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Why Electricity Demand Is Highly Income-Elastic in Spain: A Cross-Country Comparison Based on an Index-Decomposition Analysis

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Abstract: Since 1990, Spain has had one of the highest elasticities of electricity demand in the European Union. We provide an in-depth analysis into the causes of this high elasticity, and we examine how these same causes influence electricity demand in other European countries. To this end, we present an index-decomposition analysis of growth in electricity demand which allows us to identify three key factors in the relationship between gross domestic product (GDP) and electricity demand: (i) structural change; (ii) GDP growth; and (iii) intensity of electricity use. Our findings show that the main differences in electricity demand elasticities across countries and time are accounted for by the fast convergence in residential per capita electricity consumption. This convergence has almost concluded, and we expect the Spanish energy demand elasticity to converge to European standards in the near future.

Keywords: electricity demand income elasticity; index decomposition analysis; long-term demand

JEL Classification: Q4; Q43; L; L5; L94

1. Introduction

The pressing issue of global warming has fueled attention for long-run analyses of energy demand. Competing hypotheses about the causality between economic growth and energy consumption call for very different degrees of activism for energy conserving policies. As Ozturk [1] pointed out, predicting the effects that such policies will have on economic growth requires to ex-ante know if use of energy causes growth or vice versa. If energy demand is caused by economic growth, then the costs in terms of output losses of energy conserving measures are bearable. On the contrary, if use of energy fuels economic growth then energy can be a limiting factor to economic growth, and therefore moving towards less energy-dependent economies will imply a trade-off.

Zhao et al. [2], for instance, summarized these alternatives in four competitive hypothesis: Growth hypothesis (unidirectional relationship from energy to income growth), Conservation hypothesis (unidirectional inverse relationship from income growth to energy consumption), Neutrality hypothesis (there no exists any causal relationship), and Feedback hypothesis (bi-directional causal relationship).

Although these authors provide some empirical references for each hypothesis, the most recent researches tends to reject the neutral hypothesis [3] and reinforce the feedback hypothesis, as is shown by Zhao [2] using Chinese provinces data, and Lu [4] by mean of 17 Taiwanese Industries.

According to the survey by Ozturk [1], previous works show conflicting and mixed results regarding the direction of this causality. The authors of some of these works, such as Chang et al. [5], Huang et al. [6], Holtedahl and Joutz [7], and Hondroyiannis [8] also pointed out two interesting features: First, income elasticity, or GDP elasticity of energy demand, is not constant over time nor across countries; and, second, there are significant differences in elasticities between the residential and the productive sector. These differences are linked to the degree of economic development in the energy-growth nexus, and the "mechanization" of the productive and residential sector.

With respect to the effect of the degree of economic development on the energy-growth nexus, Huang et al. [6] found no causal relationship between the two variables for low-income countries, economic growth leading energy consumption positively in middle-income countries, and economic growth leading energy consumption negatively in high-income countries. Janosi and Grayson [9] found similar results, confirming that energy consumption tends to respond to economic growth with higher intensity in less developed countries compared to advanced economies. Yoo and Lee [10] reported an inverted u-shaped relationship between electricity consumption and per capita income.

However, even though the causality direction will be correctly addressed it is interesting to know if the nexus energy usage-economic growth is stable or it is changing with the degree of economic development, and what are the causes this change can be attributed to. From a policy perspective, a changing relation will require that any conservation measure to be effective has to be adequately adapted to the "state" of economic development. Moreover, if the link between energy consumption and economic growth can be broken down by sectors (residential and no-residential) that reacts in a different way to certain type of policies (for example, measures based on prices), the policy effectiveness will be conditioned critically by the contribution to energy consumption growth of each sector.

In this way, some recent works have tried to estimate this time-varying elasticity using different econometric approach for an individual country Chang et al. [5], or panel data with different countries Chang et al. [11].

In most European countries electricity demand constitutes a significant and growing fraction of total energy demand. Between 16% and 33% of energy demand in Europe is covered by electricity. Over the last decade and independently of economic growth, in nearly all European countries, electricity demand has grown more than energy demand (see Table A1 of Appendix A). Hence, an in-depth analysis of the income elasticity of electricity demand is a first step towards a better understanding of the energy-growth nexus.

In addition to cross-country differences we also observe that over time as economies develop and mechanization increases, the nature of electricity consumption elasticities changes. Both, differences between countries and changes over time, are usually attributed to differences in the degree of penetration of electrical appliances in the productive (robotization, etc.) and residential (lighting, cooling and heating equipment, TV, mobile phones, etc.) sectors. Chang et al. [5], looking at Korean monthly data find increasing output elasticities of electricity demand for 1985–2012 in the residential, commercial, and industrial sector. The authors show that income elasticity of electricity demand increases over time, possibly driven by the proliferation of electronic devices in firms' production processes and in household consumption. Variability of elasticities can also be observed by looking at the highly dispersed estimates for income elasticities of electricity demand in different countries. For instance, Holtedahl and Joutz [7] considered Taiwanese data for 1955–1996 and find a long-run income elasticity of residential electricity demand of one, while their short-run estimate is much lower (0.23). On the other hand, Hondroyiannis [8] who examined the demand for residential electricity in Greece during 1960–1998, reports a much higher income elasticity of 1565. Other authors, such as Silk and Joutz [12] using 1949–1993 data on residential electricity consumption in the United States also find income elasticities smaller than unity. Yamaguchi [13] compared electricity demand data for 1986–1993 and 1993–2004 in Japan and finds that elasticities increased from 1076 to 1679. Zachariadis and Pashourtidou [14] used annual data for 1960–2004 to examine electricity consumption in the residential and service sector in Cyprus. Their results show that long run income elasticities of electricity consumption are larger than unity. More recently, Hasanov [15], summarized long run income elasticities of electricity consumption in resource-rich small open developing economies that ranges from 0.2, in Gulf Cooperation Council between 1975 and 1989, to 5.4 in Bahrain between 1970 and 1997.

With respect to sectorial differences in income elasticity of electricity consumption, Bianco et al. [16] found that for Italy the GDP elasticity of non-residential electricity consumption is fairly high in the short run (1.41) and even larger in the long run (2.20). Their estimated value for the short-run residential electricity consumption income elasticity, on the contrary, is only 0.29. The authors also find residential electricity consumption to be characterized by a much more irregular behavior, linked to population growth and to the increase in electricity intensity due to the diffusion of air-conditioning appliances. Other studies, such as Holtedahl and Joutz [7] and Hondroyiannis [8], found income elasticities of electricity consumption in the residential sector of one or larger for very different countries such as Greece or Taiwan. If all countries exhibited similar differences in long and short run elasticities by sectors we would expect aggregate elasticities to change over time, depending on the relative weight of residential and non-residential electricity consumption.

Nevertheless, even when Chang et al. [11], using a panel of 89 countries, highlight the role of sectoral structure, as well as residential consumption patterns, on the income elasticities of electricity consumption, they also remarks that "sectoral shifts alone are insufficient to explain the downward movement in elasticities for a selected number of these countries: France, Germany, Italy, Japan, Korea, Spain, the UK and the US".

The current paper provides an in-depth analysis of the relationship between electricity consumption and economic growth for all 28 countries of the European Union (EU). We focus on the elasticity of electricity consumption with respect to economic growth in the long run, and we show how this elasticity varies substantially across countries. Spain had one of the highest elasticities of electricity demand to GDP among European countries, (almost three times higher than Germany) being surpassed only by Italy, Portugal, and Malta. This is why we pay special attention to the Spanish case and its comparison with other European countries where this elasticity has been significantly lower.

A first descriptive analysis of our data does not confirm the intuition that differences in electricity demand elasticity are simply explained for by a country's level of development. This is why we try to provide a better understanding of the driving forces behind a country's electricity demand elasticity. To this end, we consider the evolution of electricity demand elasticity in Spain, and we present a simple framework that allows us to understand how changes in electricity demand elasticity can be related to deep economic transformations reflected in: (i) structural change; (ii) GDP growth; and (iii) the intensity of electricity use.

Existing literature highlights all three aspects as main causes for changes in the elasticity of electricity consumption over time, but there does not exist any structured framework to analyze the contribution of each. A common feature of previously cited works is that they are all essentially descriptive studies. Irrespective of the methodological approach used, electricity demand income elasticity is basically determined from the analysis of the coevolution of electricity consumption and household income, sectorial gross value added (GVA) or GDP. Most authors provide some insights into the factors behind the observed variations in elasticities (proliferation of electronic devices, increasing use of air conditioning, relative price of electricity, etc.), but without providing a clear framework to analyze these variations. Hence, to the best of our knowledge we are the first to present a structured framework that can be used to analyze electricity demand elasticities. Based on an index-decomposition methodology (see Ang [17], and Ang and Zhang [18], among others) we provide a simple, but very effective, way to analyze the contribution of the three long run drivers of the changing relationship between electricity and economic growth: structural change, GDP growth, and intensity of electricity use. Our main findings show that in particular relative intensities of electricity use play a very important role for explaining observed differences in electricity demand elasticities.

Over the past thirty years, the Spanish economy experienced significant changes to its economic structure, evolving from a high energy intensive industrial economy with high rates of GDP growth to a service economy with moderate economic growth and declining electricity consumption after 2012. In addition to the fact that Spain registered one of the highest electricity demand elasticities during this period, its dynamic economic development makes the analysis of the Spanish electricity demand particularly interesting.

The remainder of this paper is organized as follows: the next section describes the main features of electricity consumption in Spain and the EU. In Section 3 we present our decomposition methodology together with our main results. Given the importance of intensities of energy use for explaining the observed differences in electricity demand elasticities, in Section 4 we analyze how these intensities have evolved in Spain and in other European countries. Finally, Section 5 concludes.

2. Long Term Evolution of Electricity Demand in Spain and the EU

Between 1996 and 2012, electricity consumption in the 28 countries of the European Union [19] grew at an average annual rate of 1.1% while GDP increased by 1.7% [20], i.e., the income elasticity of electricity demand of the EU-28 combined was less than unity During that period as economic growth outperformed growth in electricity consumption, aggregate electricity intensity—measured as the ratio of total electricity demand to GDP—was reduced from 0.25 to 0.23 GWh/Million €. Irrespective of the causes, in general aggregate electricity intensity decreased in all European countries between 1996 and 2012.

However, country heterogeneity is one of the main characteristics of the EU and the degree of elasticity of electricity demand is not an exception. During the same period (1996–2012) we observe huge differences in average electricity demand income elasticities. For instance Denmark registered a near zero elasticity of 0.15, whereas Portugal had a highly elastic electricity demand with respect to GDP (1.7). While these differences could be attributed to differences in economic development, we also observe similar differences for countries such as Bulgaria (0.34) and France (1.14). With the latter being the more developed country. Spain with a per capita GDP slightly above the European mean had an electricity demand income elasticity of 1.3. During the period of analysis, only Malta, Portugal, and Italy had higher elasticities, while the majority of countries exhibited average elasticities of below one (see Figure 1).

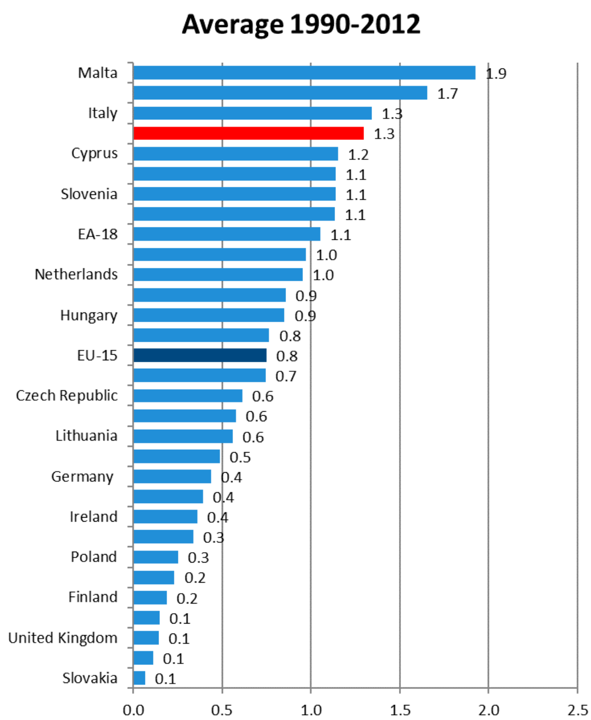


Figure 1. Elasticity of Electricity Demand to GDP (ΔDemand/ΔGDP). Source: Own calculations with Eurostat data.

Figure 2 displays annual elasticities for Spain, the EU-15, Germany, France, UK, and Italy. While Spain only experienced some transitory periods with elasticities below one, the situation in these other countries, with the exception of Italy which is more similar to Spain, was exactly the opposite, with only very few episodes when electricity demand elasticities rose above one.

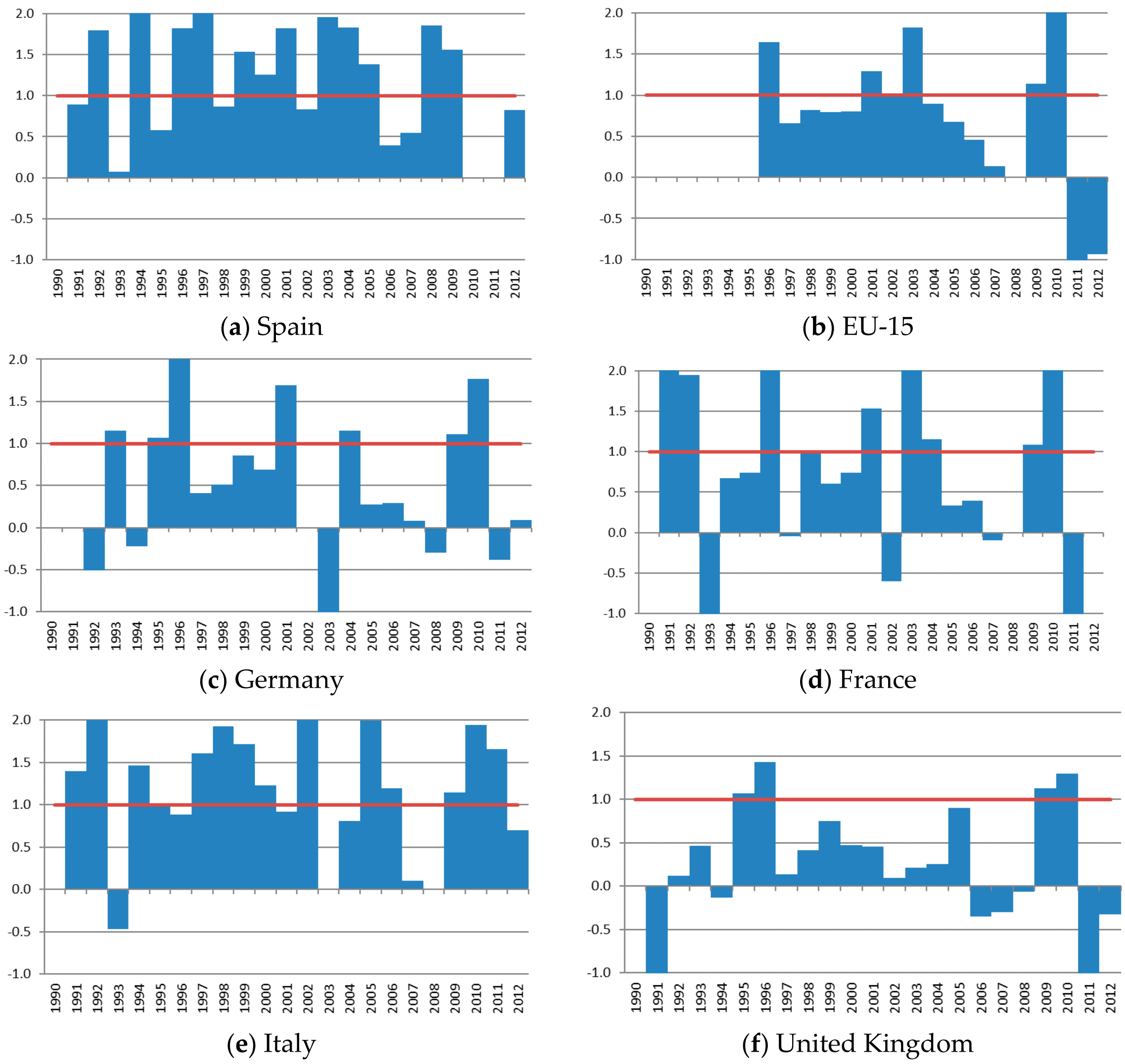


Figure 2. Elasticity Demand to GDP in selected countries. Annual data. Source: Own calculations with Eurostat data.

In order to better understand the driving forces behind such pronounced differences in electricity demand elasticity across European countries, in the following sections we analyze the characteristics of electricity demand in greater detail. We pay special attention to the case of Spain, whose GDP tripled between 1970 and 2012 [21], with electricity consumption virtually increasing six-fold during the same period. However, the Spanish electricity demand elasticity was far from constant throughout this period. Between 1970 and 1985 electricity consumption in Spain [22] registered growth rates that were considerably higher than GDP growth, resulting in an average elasticity of 2.14. On the other hand, from 1985 to 2012 electricity demand elasticity was reduced to 1.4. A thorough analysis of such profound changes requires a structured methodological framework that allows us to better disentangle the driving forces behind electricity demand elasticities. The next section presents such a framework.

3. Modeling Approach Based on Index Decomposition Methodology

Index decomposition analysis (IDA) is a simple tool that allows us to decompose changes in electricity consumption in terms of the contribution of different effects. In particular, in this framework, changes in electricity consumption can be decomposed into the three different effects mentioned before: (i) changes in sectorial structure (sectorial share in total GDP); (ii) changes in global economic activity (aggregate GDP growth); and (iii) sector specific energy intensity (energy used per unit of GVA). Following the IDA framework, we first decompose total electricity consumption in a given year t (C_t), into residential and non-residential consumption (electricity demand by firms and the public sector). Non-residential electricity consumption, is determined by changes in economic activity, (Y_t), changes in relative sectorial activity, ($\frac{Y_{it}}{Y_t}$), and changes in the intensity of electricity use per unit of sectorial output, ($I_{=}^{i,t}\frac{C_{i,t}}{Y_{i,t}}$). Change in residential consumption, on the other hand, can be determined as a function of population growth and other demographic aspects that determine changes in the number of households (H_t), and changes in the intensity of electricity consumption by households, ($I_{H,t} = \frac{C_{N,t}}{H_t}$). Combining electricity consumption by the two sectors, we can write the following expression:

$$C_t = \sum_{i=1}^{N} C_{i,t} = \sum_{i=1}^{N-1} Y_t \frac{Y_{i,t}}{Y_t}\frac{C_{i,t}}{Y_{i,t}} + H_t\frac{C_{N,t}}{H_t} = \sum_{i=1}^{N-1} Y_t S_{i,t} I_{i,t} + H_t I_{H,t} \quad (1)$$

where $S_{i,t}$ denotes the share of GVA of each sector over total GDP and $C_{i,t}$ is the breakdown of electricity consumption by sector. We specify N sectors and define all $N-1$ sectors as non-residential sectors and the Nth sector as the residential sector.

Denoting the growth rates of all variables with lower case letters, and after some operations, we arrive at the following expression:

$$1 + c_t = \sum_{i=1}^{N-1} w_{i,t-1}(1 + y_t)(1 + s_{i,t})(1 + i_{i,t}) + w_{r,t-1}(1 + h_t)(1 + i_{H,t}) \quad (2)$$

where $w_{i,t}$ is the weight of sectorial electricity consumption in total electricity consumption. Alternatively, this weight can be expressed as:

$$w_{i,t-1} = \frac{C_{i,t-1}}{C_{t-1}} = \frac{\frac{C_{i,t-1}}{Y_{i,t-1}}}{\frac{C_{t-1}}{Y_{t-1}}\frac{Y_{t-1}}{Y_{i,t-1}}} = \frac{I_{i,t-1}}{I_{t-1}}\frac{Y_{i,t-1}}{Y_{t-1}} = \frac{I_{i,t-1}}{I_{t-1}}S_{i,t-1} \quad (3)$$

In a simplified framework where we only consider two sectors, a residential and a non-residential sector, and where $w_{nr,t}$ denotes the weight of total non-residential electricity consumption, and $I_{nr,t}$ the average intensity of electricity use across all non-residential sectors, we can rewrite Equation (2) as:

$$1 + c_t = w_{nr,t-1}(1 + y_t)(1 + i_{nr,t}) + w_{r,t-1}(1 + h_t)(1 + i_{H,t}) \quad (4)$$

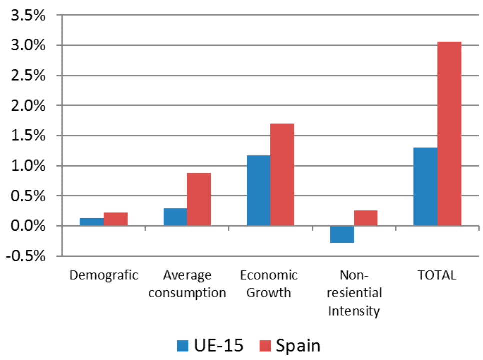
Finally, we can obtain the following expression:

$$c_t = w_{nr,t-1}y_t + w_{nr,t-1}i_{nr,t} + w_{r,t-1}h_t + w_{r,t-1}i_{H,t} + w_{r,t-1}i_{H,t}h_t + w_{nr,t-1}i_{nr,t}y_t \quad (5)$$

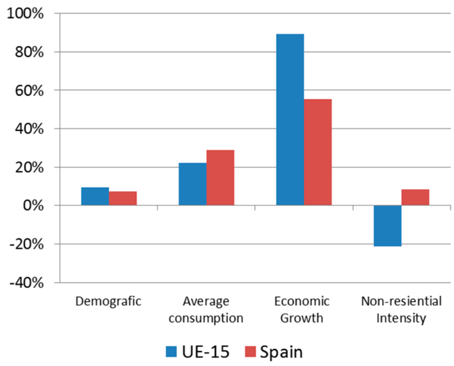
where the growth rate of total electricity consumption is expressed as the sum of the weighted contributions of the non-residential activity effect ($w_{nr,t-1}y_t$), the non-residential intensity effect ($w_{nr,t-1}i_{nr,t}$), changes in the number of households ($w_{r,t-1}h_t$) and the intensity of electricity use in the residential sector $w_{r,t-1}i_{H,t}$, plus a mixed effect either arising from residential or non-residential consumption ($w_{r,t-1}i_{H,t}h_t + w_{nr,t-1}i_{nr,t}y_t$).

To analyze in more detail the evolutions of electricity consumption in various EU countries that were presented in the previous section, we decompose the growth of total electricity consumption following Equation (5). This way we can differentiate between demographic effects (h_t), the effects of changes in average residential electricity consumption ($i_{H,t}$), economic growth (y_t), and the intensity of non-residential electricity consumption ($i_{n,r,t}$).

Figure 3 presents the absolute and relative contributions of each of these effects to the overall growth of electricity consumption during the period of analysis. As can be observed, growth in electricity demand has been mainly driven by the activity effect. In other words, economic growth has been the main factor boosting electricity consumption. This factor alone can account for nearly 90% of the observed average growth in electricity consumption in the combined EU-15. Second, the evolution of the intensity of electricity consumption by households can explain 22% of the growth in demand, and finally the demographic component (growth in the number of households) contributed on average around 10%. In the Spanish case, electricity demand has been mainly driven by economic growth (44%), while the remaining 56% are due to increases in non-residential electricity intensity (26%), average consumption per household (21%) and demographic changes (9%).



(**a**)



(**b**)

Figure 3. Break down of the consumption growth: (**a**) absolute effects (1990–2012); and (**b**) relative effects (1990–2012). Source: Own calculations with Eurostat data.

A remarkable finding is the negative contribution of the intensity of non-residential electricity use for the combined EU-15 and most other countries. For the combined EU-15 this effect reduces electricity demand by an average 0.3% (absolute effect) and contributes with a negative 20% to growth in electricity demand 20% (relative effect). This implies that over time economic activity has required less electricity per unit of output. It is important to point out that this does not mean that all economic activities have become more efficient in the use of electricity.

In the case of Spain, however, non-residential intensity of electricity use contributes positively to electricity consumption. Regarding all other reported effects we estimate higher absolute values for Spain. Particularly remarkable is the case of the demographic effect, for which Spain ranks fourth (see Figure 4), only surpassed by Malta, Ireland, and Cyprus. The main differences between Spain and the average EU-15 hence are found in the absolute effects of the industrial intensity of electricity use and GDP growth. In relative terms (percentage contribution of each effect), the largest differences are found in the effects of changes in non-residential intensity of electricity use.

Returning to Equation (5), we can easily derive a similar expression for the elasticity of electricity demand to GDP, which allows us to also decompose the observed elasticity in terms of the same three factors used before. By simply dividing Equation (5) by the GDP growth rate we obtain the following expression:

$$\varepsilon_{c,y,t} = \frac{c_t}{y_t} = w_{nr,t-1} + w_{nr,t-1}\frac{i_{n,r,t}}{y_t} + w_{r,t-1}\frac{h_t}{y_t} + w_{r,t-1}\frac{i_{H,t}}{y_t} + w_{r,t-1}\frac{i_{H,t}h_t}{y_t} + w_{nr,t-1}i_{nr,t} \quad (6)$$

We can thus break down the income elasticity of electricity demand into the following effects:

- Structure of the demand, i.e., weight of residential and non-residential demand ($w_{n,r,t-1}$).
- Non-residential intensity ($w_{nr,t-1nr,t}$) and non-residential intensity relative to GDP growth ($w_{nr,t-1}i_{nr,t}/y_t$). These effects capture changes in the intensity of electricity use in productive activities.
- Demographic growth (i.e., number of households) relative to GDP growth.($w_{r,t-1}h_t/y_t$).
- Residential intensity of electricity use relative to GDP growth ($w_{r,t-1}i_{H,t}y_t$), and residential mixed effect relative to GDP growth ($w_{r,t-1}i_{H,t}h_t/y_t$). These effects reflect changes in the intensity of electricity use by households.

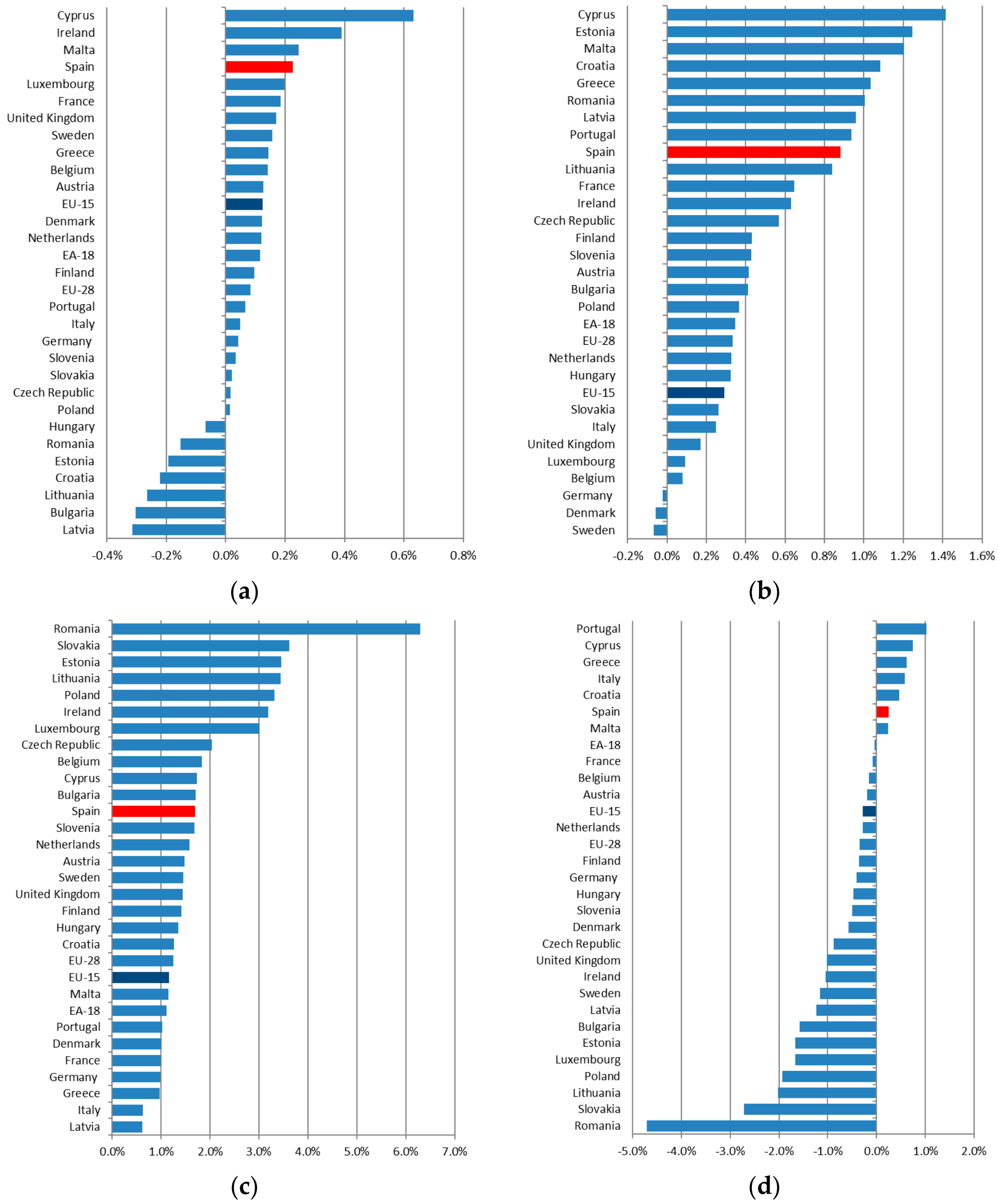


Figure 4. Contribution to growth in consumption, by country: (**a**) residential: demographic effect; (**b**) residential: average consumption effect; (**c**) non-residential: economic growth effect; (**d**) non-residential: intensity effect. Source: Own calculations with Eurostat data.

Figure 5 displays averages of each of these effects for 1990–2012 for all European countries. None of the effects alone can explain the higher elasticity of electricity demand in Spain; their combination accounts for the observed differences. All countries seem to share a similar structure regarding the contribution of the above-mentioned effects to demand elasticity. In particular, the structure of electricity demand, i.e., the share of residential and non-residential consumption, as well as the intensity of electricity use in the residential sector seem to matter most for demand elasticities.

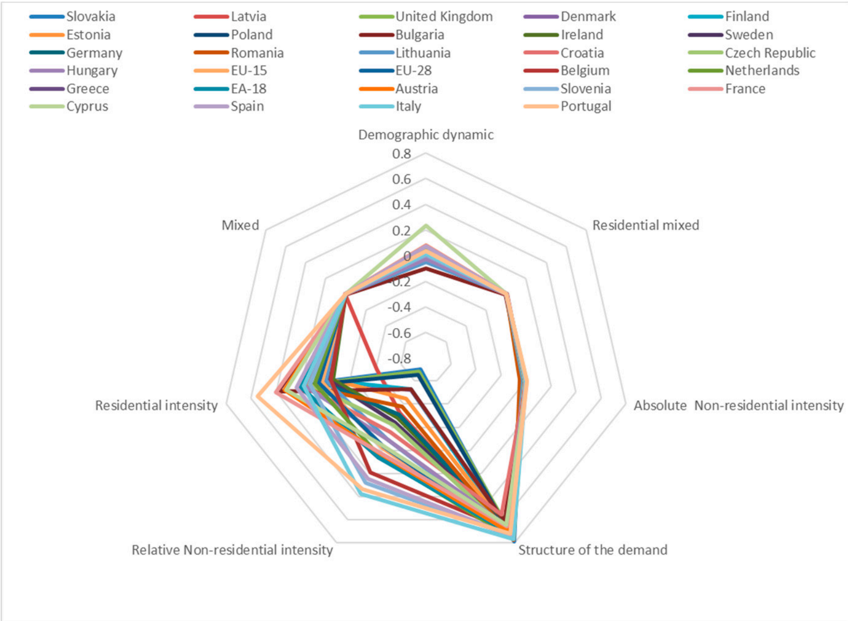


Figure 5. Average decomposition of Elasticity Demand to GDP. Source: Own calculations with Eurostat data.

Figure 6 displays the income elasticity of electricity consumption as a function of the intensities of electricity use in the residential and non-residential sector. The observed differences in electricity demand elasticity seem to be mainly driven by differences in relative intensities, in both the residential and non-residential sectors. Demographic effects only play a marginal role, and there are no substantial differences between countries regarding the importance of the remaining factors.

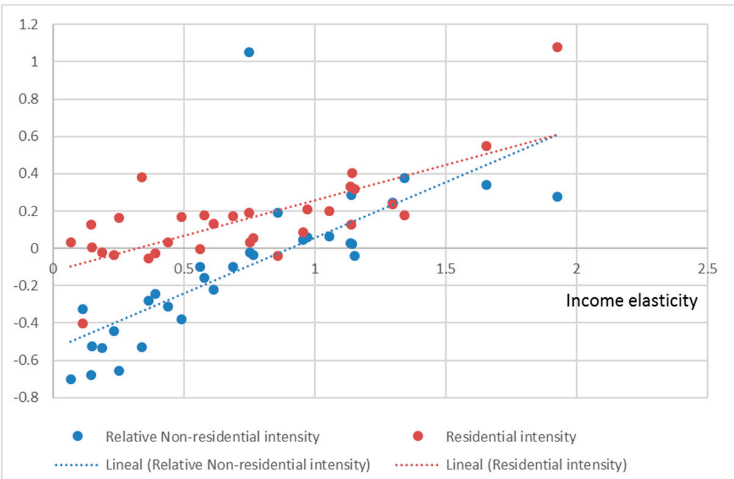


Figure 6. Income elasticity of electricity consumption versus intensities. Source: Own calculations with Eurostat data.

4. Long Term Evolution of Electricity Intensities in European Countries

The previous section showed that most observed differences in aggregate electricity demand elasticities can be explained by differences in sectorial structures (residential versus non-residential) and/or by differences in the intensities of electricity use; i.e., the same sector might use more or less electricity to produce the same amount of output. In this section we will analyze both factors—sectorial composition and intensity of use by sectors—in order to gain more insight into observed differences in electricity demand elasticities across countries as well as over time.

Taking into account that growth in the intensity of electricity use by the non-residential sector can be approximated by a weightedaverage growth of all industry-specific intensities, $w\prime_{i,t-1} = \frac{C_{i,t-1}}{C_{n,r,t-1}}$, $\sum_i w\prime_{i,t-1} = 1$, we can write the following expression for changes in the intensity of electricity use by the non-residential sector:

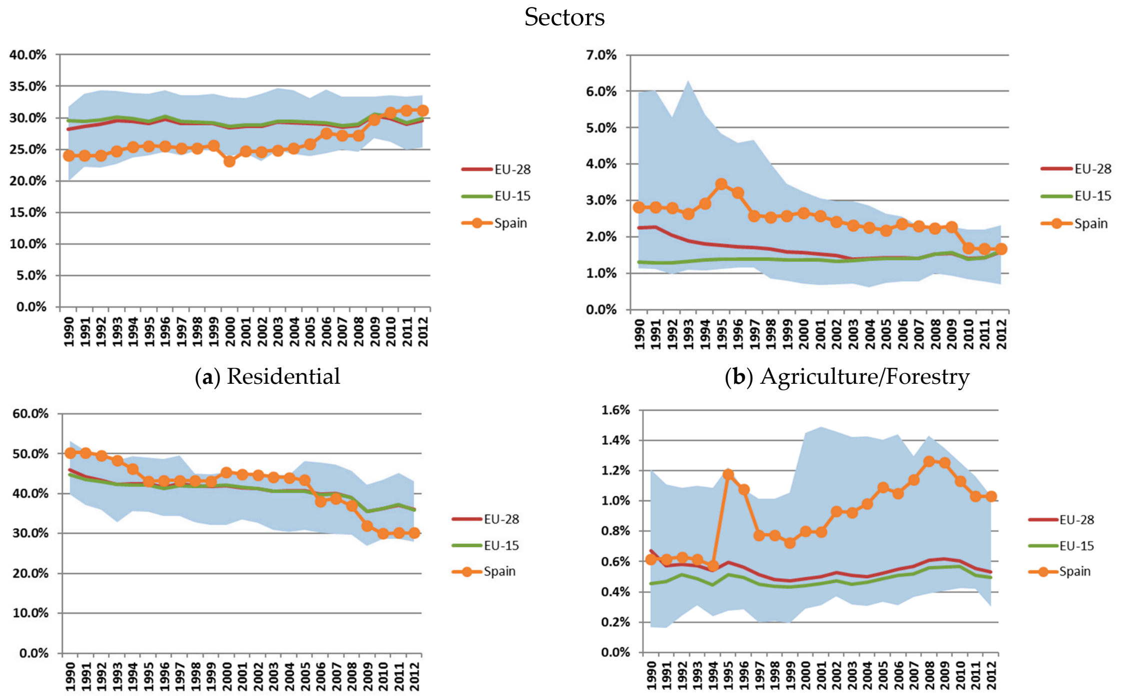
$$i_{nr,t} \approx \sum_{i=1}^{M} i_{i,t} w\prime_{i,t-1} + \sum_{i=1}^{M} y_{i,t} w\prime_{i,t-1} - y_t \quad (7)$$

Equation (7) uses the fact that changes in the intensity of electricity use by the non-residential sector can be expressed as changes in sector specific intensities ($I_{s,t} = \frac{C_{S,t}}{Y_{S,t}}$), changes in the structure of electricity consumption, ($w\prime_{i,t-1}$), and changes in sectorial activity, ($Y_{i,t}$).

In order to analyze the structure of electricity consumption by industrial sector and over time, we calculate the share of each sector's electricity consumption over total consumption for all countries and years available:

$$w_{i,t} = \frac{Consumption_{i,t}}{\sum_i Consumption_{i,t}} = w\prime_{i,t} w_{n,r,t} \quad (8)$$

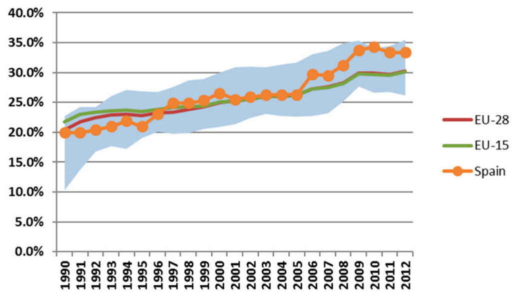
Figure 7 depicts the above shares for basic sectors (Figure 7a) and detailed industrial activities (Figure 7b) for Spain and the averages of EU-28 and EU-15. In order to also include information on other European countries, we mark the range between the second and third quartile of the respective values by blue bands.



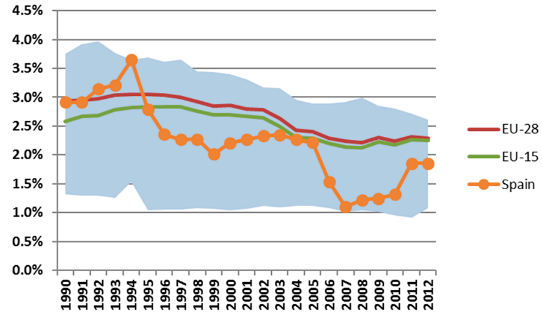
(**a**) Residential (**b**) Agriculture/Forestry

(**c**) Total Industry (**d**) Construction

Figure 7. *Cont.*

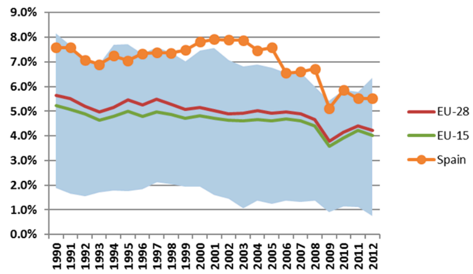


(**e**) Services

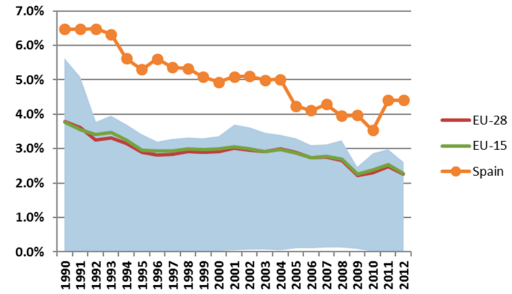


(**f**) Transport

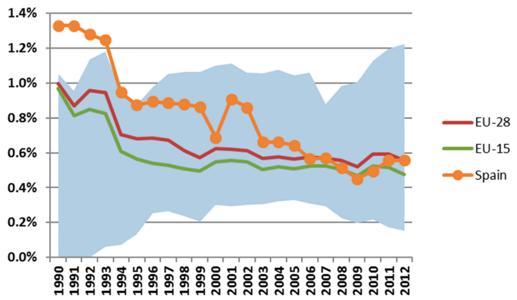
Breakdown of industrial activities



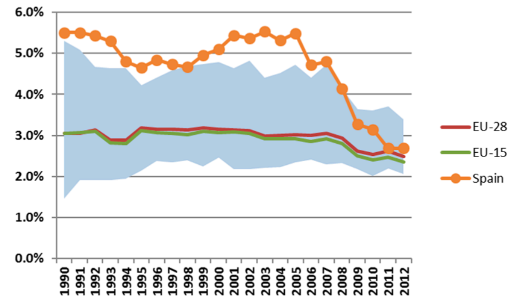
(**g**) Iron and Steel



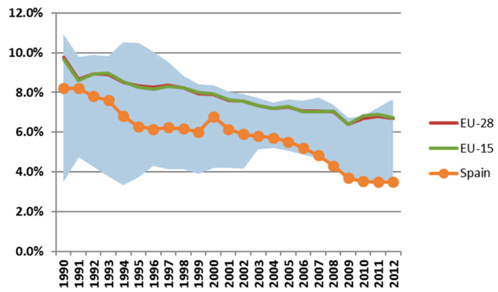
(**h**) Non-Ferrous Metals



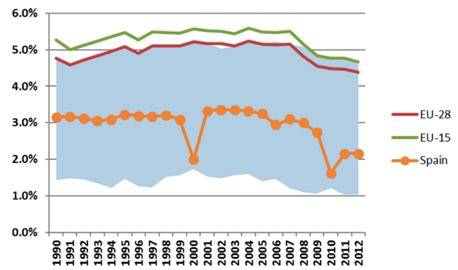
(**i**) Mining and Quarrying



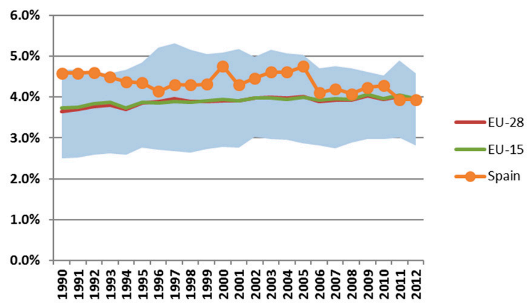
(**j**) Non-Metallic Minerals



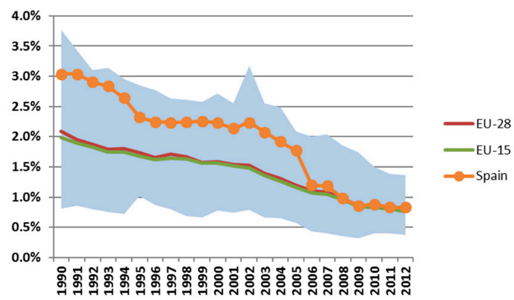
(**k**) Chemical and Petrochemical



(**l**) Paper, Pulp and Print

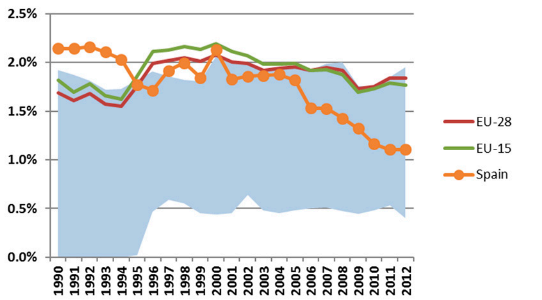


(**m**) Food and Tobacco

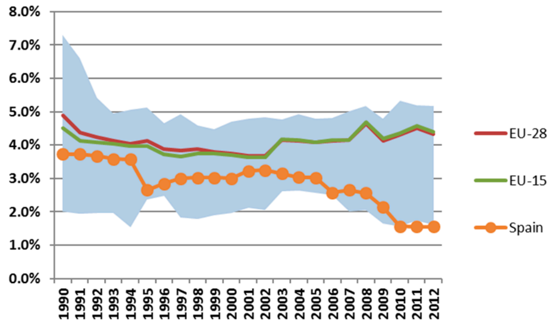


(**n**) Textile and Leather

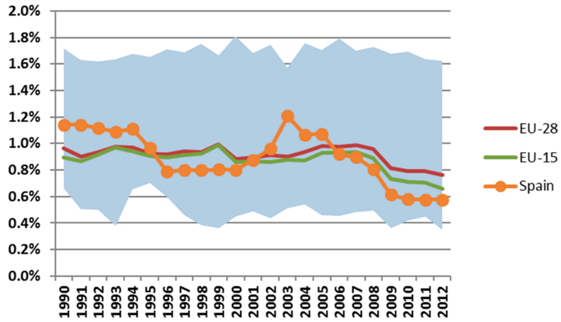
Figure 7. *Cont.*



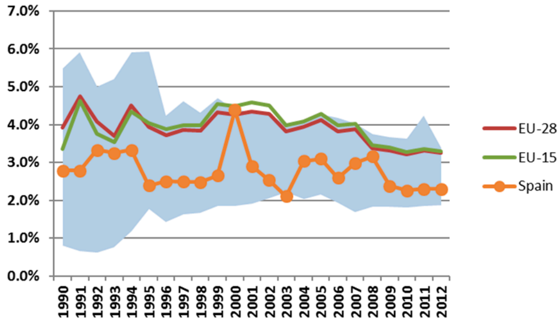
(**o**) Transport Equipment



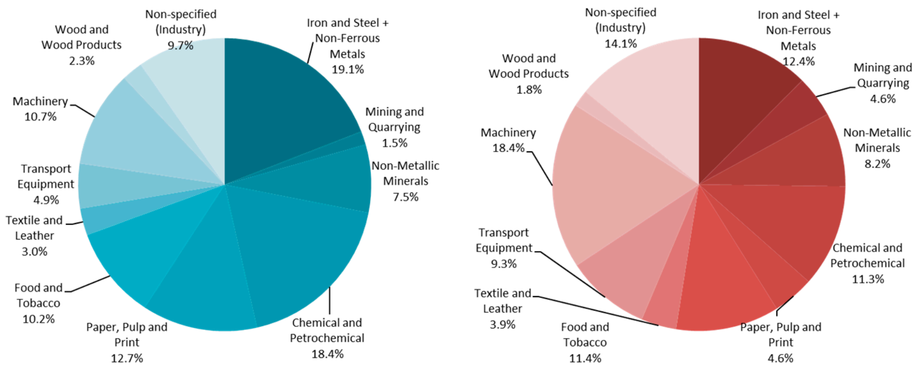
(**p**) Machinery



(**q**) Wood and Wood Products

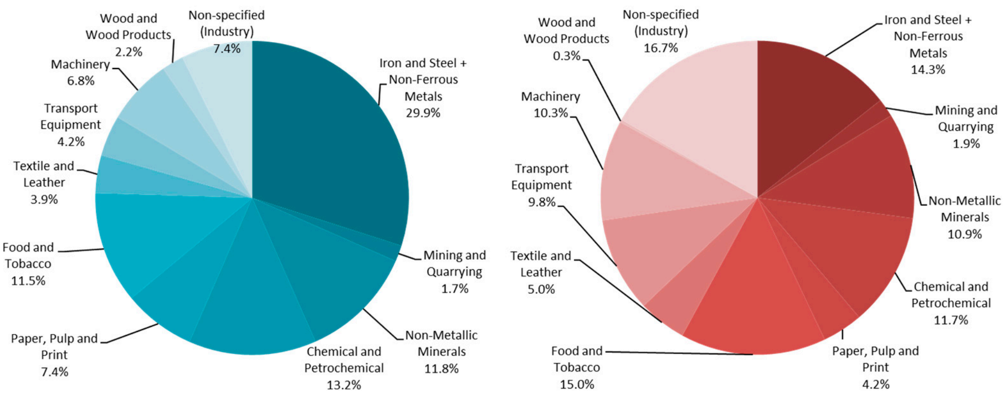


(**r**) Non-specified (Industry)



Electricity structure GVA structure

(**s**) EU-28. Shares on electricity industrial demand versus Shares on Industrial GVA (2000-2012 average)



Electricity structure GVA structure

(**t**) Spain. Shares on electricity industrial demand versus. Shares on Industrial GVA (2000–2012 average)

Figure 7. Shares on total final consumption of electricity. Source: Own calculation with Eurostat's data.

The graphs in Figure 7 show that, in general, the structure of electricity consumption in Spain is quite similar to the EU-28 and EU-15 averages. However, there are some specific sectors where we observe clear differences between Spain and the EU averages, both in the level of shares, as well as in their trends over time. The main aspect to be highlighted is the fact that in Spain, for more recent data, we observe a larger share of electricity consumption in the construction, service, and the residential sectors. Industrial activities, on the other hand, represent a lower fraction in total electricity consumption compared to other EU countries. Going back to the mid-1990s, the situation in Spain was exactly the opposite, with consumption shares in residential and service sectors in the lower range and the share in industrial activities located in the upper range. In addition to these features for Spain, the data show a remarkable decreasing trend in all EU countries in relative electricity consumption by industrial activities and by the transportation sector. On the other hand, we observe increasing shares in the service sector and almost constant shares in agriculture, construction, and the residential sector.

For the residential sector in Spain, we observe an increase in the share of electricity consumption that is substantially higher compared to other EU countries. While in the early 1990s, values registered for residential electricity consumption in Spain were found in the second quartile, in recent years Spanish residential electricity consumption has exceeded the mean and has approached the third quartile. The rapid increase in per capita income during the period of analysis together with the specific usages of electricity by Spanish households (cooling and heating equipment) can explain this increase in electricity intensity in the Spanish residential sector.

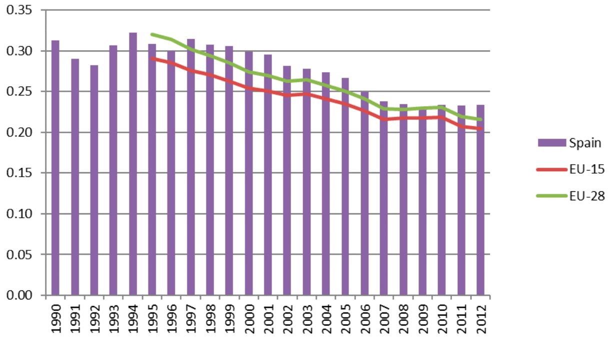
Regarding non-residential electricity use, until 2010, the agricultural share in electricity consumption in Spain was nearly 2% above the EU-15 average. This was due to the larger presence of the primary sector in Spain's productive structure. Similarly, the Spanish construction sector, even though its share in total electricity consumption is relatively low, triples the EU-15 average given the importance of construction for the Spanish economy during the period of analysis.

Electricity consumption by the Spanish service sector is characterized by a development similar to that of the residential sector, with recent increases in shares above the EU-15 average. In the case of the Spanish transportation sector, although we do observe a trend similar to that of most countries, its absolute share in electricity consumption is substantially lower than the EU-average, especially in recent periods. These lower levels can be explained by the relatively low share of rail freight transport compared to road freight transport in Spain. Finally, for all industrial activities, the decreasing trend shared by all countries is characterized by a steeper slope in Spain. In particular, relative electricity consumption by Spanish industrial activities decreased from the third quartile in the early nineties to the second quartile in recent years. The evolution of the productive structure and in particular the progressive loss of industrial activities experienced by the Spanish economy can explain this last observation.

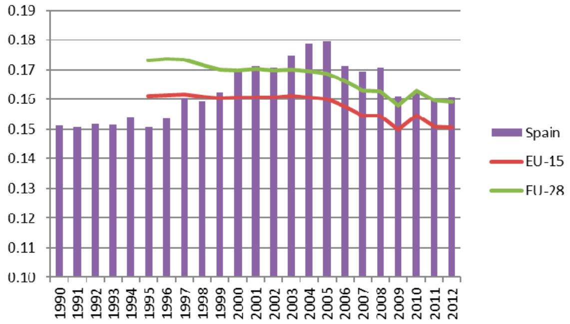
Regarding specific industrial activities, the most basic industries such as steel and metallurgy have a significantly higher share—above the third quartile—in electricity consumption in Spain compared to other EU countries. This is because Spanish firms use production technologies that are more electricity intensive compared to firms in other countries. On the other hand, we observe a reduction over time in relative electricity consumption by machinery and equipment in Spain, while the shares for the EU averages remain stable or even show a slightly increasing trend. It is most likely that differences in technologies leading to differences in the intensity of electricity use in these specific industries are responsible for this trend.

In order to provide a better understanding of how differences in the intensity of electricity use affect electricity demand elasticities we complement our analysis by looking at sectorial intensities ($I^i{}_{s,t} = \frac{C^i{}_{s,t}}{Y^i{}_{s,t}}$). These intensities are defined as the ratio of sectorial electricity consumption, $C_{s,t}$, and sectorial production, $Y_{s,t}$, measured in terms of gross value added. We obtain our measure by dividing electricity consumption by the total value added of each industry, measured in millions of Euros [20]. These intensities indicate how much electricity is needed in order to produce one unit of output. In the case of the residential sector intensities are calculated as the ratio of electricity consumption to population instead of production. We use average per capita consumption instead of consumption per household because data on the number of households in each EU country are not available for years before 2006.

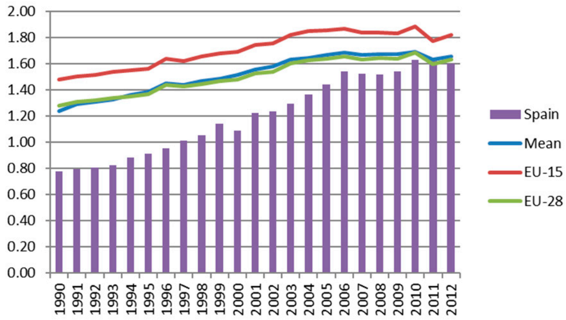
Figure 8 displays the evolution of total electricity intensity (total electricity consumption in GWh/volume of GVA) in Spain (bars) together with the average for the EU-15 and EU-28 (lines). We also display the same data separately for the residential and non-residential sector. Over time, Spanish total electricity intensity has converged towards the EU average. This convergence is driven by a reduction in the non-residential intensity of electricity use and by a large increase in residential per capita electricity consumption.



(**a**) Total. GWh/Million € GVA (2005)



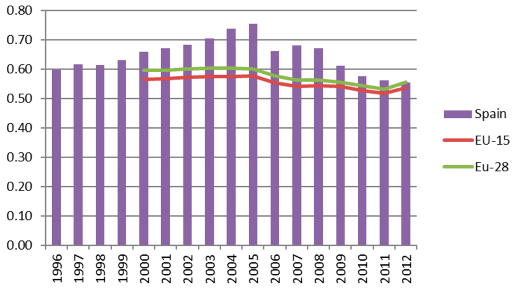
(**b**) Non Residential. GWh/Million € GVA (2005)



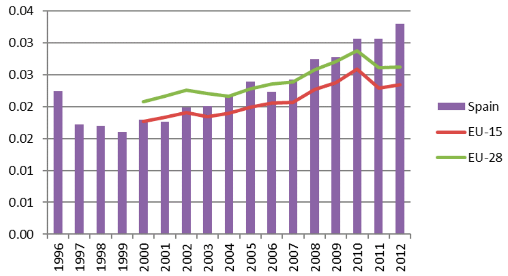
(**c**) Residential per Capita. GWh/1000 p

Figure 8. Intensity of electricity use (GWh/GVA and GWh per capita), 1990–2012. Source: Own calculation with Eurostat's data.

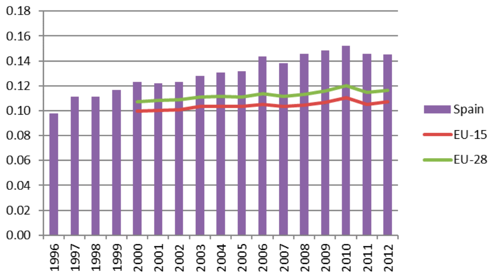
Looking at the intensities by broad sectors (see Figure 9), we observe a higher relative intensity of electricity use by the service sector in Spain. This is most likely because tourism, a sector that is more intensive in electricity demand (heating and cooling equipment in hotels and restaurants), has a relatively large weight in Spanish GDP. In a similar manner and as mentioned before, the lower intensity of electricity use in the transportation sector is linked to the lower relative share of rail freight transport in Spain. Regarding aggregate industrial activities, the intensity of electricity use seems to be converging to EU standards. In Figure 10 we display intensities of electricity use for detailed industrial activities (Table A2 of the Appendix A shows the correspondence between sectors and statistical classifications of economic activities NACE 2009 codes). Most noteworthy are the differences in intensities of electricity use between Spain and the EU averages for "Mining and Quarrying", "Wood and Wood Products" and "Paper, Pulp and Print", but these last results are not directly comparable due to discrepancies across countries regarding the sectoral allocation of the paper pulps.



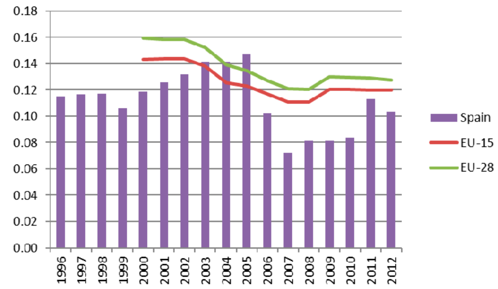
(**a**) Industry



(**b**) Construction

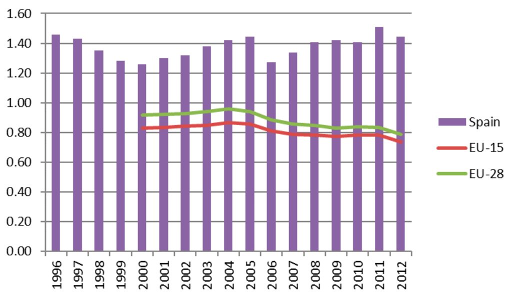


(**c**) Services

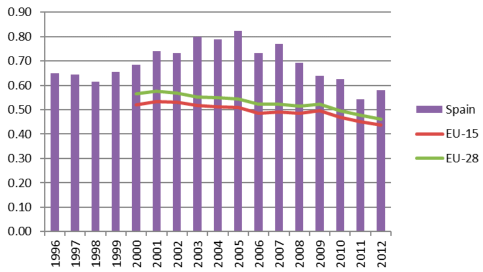


(**d**) Transport

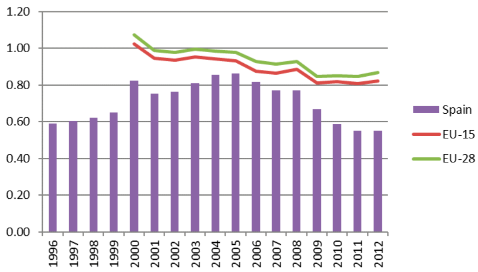
Figure 9. Sectorial intensity. Measured in GWh/million € GVA (2005). Source: Own calculations with Eurostat data.



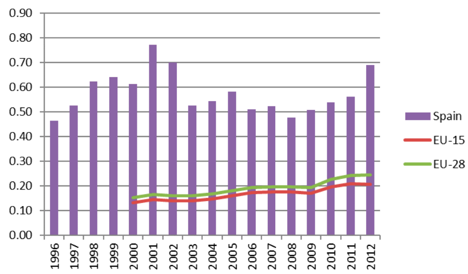
(**a**) Iron and Steel & Non-Ferrous Metals



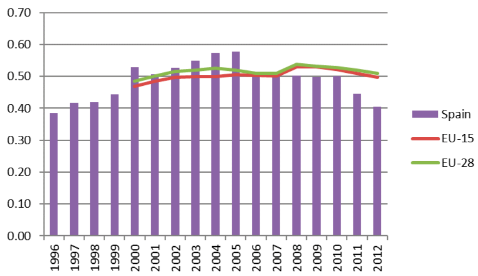
(**b**) Non-Metallic Minerals



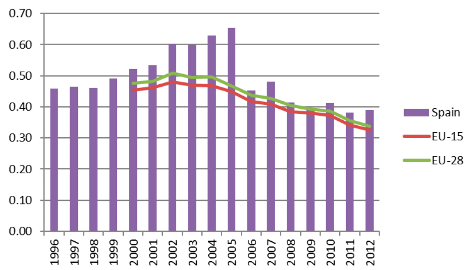
(**c**) Chemical and Petrochemical



(**d**) Mining and Quarrying

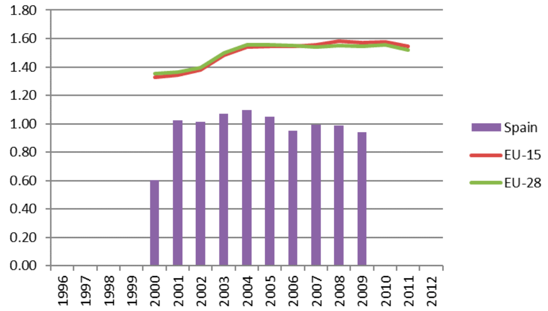


(**e**) Food and Tobacco

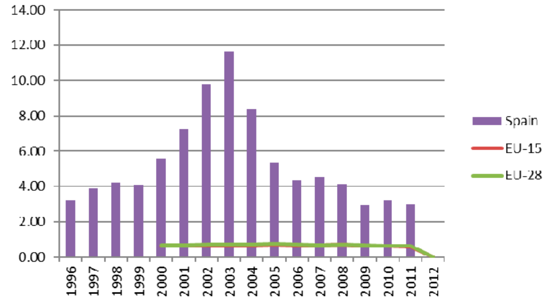


(**f**) Textile and Leather

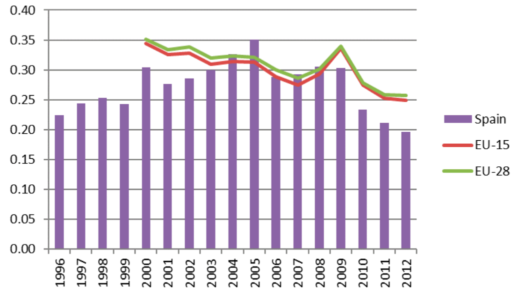
Figure 10. *Cont.*



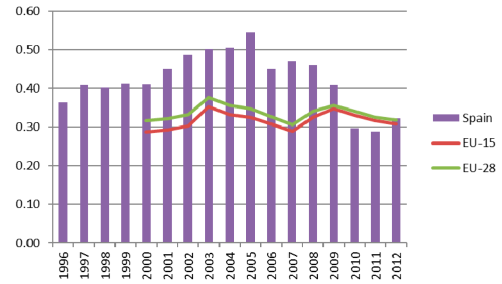
(**g**) Paper, Pulp and Print



(**h**) Wood and Wood Products



(**i**) Transport Equipment



(**j**) Machinery

Figure 10. Industrial activities intensity. Measured in GWh/million € GVA (2005). Source: Own calculations with Eurostat data.

Table 1 presents the relative intensities of electricity use for different industrial activities for the most recent period (2010–2012 averages), as well as the variation in intensities observed over the entire period (1996–2012). For a quick visual overview, in columns 5–8 we display bars indicating the size of the intensities reported in columns 1–4. The last three columns specify if variations reported in columns 9–11 are positive (black bars) or negative (red bars).

Table 1. Industry specific electricity intensities. Spain and the European Union.

Item	**2010–2012**					**2012/1996**			
Sectors (GWh/Million € GVA)	EU-28	EU-15	EA	Spain		Δ EU-28	Δ EU-15	Δ Spain	
TOTAL	0.222	0.210	0.216	0.233		−3.4	−1.9	−1.7	
No residential									
Iron and Steel & Non-Ferrous Metals	0.819	0.767	0.826	1.477		−2.0	−0.8	0.1	
Chemical and Petrochemical	0.854	0.816	0.849	0.552		−2.5	−1.7	0.3	
Non-Metallic Minerals	0.478	0.451	0.464	0.562		−2.2	−1.5	−0.4	
Mining and Quarrying	0.239	0.203	0.306	0.626		2.8	4.2	1.9	
Food and Tobacco	0.519	0.510	0.544	0.426		1.0	0.5	1.1	
Textile and Leather	0.360	0.347	0.329	0.385		−2.0	−2.7	−0.7	
Paper, Pulp and Print	1.537	1.560	1.393	0.974		−0.6	1.6	2.7	
Transport Equipment	0.265	0.259	0.266	0.204		−0.3	−2.4	−0.02	
Machinery	0.327	0.318	0.316	0.304		−2.4	0.8	−0.9	
Wood and Wood Products	0.621	0.597	0.630	2.988		−0.7	−0.3	2.0	
Construction	0.027	0.024	0.024	0.032		0.7	2.9	3.6	
Non-specified (Industry)	0.344	0.338	0.298	0.202		5.8	−2.9	0.2	
Transport	0.129	0.120	0.133	0.108		−1.8	−1.6	−0.9	
Fishing	0.048	0.044	0.054			32.2	4.8		
Agriculture/Forestry	0.218	0.233	0.208	0.777		16.4	2.1	−1.6	
Services	0.117	0.108	0.116	0.145		1.2	0.7	2.4	
Residential									
Residential (GWh × 1000 Households)	3.91	4.22	4.06	4.35		−0.4	−1.3	0.8	
Residential (GWh × 1000 inhabitants)	1.64	1.83	1.74	1.62		1.6	0.9	3.9	

Source: Own calculations with Eurostat data.

Noteworthy are the high intensity of electricity use in the Spanish basic metals sector, more than 90% above the EU-15 average. As mentioned before, Spanish firms use production technologies that are more electricity intensive compared to firms in other countries. The intensity of electricity use in the Spanish primary sector is more than double the average EU-15 intensity. This last observation is likely due to Spain's relatively warm climate requiring an increased use of electricity for irrigation. As mentioned before, observed differences in the wood and furniture sectors may be due to discrepancies across countries regarding the sectoral allocation of some activities such as industries of paper pulp and celluloses.

Regarding the dynamics of intensities, it is interesting to note how sectors such as basic metals, and chemicals display increasing intensities of electricity use in Spain while on average for the EU they show downward trends. On the other hand, agriculture in Spain has shown a declining trend in intensity of electricity use while the intensity for the EU average has risen over time.

5. Conclusions

There is a clear nexus between economic growth and electricity consumption. Along this article we have referred to that relationship as "Income elasticity of electricity consumption" defined as the rate between changes in electricity consumption and GDP, in parallel with the most common meaning of "price elasticity", which refers to the unity changes induced in electricity consumption for each unity change in prices.

In the EU-28, electricity consumption grew at an annual rate of 1.1% between 1996 and 2012, while GDP increased by 1.7%. Aggregate electricity intensity (GWH/Mill. €) in all European countries and the combined EU-28 was reduced from 0.25 to 0.23 during that same period. As we have shown in this paper, across Europe electricity intensity has been reduced mainly due to the progressive loss of the weight of industrial activities in electricity consumption and GDP and partially due to a reduction in the intensity of electricity use by industrial activities. These factors have been strong enough to compensate for the increased weight of services and households in electricity consumption and their higher intensity of electricity use. The loss of the weight of industrial activities in electricity consumption is correlated with the de-industrialization of the European economies. Similarly, in Spain, the progressive reduction of electricity demand income elasticity can be explained for by the progressive loss of industrial activities.

If we focus on the non-residential consumption, electricity demand can be analyze as a production input, so that, in absence of technological changes, the production (i.e., Income) elasticity should be 1.

Nevertheless, there are, at least, two opposite trends that can alter this elasticity.

On the one hand, the progressive substitution of capital goods, (production equipment) powered by electricity instead of other fuels (coal, gas, oil, etc.), or the substitution of labor for capital inputs (automatization or robotization) can yield elasticities larger than one. This effect can be denoted as "electrification" process.

Obviously, the substitution process among different energy sources is not just a matter of technological change, and not infrequently this process is driven by relative prices among different energy sources, and these differences in relative prices can explain different levels of electricity intensity among European countries, and along time.

On the other hand, the technological process also generates more efficient equipment, not only in the non-residential sector, but also in residential one (for instance, low consumption lighting devices). This increase in efficiency would lead to elasticity levels below one. We can refer to this process as "Energetic efficiency".

In a very naïve interpretation we could say that as a country develops its income elasticity should be larger than one, as the electrification process weights more than energetic efficiency, but once reached an adequate development level, this elasticity should be going progressively reduced, as the energetic efficiency becomes the main driver.

Results presented in this paper are based on the application of a simple, but very effective, methodological approach to decompose the growth rates of electricity demand into a number of effects. In particular, the evolution of electricity demand is influenced by both demographic effects (increases in population and number of households), as well as economic effects, both structural or long term (sectoral distribution of production) and cyclical or short term (GDP growth).

Regarding our decomposition analysis of growth of electricity demand in Spain, the following points should be highlighted:

- During our period of analysis (1990–2012) energy demand in Spain has been mainly driven by economic growth (44%), while the remaining 56% is due to increases in the non-residential electricity intensity (26%), average consumption per household (21%) and demographic changes (9%).
- The contribution of the average consumption per household to growth in electricity demand has remained fairly constant along the entire period (1990–2012), only turning negative in 2006 and during the last economic crisis (2008–2012).
- Similarly, the intensity of electricity use by the non-residential sector has had a positive impact on growth in electricity demand during most of the period, being especially significant for earlier years. This effect has been somewhat reduced, reflecting energy saving motives during the last economic crisis (2008–2012).
- The demographic effect only contributed significantly to electricity demand from the end of the nineties until the start of the crisis, most likely linked to migratory in-flows.

Our proposed approach allows us to analyze the evolution of the elasticity of electricity demand with respect to GDP and to identify key factors underlying its evolution. For the Spanish case, we observe that the most relevant factor for the evolution of the income elasticity of electricity demand has been the progressive loss of the relative weight of non-residential consumption, together with different developments in intensities of electricity demand of various productive sectors. Considering the trend in both magnitudes—electricity demand intensity and elasticity of electricity demand—we expect that the currently very high elasticity of electricity demand in Spain will continue to decline in the future.

These features have notable implications in terms of policy. On the one hand, long term grid planning has to take into account the progressively "residential" nature of the demand. This demand is usually more dispersed/distributed than the industrial demand, more sensitive to temperature variations, and more price inelastic. Both characteristics increased the stress of the grid capacity (peak demand/valleys demand), and therefore the risk of local failures, and, more importantly, could increase the losses in electricity distribution. As total electricity, effectively consumed or lost, is equally paid by the final consumers, the incentives to invest in loss reduction have to come from the Public regulator. On the other hand, energy conservation policies have to take into account this long term demand feature. Due to the increasing weight of residential demand in total electricity demand policies has to be targeted adequately. An effective impact on household electricity demand requires adopting not only measures based on prices (taxation and so on) or subsidizing investment in more efficient technologies, but also psychology based incentives to conserve or even compulsory measures.

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Author Contributions: The study is a result of the full collaboration of all the authors. Julián Pérez-García conceived the idea of applying the index decomposition analysis to the study of the changing pattern in GDP elasticity of electricity consumption, and their application to European countries. Julián Moral-Carcedo performed the analysis of previous works and the motivation and paper' writing.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Energy indicators in Europe.

Country	Energy Intensity (TOE/Mill. €) (2012)	Electricity Share (1) (2012)	Energy Growth (2) (2004–2012)	Electricity Growth (3) (2004–2012)	GDP Growth (2004–2012)
European Union (28 countries)	19.44	21.8%	−0.9%	0.2%	1.0%
Euro area (18 countries)	19.11	22.3%	−0.9%	0.3%	0.8%
Belgium	19.98	20.7%	−1.4%	0.1%	1.2%
Bulgaria	69.54	25.9%	−0.6%	1.4%	2.8%
Czech Republic	32.04	20.6%	−1.3%	0.6%	2.6%
Denmark	11.92	18.8%	−0.8%	−0.6%	0.4%
Germany	17.82	21.3%	−0.5%	0.1%	1.4%
Estonia	36.83	20.9%	0.2%	2.1%	2.7%
Ireland	12.17	19.5%	−1.4%	0.6%	1.1%
Greece	24.11	26.1%	−2.2%	0.6%	−1.5%
Spain	20.12	24.8%	−1.6%	0.5%	0.8%
France	19.20	25.3%	−1.1%	0.4%	0.9%
Croatia	31.27	22.3%	−0.6%	1.4%	0.5%
Italy	17.19	20.9%	−1.0%	0.1%	−0.3%
Cyprus	22.68	21.5%	−0.5%	2.0%	1.7%
Latvia	28.59	14.6%	0.4%	3.0%	2.0%
Lithuania	24.87	15.8%	1.2%	1.9%	2.8%
Luxembourg	14.55	12.9%	−0.6%	−0.2%	1.8%
Hungary	28.41	19.0%	−2.1%	0.4%	0.3%
Malta	26.74	32.8%	1.6%	0.9%	2.2%
The Netherlands	15.81	17.9%	−0.4%	0.2%	1.1%
Austria	18.87	19.7%	0.2%	1.3%	1.6%
Poland	25.82	16.4%	1.2%	2.0%	4.2%
Portugal	24.44	24.5%	−1.9%	0.4%	−0.1%
Romania	27.44	16.0%	−1.1%	1.1%	2.5%
Slovenia	31.65	22.3%	0.1%	0.0%	1.4%
Slovakia	30.69	19.9%	−0.8%	0.0%	4.3%
Finland	38.85	27.6%	−0.5%	−0.4%	1.1%
Sweden	31.24	33.8%	−0.6%	−0.3%	1.9%
United Kingdom	15.24	20.3%	−1.6%	−0.8%	0.8%

Source: Eurostat. GDP measured in 2008 euros. (1) Share of Electrical energy in Total Final Energy Consumption TOE (tonnes of oil equivalent); (2) Final Energy Consumption. Average growth rate (2004–2012); (3) Electrical energy consumption. Average growth rate (2004–2012).

Table A2. Sectorial definition and NACE 2009.

NACE rev 2 2009	Sector
1, 2, 3	Agriculture, Hunting, Forestry and Fishing
5	Mining and Coal
6, 19	Oil and Natural Gas Extraction
35	Energy Utilities
7, 8, 9	Mining
25	Basic Metals
24	Non-Ferrous Metallurgy
23	Building Materials
20, 21	Chemical Industry
26, 27, 28, 33	Metal Machinery
30	Naval Construction and Repair
29	Transport Manufacturing Industry
10, 11, 12	Manufacture of Food, Beverage and Tobacco
13, 14, 15	Textile, Clothing, Leather and Footwear
16, 31	Wood, Cork and Furniture
17	Pasta Paper, Paper and Cardboard
18, 58	Printing and Publishing
22, 32	Rubber Industries, Plastic and Other
41, 42, 43	Construction and Public Works
49, 51, 64, 53	Transportation
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