	9,367	2,634	6,733		1.1
1966	9,564	2,867	6,697		1.1

	CO_2 fossil fuels thousand tonnes	**CO_2 coal** thousand tonnes	**CO_2 oil** thousand tonnes	**CO_2 natural gas** thousand tonnes	**CO_2** per capita ton
1967	10,236	2,685	7,551		1.2
1968	10,654	2,420	8,234		1.2
1969	11,752	2,709	9,043		1.4
1970	13,593	2,474	11,119		1.6
1971	14,365	1,890	12,475		1.7
1972	15,599	1,671	13,928		1.8
1973	17,259	1,944	15,315		1.9
1974	17,794	1,539	16,255		2.0
1975	19,629	1,591	18,038		2.1
1976	20,489	1,563	18,927		2.2
1977	20,384	1,601	18,783		2.2
1978	20,455	1,724	18,731		2.1
1979	22,617	1,731	20,886		2.3
1980	24,680	1,683	22,997		2.5
1981	26,280	1,477	24,803		2.7
1982	27,035	1,291	25,745		2.7
1983	27,871	1,556	26,315		2.8
1984	27,373	1,699	25,674		2.8
1985	26,796	3,096	23,700		2.7
1986	29,977	5,765	24,212		3.0
1987	31,131	7,510	23,621		3.2
1988	32,914	8,282	24,632		3.3
1989	41,224	10,186	31,038		4.2
1990	42,150	10,960	31,190		4.3
1991	43,296	11,551	31,745		4.4
1992	47,789	11,729	36,059		4.8
1993	46,378	12,474	33,905		4.7
1994	47,134	13,201	33,933		4.8
1995	51,777	14,332	37,445		5.2
1996	50,145	13,626	36,519		5.0
1997	54,452	13,965	40,284	203	5.4
1998	57,408	12,864	42,900	1,643	5.7
1999	63,735	14,905	44,237	4,593	6.3
2000	62,690	15,166	42,496	5,027	6.2
2001	61,950	12,678	43,947	5,325	6.0
2002	66,985	13,864	46,678	6,443	6.4
2003	61,990	13,288	42,480	6,221	5.9
2004	63,571	13,368	42,414	7,790	6.0
2005	65,932	13,264	43,834	8,834	6.2
2006	62,676	13,116	41,117	8,443	5.9

Appendix D

Energy Prices, Portugal

Table D.1 Energy prices, Escudos /GJ, Portugal: 1856-1980

	Coal	**Domestic Coal**	**Crude Oil**	**Fire-wood**	**Fire-wood**	**Firewood**	**Char-coal**
	Imports	**Pithead**	**Imports**	**Lisbon**	**Porto**	**Industrial**	**Lisbon**
	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ
1856	0.168			0.229	0.239		0.262
1857	0.151			0.230	0.286		0.309
1858	0.130			0.230	0.276		0.313
1859	0.121			0.242	0.296		0.311
1860	0.116			0.225	0.305		0.321
1861	0.152			0.236	0.305		0.345
1862				0.235	0.305		0.373
1863				0.267	0.288		0.430
1864				0.273	0.360		0.456
1865	0.144			0.280	0.394		0.474
1866	0.136			0.271	0.398		0.463
1867	0.165			0.264	0.398		0.436
1868	0.168			0.280	0.578		0.426
1869	0.153			0.237	0.659		0.434
1870	0.174			0.307	0.321		0.460
1871	0.175			0.301	0.452		0.452
1872	0.181			0.302	0.540		0.451
1873	0.198			0.310	0.549		0.454
1874				0.325	0.636		0.468
1875	0.196			0.243	0.607		0.468
1876	0.189			0.256			0.445
1877	0.216			0.256	0.420		0.468
1878	0.161			0.279	0.414		0.468
1879	0.161			0.279	0.352		0.468
1880	0.160			0.279	0.393		0.468
1881	0.137			0.245	0.342		0.468
1882	0.138			0.247	0.321		0.468
1883	0.138			0.245	0.334		0.468
1884	0.140			0.245	0.337		0.468
1885	0.133			0.418	0.337		0.499
1886	0.131			0.418	0.342		0.499

	Coal Imports Esc/GJ	**Domestic Coal Pithead** Esc/GJ	**Crude Oil Imports** Esc/GJ	**Fire-wood Lisbon** Esc/GJ	**Fire-wood Porto** Esc/GJ	**Firewood Industrial** Esc/GJ	**Char-coal Lisbon** Esc/GJ
1887				0.327	0.340		0.522
1888	0.119				0.342		0.522
1889	0.125				0.352		0.522
1893	0.118	0.194			0.366		0.477
1894	0.117	0.195			0.398		0.477
1895	0.112	0.164			0.398		0.477
1896	0.108	0.203			0.477		0.477
1897	0.106	0.229			0.477		0.477
1898	0.143	0.194			0.480		0.477
1899	0.154	0.150			0.517		0.477
1900	0.223	0.100			0.517		0.477
1901	0.213	0.109			0.589		0.477
1902	0.177	0.115			0.597		0.477
1903	0.162	0.101			0.597		0.477
1904	0.150	0.101					0.477
1905	0.138	0.097					0.477
1906	0.127	0.124					0.477
1907	0.137	0.185					0.477
1908	0.136	0.193					0.477
1909	0.129	0.204					0.477
1910	0.130	0.200					0.477
1911	0.128	0.251					0.477
1912	0.142	0.235					0.477
1913	0.152	0.214					0.477
1914	0.155	0.189					0.715
1915	0.295	0.212					1.730
1916	0.781	0.413					2.422
1917	1.493	0.515					3.114
1918	2.312	0.668					3.461
1919	1.347	0.919					7.613
1920	4.001	1.280					7.959
1921	3.597	1.686					9.343
1922	3.254	2.605					
1923	6.153	3.993					11.5
1924	6.910	5.041					15.7
1925	4.748	5.230					16.1

	Coal	Domestic Coal	Crude Oil	Fire-wood	Fire-wood	Firewood	Char-coal
	Imports	Pithead	Imports	Lisbon	Porto	Industrial	Lisbon
	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ	Esc/GJ
1926	5.466	4.025					23.209
1927	4.696	3.139					24.248
1928	4.372	2.356					
1929	4.255	2.561					
1930	4.182	2.709					
1931	4.098	2.690					
1932	4.142	2.405					
1933	3.832	2.000					
1934	4.072	1.717					
1935	4.136	1.580					
1936	4.256	1.575					
1937	5.038	1.426					
1938	5.147	1.660					20.784
1939	5.400	2.211					20.784
1940	9.537	3.468	14.8				21.477
1941	12.423	4.852	22.9				22.516
1942	14.785	7.356	28.2				25.288
1943	19.807	8.299					30.830
1944	21.545	8.539				13.8	33.948
1945	20.917	6.966	33.0			16.7	36.373
1946	18.569	6.498	31.3			20.3	38.105
1947	17.728	6.249	14.7			39.4	38.105
1948	16.510	6.426	19.2			37.3	47.111
1949	15.279	6.726	19.4			33.1	53.693
1950	13.703	7.079	17.3			16.3	47.804
1951	16.699	7.163	20.1			16.0	46.072
1952	18.434	6.878	18.4			15.9	48.497
1953	16.551	6.778	15.6			36.7	48.497
1954	15.924	6.860	15.4			16.0	48.497
1955	16.552	7.071	15.8			15.2	48.497
1956	19.219	7.003	17.6			15.1	48.843
1957	19.396	6.964	22.1			14.6	51.961
1958	17.372	7.240	15.6			13.9	51.961
1959	15.839	7.462	15.0			14.2	51.961
1960	14.312	7.689	15.0			30.2	51.961
1961	15.38	7.740	15.0			13.9	51.961
1962	15.953	8.828	14.8			12.6	51.961
1963	16.796	10.177	14.6			12.9	51.961
1964	17.053	11.161	14.6			12.9	51.961

	Coal Imports Esc/GJ	Domestic Coal Pithead Esc/GJ	Crude Oil Imports Esc/GJ	Fire-wood Lisbon Esc/GJ	Fire-wood Porto Esc/GJ	Firewood Industrial Esc/GJ	Char-coal Lisbon Esc/GJ
1965	17.864	11.363	14.2			12.8	51.961
1966	17.888	11.305	14.3			13.0	51.961
1967	19.548	11.512	15.9			12.1	51.961
1968	17.014	13.129	16.4			10.8	51.961
1969	19.937	13.614	16.0			11.1	51.961
1970	24.986	13.943	17.3			11.9	55.425
1971	42.519	11.422	16.8			13.5	62.353
1972	30.389	11.301	15.3			13.6	62.353
1973	24.559	15.053	17.5			14.6	86.602
1974	50.036	22.960	48.2			17.5	98.033
1975	64.268	35.410	55.2			20.3	121.242
1976	71.542	45.398	70.1			26.1	
1977	88.552	56.564	93.6			80.6	
1978	113.753	69.260	107.3			34.7	
1979	114.474	90.959	160.0			41.4	
1980	161.406	124.147	290.7			49.4	

Sources: Coal imports my compilation from INE, *Comércio Externo*, several issues. Domestic coal pithead prices, own construction from several sources: INE, *Anuário Estatístico* for 1890 to 1900, 1911 to 1914, 1938 and 1940 to 47; INE, *Estatísticas Industriais*, several issues, for 1947 to 1967. For years 1901 to 1910 and 1915 to 1937 and 1939 see Direcção Geral de Minas e Serviços Geológicos, Repartição de Minas, *Boletim de Minas*, 1928, 1930 and 1939. For 1968 to 1980 see also *Boletim de Minas*, several issues. Crude Oil, my compilation from INE, *Comércio Externo*, several issues. Firewood for Lisbon 1856-1888 is from Mappa Estatístico... (1854/1855 to 1865-1866); *Estatística da Alfândega* for 1866-67 to 1888-1889. Firewood for Oporto 1856 to 1903 is derived from Pinheiro (1983). Industrial firewood is constructed from INE, *Estatísticas Industriais*, several issues. Charcoal for Lisbon is derived from taxation data: same sources as firewood from *1856 to* 1888; Ministério da Fazenda, *Consumo em Lisboa...* 1891-1907; Ministério da Fazenda,.. *Consumo e real de água: Lisboa e Porto* (1908-1922) and from 1923 to 1975 is taken from INE, *Anuário Estatístico*, several issues.

Appendix E

International database

This appendix presents some of the basic indicators which were used in Chapter 3 for analyzing energy transitions.

Table E.1 Canada, basic indicators, selected years

	Coal	**Oil**	**Natural Gas**	**Primary electricity**	**Muscle**	**Water**	**Firewood & Others**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1871	24	1			60		179
1913	796	27	23	5	119	3.6	173
1938	678	258	38	86	119	8.0	186
1950	1150	659	80	181	202	10.1	105
1973	639	3018	1561	707	115		327
1990	1003	2730	2150	1338	129		341
2006	1183	3097	3192	1576	131		491

	Total Energy	**GDP**	**Population**	**Energy Intensity**	**Energy per capita**	**CO_2**	**CO_2**
	PJ	million $1990	thousands	MJ/$1990	GJ	million tonnes	per capita, ton
1871	264	6669	3801	40	69	2	1
1913	1147	34916	7852	33	146	79	10
1938	1474	52060	11452	28	129	85	7
1950	2387	102164	14011	23	170	162	12
1973	6376	312176	22560	20	283	369	16
1990	7690	524475	27791	15	277	416	15
2006	9671	814835	33099	12	292	518	16

Sources: Steward (1978) 1871-1960, IEA (2008a) for 1960-2008. Mitchell (2007) for muscle power and Maddison (2008) for GDP. Primary electricity converted to its heat content. CO_2 emissions own calculations.

Table E.2 England & Wales, basic indicators, selected years

	Coal	Oil	Natural Gas	Primary electricity	Muscle	Water, solar & geo heat	Fire-wood & Others
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1800	370				75	12	20
1870	2699	1			133		
1913	5647	58			211		
1938	5208	300			150		
1950	5928	528			180		
1973	3841	3887	1059	105	197		
1990	3118	2892	1947	273	159	0	24
2006	1941	2952	3402	304	190	1	149

	Total Energy	GDP	Population	Energy Intensity	Energy per capita	CO_2	CO_2
	PJ	million $1990	thousands	MJ/$1990	GJ	million tonnes	per capita, ton
1800	478	16935	9201	28	52	35	4
1870	2834	90945	21696	31	131	255	12
1913	5916	216297	36411	27	162	538	15
1938	5659	295270	41277	19	137	515	12
1950	6636	320152	43553	21	152	600	14
1973	9089	600241	49241	15	185	708	14
1990	8414	847121	50638	10	166	616	12
2006	8940	1237885	53129	7	168	591	11

Sources: Energy carriers from Warde (2007), oil figures revised by the author. Primary electricity recalculated by its heat content. CO_2 emissions own calculations.

Table E.3 France, basic indicators, selected years

	Coal	**Oil**	**Natural Gas**	**Primary electricity**	**Muscle**	**Water, solar & geo heat**	**Fire-wood & Others**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1820	32	0	0	0	194		322
1870	547	1	0	0	276		240
1913	1862	5	0	0	318		180
1938	1989	333	0	39	314		180
1950	1796	453	9	60	273		267
1973	1224	4545	505	177	260	0	410
1990	835	3176	1010	1337	245	5	484
2006	547	3263	1590	1781	261	6	506

	Total Energy	**GDP**	**Population**	**Energy Intensity**	**Energy per capita**	**CO_2**	**CO_2**
	PJ	million $1990	thousands	MJ/$1990	GJ	million tonnes	per capita, ton
1820	547	35468	30250	15	18	3	0
1870	1064	72100	36870	15	29	52	1
1913	2366	144489	39771	16	59	177	4
1938	2855	187402	41960	15	68	213	5
1950	2859	220492	41836	13	68	204	5
1973	7121	683965	52118	10	137	477	9
1990	7093	1026491	56735	7	125	369	6
2006	7955	1380352	60876	6	131	380	6

Sources: Energy carriers from Gales and Warde (unpublished) and IEA (1960-2006) in order to deduct non-energy uses of oil and natural gas. Primary electricity calculated by its heat content. GDP and population figures from Maddison (2008). CO_2 emissions own calculations.

Table E.4 Germany, basic indicators, selected years

	Coal & Peat	**Oil**	**Natural Gas**	**Primary electricity**	**Muscle**	**Water, solar & geo heat**	**Fire-wood & Others**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1870	845	4		0	263	11	243
1913	5821	50		0	452	9	173
1938	6513	24	1	29	397		106
1950	5449	137	4	35	363		106
1973	5741	6170	1167	141	333	0	105
1990	5346	4440	2208	622	331	1	201
2006	3433	4220	3237	737	343	18	676

	Total Energy	**GDP**	**Population**	**Energy Intensity**	**Energy per capita**	**CO_2**	**CO_2**
	PJ	million $1990	thousands	MJ/$1990	GJ	million tonnes	per capita, ton
1870	1366	72149	40805	19	33	80	1
1913	6504	237332	66978	27	97	554	8
1938	7070	342351	68558	21	103	618	9
1950	6094	265354	68375	23	89	526	8
1973	13657	944755	78950	14	173	1061	13
1990	13149	1264438	79380	10	166	955	12
2006	12665	1647840	82422	8	154	816	10

Sources: Gales, Kander and Warde, unpublished. IEA (1960-2006) in order to deduct non-energy uses of oil and natural gas. Primary electricity calculated by its heat content. GDP and population figures from Maddison (2008). CO_2 emissions own calculations.

Table E.5 Italy, basic indicators, selected years

	Coal	**Oil**	**Natural Gas**	**Primary electricity**	**Muscle**	**water wind solar & geo heat**	**Fire-wood & Others**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1870	32	2		0	190	5	228
1913	348	10	0	7	308	2	182
1938	411	101	1	54	305	1	183
1950	315	215	17	83	314	1	192
1973	427	3484	598	164	310	0	188
1990	661	3186	1562	263	300	9	186
2006	691	3027	2857	326	302	10	202

	Total Energy	**GDP**	**Population**	**Energy Intensity**	**Energy per capita**	**CO_2**	**CO_2**
	PJ	million $1990	thousands	MJ/$1990	GJ	million tonnes	per capita, ton
1870	457	43526	27390	10	17	3	0.1
1913	858	96856	36275	9	24	34	1
1938	1056	148676	43154	7	24	46	1
1950	1138	170190	46768	7	24	47	1
1973	5172	578953	53882	9	96	329	6
1990	6166	939038	57746	7	107	384	7
2006	7415	1169690	58259	6	127	448	8

Sources: Malanima (2006) and IEA (2008a) (1973,1990 and 2006) in order to deduct non-energy uses of oil and natural gas. Primary electricity recalculated by its heat content. CO_2 emissions own calculations.

Table E.6 Netherlands, basic indicators, selected years

	Coal PJ	**Oil** PJ	**Natural Gas** PJ	**Primary electricity** PJ	**Muscle** PJ	**Wind , solar & geo heat** PJ	**Fire-wood, Peat & Others** PJ
1800	4	0	0		15	9	18
1870	54	1	0		26	10	39
1913	320	7	0		42	6	15
1938	405	77	0		51	1	13
1950	469	94	2	0	54	1	8
1973	107	696	1326	-1	55	0	3
1990	384	457	1433	46	60	0	49
2006	361	644	1594	100	66	1	303

	Total Energy PJ	**GDP** million $1990	**Population** thousands	**Energy Intensity** MJ/$1990	**Energy per capita** GJ	**CO₂** million tonnes	**CO₂** per capita, ton
1800	46	3791	2112	12	22	0	0.2
1870	130	9560	3610	14	36	5	1
1913	390	24349	6184	16	63	31	5
1938	547	44486	8685	12	63	44	5
1950	628	60642	10114	10	62	51	5
1973	2186	175791	13439	12	163	135	10
1990	2430	258094	14952	9	163	150	10
2006	3070	385709	16510	8	186	171	10

Sources: Database from Ben Gales in Gales *et al.*, IEA (2008a) for 2006. CO_2 emissions own calculations.

Table E.7 Spain, basic indicators, selected years

	Coal PJ	Oil PJ	Natural Gas PJ	Primary electricity PJ	Muscle PJ	water solar & geo heat PJ	Fire-wood & Others PJ
1870	32	1			143	10	124
1913	236	2		1	133	32	105
1935	239	34		12	193	41	113
1950	365	76		18	199		89
1973	414	1470	43	97	213		102
1990	795	1722	192	90	196		173
2006	793	2661	1280	166	214	3	219

	Total Energy PJ	GDP million $1990	Population thousands	Energy Intensity MJ/$1990	Energy per capita GJ	CO_2 million tonnes	CO_2 per capita, ton
1870	310	19556	16060	16	19	3	0.2
1913	509	41653	20340	12	25	22	1
1935	632	63482	24726	10	26	25	1
1950	747	61429	27976	12	27	40	1
1973	2340	266896	34858	9	67	149	4
1990	3168	474366	39102	7	81	212	5
2006	5336	762373	41324	7	129	342	8

Sources: Rubio (2005), revised firewood series. IEA (2008a) to deduct non-energy uses of oil and natural gas (1973, 1990 and 2006). Firewood was revised for the years 1973, 1990 and 2006 taking into account the values of Odyssee (2009) for residential firewood consumption in Spain (1980-2006). GDP and population figures from Maddison (2008). CO_2 emissions own calculations.

Table E.8 Sweden, basic indicators, selected years

	Coal	**Oil**	**Natural Gas**	**Primary electricity**	**Muscle**	**solar & geo heat**	**Fire-wood, Peat & Others**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
1800	0			0	22		88
1870	13	0		0	36		104
1913	166	7		4	46		140
1938	239	51		22	39		121
1950	222	146		52	33		121
1973	77	977		226	33		132
1990	122	521	24	503	35	0.1	254
2006	110	512	37	491	36	0.2	384

	Total Energy	**GDP**	**Population**	**Energy Intensity**	**Energy per capita**	**CO_2**	**CO_2**
	PJ	million $1990	thousands	MJ/$1990	GJ	million tonnes	per capita, ton
1800	111	1367	2336	81	47	22	0
1870	153	4553	2585	34	59	1	0.3
1913	363	14016	4169	26	87	16	3
1938	473	26449	5639	18	84	26	4
1950	574	41964	6310	14	91	32	4
1973	1446	107685	7042	13	205	79	10
1990	1458	151452	8144	10	179	51	6
2006	1570	213177	8591	7	183	50	6

Sources: Kander (2002) and IEA (2008a) for 2000-2006. GDP figures from Krantz and Schön (2007). CO_2 emissions own calculations.

Table E.9 US, basic indicators, selected years

	Coal PJ	**Oil** PJ	**Natural Gas** PJ	**Primary electricity** PJ	**Muscle** PJ	**Solar & geo heat** PJ	**Fire-wood & Others** PJ
1870	1106	12	0		620		3052
1913	15025	1280	654	37	1544		1813
1938	10507	7058	2425	132	1238		1449
1950	13028	14049	6297	370	979		1648
1973	13678	33633	21542	1340	841		1613
1990	20233	30856	17767	3286	993	14	2888
2006	23747	37314	20614	4222	1185	92	3546

	Total Energy PJ	**GDP** million $1990	**Popula-tion** thousands	**Energy Intensity** MJ/$1990	**Energy per capita** GJ	**CO_2** million tonnes	**CO_2** per capita, ton
1870	4790	98374	40241	49	119	105	2.6
1913	20353	517383	97606	39	209	1552	16
1938	22051	799357	130476	28	169	1647	13
1950	36370	1455916	152271	25	239	2615	17
1973	72647	3536622	211909	21	343	3816	18
1990	76038	5803200	250132	13	304	4235	17
2006	90721	9266364	298444	10	304	5052	17

Sources: Schurr and Netschert (1960), EIA (2009) and IEA (1960-2006) for deducting non-energy uses. US Department of Commerce (1975) and Mitchell (2007) to take account for animal power. GDP from Maddison (2008). Primary electricity recalculated by its heat content.

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