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# International inequality in energy intensity levels and the role of production composition and energy efficiency: an analysis of OECD countries

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## ABSTRACT

This paper analyses the inequality of energy intensity levels between OECD countries, its causes and evolution. The paper develops a methodology which allows the inequality in energy consumption per capita to be decomposed into explanatory factors. It also analyses the contribution of different groups of countries to this inequality. The results show that, although differences in affluence are the most significant factor in explaining inequality in energy consumption per capita, the inequality in energy intensity levels plays a prominent role in reducing the inequality in energy consumption per capita over the analysed period. The paper also develops a methodology which determines the importance of different production structures and energy efficiency of productive sectors in the differences in energy use per unit of GDP between the various countries and groups of countries. The results show that sector specialisation becomes increasingly important in explaining the inequality of energy intensity, while there is a significant trend towards the convergence of energy efficiency between countries sector by sector. This trend would explain the decreasing weight of energy intensity as an explanatory factor of the inequalities in energy consumption per capita.

**JEL Codes:** C69, D39, Q43.

**Key words:** energy efficiency, energy intensity, inequalities between countries, inequalities between regions, sectoral composition, shift-share analysis.

## 1. Introduction

Energy intensity of GDP can be very variable among different countries and periods (Ang, 1999; Roca and Alcántara, 2002; Alcántara and Padilla, 2005). Differences in energy intensity might show differences in economic structure and technologies. Various studies analyse international differences and the evolution of energy intensity inequalities. For example, Alcántara and Duro (2004) and Sun (2002) analyse a reduction in the inequality of energy intensity between Organisation for Economic Co-operation and Development (OECD) countries. Sun (2002) does this through an analysis of deviations from the mean. Alcántara and Duro (2004) use the Theil index, which weights observations according to GDP, giving greater importance to those countries with a greater share in global production. Miketa and Mulder (2005) analyse the convergence of energy productivity in 10 manufacturing sectors across 56 countries. They find that the differences in the energy intensity levels of these sectors are diminishing across some countries. Greening et al. (1997) compare 6 different decomposition methods to analyse energy intensity evolution in the manufacturing industries of 10 OECD countries. In their study, they found that most of the changes in energy intensity levels, which tended to decrease, could be explained by changes in the energy intensity of individual sectors, more than by changes in the sectoral composition of production.

This paper will first show the relevance of final energy intensity and GDP per capita in explaining the inequality across all OECD countries in final energy consumption per capita between 1980 and 2006. For the period considered, final energy consumption per capita of OECD countries has increased by 6.1%. This is the result of a 63.5 increase in GDP per capita and a 35.1% decrease in energy intensity of GDP. Our analysis will investigate if this evolution of energy consumption, an its components, has been followed by changes in international inequality in energy intensity and its components. Moreover, the meaning of a reduction of energy intensity inequality in a context of a great reduction of global energy intensity would mean a convergence to more apparent efficiency in the use of energy.

Energy intensity levels and the differences between countries are associated with the sectoral structure —which might be biased to activities using more or less energy— and with the degree of energy efficiency. Studying the factors that influence on the differences in energy intensity levels, both in static and dynamic terms, could be useful in forming public policies which aim to reduce energy consumption and mitigate pollution. If greater weight is attributed to the sectoral structure component, reducing energy intensity disparities would require production structures to converge to the less energy intensive ones, which, according to several theories, could take a long time. If energy efficiency plays a significant role, public administrations would have to prioritise energy-saving measures across sectors, particularly in countries with lower energy efficiency.

In Section 3, the paper appraises the weight of both factors in explaining energy intensity disparities between countries. Due to data availability, this analysis is restricted to 16 OECD countries and to the period 1995–2005. The results could be of use in forming policies aimed at reducing energy use (and $CO_2$ emissions). A shift-share method has been developed for this purpose. The technique is based on the one employed by Esteban (2000) in his analysis of European regional productivity. The method allows three separate analytical components to be obtained: the structural component, linked to the particular productive composition of a country; the “efficiency” component, associated with the specific energy consumption of a country in each sector; and, finally, the “allocative” component, which indicates the extent to which a country is specialised in the sectors in which it consumes more energy per unit of output than the average across all countries. This technique has been applied to the study of OECD countries, a sample that amounts to almost half of the world's final energy consumption and GDP. These were the countries for which sectoral GDP and energy consumption data was available.

The paper is organised as follows. Section 2 analyses the explanatory role of energy intensity and affluence on the differences in final energy consumption per capita. For this a multiplicative decomposition of the Theil index is employed. Section 3 decomposes the inequalities in final energy intensity levels between 16 OECD countries by applying a shift-share method. Section 4 assembles the main conclusions of the research.

## 2. Energy intensity and inequalities in final energy consumption per capita in OECD countries

In order to evaluate the importance of energy intensity in explaining inequalities in final energy consumption per capita, we adapted the decomposition method proposed by Duro and Padilla (2006).

First, we took as a reference a simple bifactorial separation of energy consumption per capita in the following way:

$$\frac{E_{it}}{P_{it}} = \frac{E_{it}}{Y_{it}} * \frac{Y_{it}}{P_{it}} \text{ ; } c_{it} = e_{it} * y_{it} \qquad (1)$$

where $E_{it}$ is the energy consumption of country *i* in moment *t*; $P_{it}$ is its population; $Y_{it}$ is its GDP; *c* is the energy consumption per capita; *e* is the energy consumption per unit of GDP (energy intensity); *y* is the GDP per capita (economic affluence index).

Consequently, the level of consumption per capita, and any increases, depend both on the energy intensity factor and the affluence factor (GDP per capita).

Secondly, in order to clarify the role of both factors in explaining the global inequality of final energy consumption, two hypothetical energy consumption vectors are defined. In each vector, only the value of one of the factors included in (1) is allowed to diverge from the mean. The following factors are obtained:

$$c_{it}^{e} = e_{it} * \bar{y}_t$$

$$c_{it}^{y} = \bar{e}_t * y_{it} \qquad (2)$$

where $\bar{e}_t$, $\bar{y}_t$ are the means of all the countries in the sample in year *t*.

In this context, it has been shown (see Duro and Padilla, 2006) that the application of the Theil index (Theil, 1967)[1] as an inequality index allows global inequalities in energy consumption per capita, T(c,p), to be decomposed into three factors:

$$T(c,p) = T\left(c^{e},p\right) + T\left(c^{y},p\right) + \log\left(1 + \frac{\sigma_{e,y}}{\bar{c}_{e}}\right) \qquad (3)$$

where $\sigma_{e,y}$ is the covariance between the two factors and $\bar{c}_e$ is the average value of the first factor.

In this way, total inequality can be perfectly decomposed into two indexes that show the partial contribution of each factor to global inequality, and an interaction component that gathers the interfactorial correlation. Note that, with this approach, the significance of each factor can be perceived as the amount of inequality that would persist if only this factor were allowed to vary among

[1] The Theil index has been used in several works on distribution and the environment (see, e.g., Alcántara and Duro, 2004; Duro and Padilla, 2006; Padilla and Serrano, 2006; Cantore and Padilla, 2010). Its advantages are highlighted in, e.g., Cowell (1995). One of these is that, as a logarithmic function, it allows a series of multiplicative factors to be decomposed in an additive manner.

countries, while the other factor equalised to the mean of the sample. The third component gathers the effect of the joint interaction of both factors on global disparities. In this way, the global effect attributed to each factor would come from its partial contribution plus this indirect effect. A positive interaction component would indicate that both factors tend to reinforce each other increasing or, if it were the case, reducing inequality. A negative interaction component would imply a compensatory effect between the factors. In other words, a positive interaction component shows the extent to which, for example, countries with greater energy intensity tend to be the ones with the greatest GDP per capita, with one inequality reinforcing the other.

This decomposition methodology can also be extended to analyse the components of inter- and intra-group inequality. Another characteristic of the Theil index is that it can be decomposed into population subgroups in the following way (Theil, 1967; Shorrocks, 1980):

$$T(c)=\sum_{g=1}^{G} p_g T(c)_g + \sum_{g=1}^{G} p_g * \ln\left(\frac{\bar{c}}{c_g}\right) \qquad (4)$$

where $p_g$ is the population share of group $g$; $T_g$ is the internal inequality in group $g$; $c_g$ is $CO_2$ emissions per capita in group $g$.

Note that the intra-group component is a weighted mean of the internal Theil indexes. It can therefore be decomposed in a multiplicative way as in (3). The inter-group component is a Theil index weighted according to population. The application of our methodology is, therefore, straightforward.

Table 1 shows the results of decomposing the inequalities in energy consumption per capita into two factors —following the proposed multiplicative decomposition of the Theil index— for various selected years between 1980–2006 and all OECD countries[2]. The data employed comes from the IEA database.

**Table 1. The role of inequality in energy intensity levels and other factors in explaining the inequality in final energy consumption per capita between OECD countries**

| | **Inequality in Energy Consumption per capita** | **Energy intensity component** | **Affluence component** | **Interaction component** |
|---|---|---|---|---|
| **1980** | 0.2029 | 0.0631 (31.1%) | 0.0908 (44.8%) | 0.0489 (24.1%) |
| **1985** | 0.1822 | 0.0510 (28.0%) | 0.0974 (53.4%) | 0.0338 (18.5%) |

[2] The countries included in the sample are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States of America.

| | | | | |
|---|---|---|---|---|
| **1990** | 0.1507 | 0.0363 (24.1%) | 0.1017 (67.5%) | 0.0127 (8.4%) |
| **1995** | 0.1436 | 0.0302 (21.0%) | 0.1053 (73.3%) | 0.0081 (5.6%) |
| **2000** | 0.1493 | 0.0234 (15.7%) | 0.1023 (68.5%) | 0.0234 (15.7%) |
| **2006** | 0.1278 | 0.0166 (13.0%) | 0.0941 (73.6%) | 0.0171 (13.4%) |

Note: relative weights within brackets.

Source: own elaboration with IEA data.

The results of Table 1 show a clear trend towards convergence in the energy consumption per capita of OECD countries. The determinant factor of reduced inequality has been the convergence of energy intensity levels. Inequalities in energy intensity levels have diminished by 73.7%, falling from 31.1% of total inequality to only 13.0%. In other words, 61.9% of the reduction in inequalities in energy consumption per capita is due to the reduction in inequality in energy intensity levels between OECD countries. The rest of the reduction is due to the evolution of the interaction factor. The correlation between higher energy intensity levels and higher GDP per capita decreased over time.

Currently, the bulk of inequalities in energy consumption per capita is due to the inequality in GDP per capita (affluence factor), which increased its contribution from 44.8% to 73.6%. While the other factors experienced a strong reduction, there has not been a reduction in the contribution of this factor between 1980 and 2006. Actually, the contribution of inequality in GDP per capita between OECD countries in 2006 is a little greater than in 1980.

Given its importance in the evolution of inequalities in energy consumption across OECD countries, it is especially interesting to know the factors contributing to the evolution of inequality in energy intensity. In short, it would be useful to analyse the role of production composition and energy efficiency in this process. These issues are developed in Section 3.

The inter- and intra-group components are broken down according to the decomposition methodology established in (4) and three groups are considered: North America, Pacific and Europe[3]. Tables 2 and 3 show the results.

**Table 2. The role of energy intensity and affluence in explaining the inequality in final energy consumption per capita between groups of OECD countries**

| | **Inequality in Energy Consumption per capita** | **Inter-group Component** | **Energy Intensities** | **Affluence** | **Interaction** |
|---|---|---|---|---|---|
| 1980 | 0.2029 | 0.0783 *(38.6%)* | 0.0332 (42.5%) | 0.0091 (11.6%) | 0.0359 (45.9%) |

[3] This is an analysis of OECD countries, and so of industrialised countries, a geographical classification has been chosen to analyse the differences between and within groups of countries.

| | | | | | |
|---|---|---|---|---|---|
| 1985 | 0.1822 | 0.0650<br>*(35.7%)* | 0.0243<br>(37.5%) | 0.0102<br>(15.7%) | 0.0304<br>(46.8%) |
| 1990 | 0.1507 | 0.0472<br>*(31.3%)* | 0.0185<br>(39.2%) | 0.0073<br>(15.5%) | 0.0214<br>(45.3$) |
| 1995 | 0.1436 | 0.0407<br>*(28.4%)* | 0.0154<br>(37.9%) | 0.0068<br>(16.7%) | 0.0185<br>(45.4%) |
| 2000 | 0.1493 | 0.0418<br>*(28.0%)* | 0.0131<br>(31.4%) | 0.0080<br>(19.0%) | 0.0207<br>(49.6%) |
| 2006 | 0.1278 | 0.0318<br>*(24.9%)* | 0.0086<br>(27.0%) | 0.0075<br>(23.4%) | 0.0158<br>(49.6%) |

Note: percentages (within brackets) with respect to inter-group component, except percentages in italics, which are referred to total inequality. The groups are North America, Pacific and Europe.

Source: own elaboration with IEA data.

**Table 3. The role of energy intensity and affluence in explaining the inequality in final energy consumption per capita within groups of OECD countries**

| | **Inequality in Energy Consumption per capita** | **Within-groups Component** | **Energy Intensities** | **Affluence** | **Interaction** |
|---|---|---|---|---|---|
| 1980 | 0.2029 | 0.1246<br>*(61.4%)* | 0.0408<br>(32.7%) | 0.0817<br>(65.6%) | 0.0021<br>(1.7%) |

| | | | | | |
|---|---|---|---|---|---|
| 1985 | 0.1822 | 0.1173<br>*(64.3%)* | 0.0342<br>(29.2%) | 0.0871<br>(74.3%) | -0.0041<br>(-3.5%) |
| 1990 | 0.1507 | 0.1035<br>*(68.7%)* | 0.0246<br>(23.8%) | 0.0944<br>(91.2%) | -0.0155<br>(-15.0%) |
| 1995 | 0.1436 | 0.1029<br>*(71.6%)* | 0.0209<br>(20.3%) | 0.0985<br>(95.8%) | -0.0166<br>(-16.1%) |
| 2000 | 0.1493 | 0.1076<br>*(72.0%)* | 0.0162<br>(15.1%) | 0.0943<br>(87.7%) | -0.0030<br>(-2.8%) |
| 2006 | 0.1278 | 0.0959<br>*(75.1%)* | 0.0114<br>(11.9%) | 0.0867<br>(90.3%) | -0.0021<br>(-2.2%) |

Note: percentages (within brackets) with respect to intra-group component, except percentages in italics, which are referred to total inequality. The groups are North America, Pacific and Europe.

Source: own elaboration with IEA data.

The results for the selected country groups show the predominant role of intra-group inequality in explaining the inequality in energy consumption per capita. Moreover, there is an important downward trend in the relative weight of inter-group inequality, which decreases from 38.6% to just 24.9% of total inequality. However, although group classification has been made following geographical criteria, it is able to explain around one third of the inequality in energy consumption per capita over the period.

Both the inter- and intra-group components of inequality diminish significantly during the period, which explains the strong reduction in global inequality. The inter-group component decreases by 0.0465 while the intra-group component decreases by 0.0287. In percentage terms, the reduction of the inter-group component is much larger, as it decreases by 59.4%, showing a clear convergence between the three different country groups. However, convergence between countries within each group is also significant, with a reduction in inequality of 23.0%.

As regards the inter-group component, the reduction in its value is basically explained by the reduction in inequality due to the energy intensity factor, although the interaction component also diminishes significantly. The lower weight of the affluence factor in the inter-group component compared to global or intra-group inequality is also significant; it represented only 11.6% in 1980 and 23.4% in 2006. That is to say, the differences in GDP per capita between the three country groups are less relevant than the other factors in determining inter-group differences in energy consumption per capita. Another important point is the weight of the interaction factor which, in spite of decreasing in absolute terms, accounts for almost half of energy consumption inequality. This significant positive value indicates that the groups with larger energy intensity tend to be the ones with larger GDP per capita (e.g., North America), with both inequalities reinforcing each other.

With respect to intra-group inequality, the results show that the bulk of inequality is explained by the affluence factor, which increases its level (in absolute and relative terms) over the period, amounting to 90.3% of total inequality in 2006. Again, the factor that explains the strong reduction of inequality in energy consumption per capita is the strong reduction of the energy intensity component, whose contribution to inequality decreases by 72.1%; its contribution to intra-group inequality being only 11.9% at the end of the period. The negligible weight of the interaction factor to intra-group inequality in contrast to inter-group is also worth highlighting. In this sense, within a group, higher levels of energy intensity are not correlated to greater affluence, but on the contrary, although to a very small degree[4].

In brief, the most significant result shown by the three tables is the strong reduction in the contribution of energy intensity inequality to energy consumption inequality. If the subperiod 1995–2005 is taken —the subperiod employed in the analysis of the next section— the conclusions remain unchanged. This inequality reduction occurs in a period where there are important reductions in energy intensity levels —a 35.1% reduction in final energy intensity of OECD countries. Therefore, there is a convergence toward lower energy intensity levels. According to the results, the diffusion of energy-

[4] Alternative classification of the groups would lead to different results concerning the relevance of different factors. For example, groups classified according to income per capita would change the importance of the affluence component in both inter- and intra-groups, so the contribution of affluence to inter-group inequality would notably increase and its contribution to intra-group inequality would be much smaller. Moreover, given the importance of affluence inequality in explaining inequality in energy consumption per capita, grouping countries according to income would also lead to a greater relevance of inter-group inequality.

efficient technologies would have a greater effect within a group than between groups. In this period, the inequality in GDP per capita between OECD countries did not change significantly.

In the next section, we study the factors that have lead to the strong reduction in inequality in energy intensity levels which, as we have seen, has caused an important reduction in the inequality of energy consumption per capita. Due to data availability, the analysis is restricted to 16 OECD countries and the period 1995–2005.

**3. Analysis of the factors affecting inequality in final energy intensity levels and its evolution**

Energy intensity is defined as the quantity of energy consumed per unit of GDP, $\frac{E_i}{Y_i}$. This factor shows both the degree of energy efficiency as well as the sectoral structure of an economy. Thus, for country *i*:

$$e_i = \frac{E_i}{Y_i} = \sum_{j=1}^{k} \left( \frac{E_{ij}}{Y_{ij}} \right) \left( \frac{Y_{ij}}{Y_i} \right) = \sum_{j=1}^{k} e_{ij} s_{ij} \qquad (5)$$

were subindexes *i* and *j* denote country and sector respectively; *E* is the volume of energy consumption; *Y* is the GDP; *e* is energy intensity; *s* is the weight of each sector in the economy of the country.

A country can show an energy intensity above the average level either because it is specialised in sectors with high energy intensity levels, or because the country shows greater energy intensity levels sector by sector than the average, or both. Thus, although there may be no disparity in the energy intensity levels of each sector in different countries, differences in energy intensity levels could persist due to the fact that the different countries specialise in different sectors.

In order to assess the relevance of these two factors, we use a methodology based on the technique developed by Esteban (2000) in his analysis of differences in European regional productivity.

First, average energy intensity is defined as:

$$e = \frac{E}{Y} = \sum_{j=1}^{k} e_j * s_j \qquad (6)$$

where $e_j$ is the energy intensity in sector $j$ and $s_j$ is its weight in terms of GDP on the average level of the countries considered.

In order to isolate the role played by the sectoral structure of the country on energy intensity, (6) can be expressed as:

$$e_i = \sum_{j=1}^{k} e_{ij} s_{ij} = \sum_{j=1}^{k} \left[ (s_{ij} - s_j) + s_j \right] \left[ (e_{ij} - e_j) + e_j \right] \qquad (7)$$

The expression can be written as:

$$e_i - e = \sum_{j=1}^{k} \left(s_{ij} - s_j\right) e_j + \sum_{j=1}^{k} \left(e_{ij} - e_j\right) s_j + \sum_{j=1}^{k} \left(e_{ij} - e_j\right)\left(s_{ij} - s_j\right) \qquad (8)$$

In this way, the difference between the energy intensity of a country and the average of the sample (in our case, a sample of OECD countries) can be broken down into three parts: the first summand expresses the role of sectoral specialisation in the country considered (*structural component*); the second shows the role of the differences between the country's energy consumption per unit of production and the average of the sample (*energy efficiency component*); and the third captures whether the country consumes more energy per unit of production than the average across all countries (*allocative component*).

In a simplified expression:

$$e_i - e = \pi_i + \gamma_i + \delta_i \qquad (9)$$

where $\pi_i$ is the structural component; $\gamma_i$ is the energy efficiency component; $\delta_i$ is the allocative component.

Once the role of the sectoral structure in each country has been identified, the next step is to obtain an indicator of its contribution to international inequality in energy intensity and its evolution. For this purpose, we take expression (9), standardise all summands by dividing by *e* and apply a decomposition of the variance. The next expression obtained is:

$$\mathrm{var}\left(\frac{e_i - e}{e}\right) = \mathrm{var}\left(\frac{\pi_i}{e}\right) + \mathrm{var}\left(\frac{\gamma_i}{e}\right) + \mathrm{var}\left(\frac{\delta_i}{e}\right) + 2Cov\left(\frac{\pi_i}{e}, \frac{\gamma_i}{e}\right) + 2Cov\left(\frac{\pi_i}{e}, \frac{\delta_i}{e}\right) + 2Cov\left(\frac{\delta_i}{e}, \frac{\gamma_i}{e}\right) \qquad (10)$$

The dispersion measure that appears in the left-hand term gathers the main characteristics required for a satisfactory index of inequality (Cowell, 1995). In short, it is a measure independent of the scale and approaches to the logarithmic variance, a measure widely used in the field of income inequality and convergence analysis. The variance can be taken in its simple version — homogeneous weight of observations— or weighted according to the share of production of each country. For consistency with the use of the Theil index in the previous section, the results presented refer to the weighted calculations.

In order to determine the total contribution of each component to the international inequality in energy intensity, it is necessary to establish some criteria that allow the correlation components to be allocated to the different individual explanatory factors. In the absence of other indicators, Shorrocks (1983) suggested that an alternative method would be to allocate the interactive components in a uniform way to the diverse factors involved. In this way, a "net" decomposition of the interactive components is obtained:

$$\mathrm{var}\left(\frac{e_i - e}{e}\right) = \mathrm{var}_a\left(\frac{\pi_i}{e}\right) + \mathrm{var}_a\left(\frac{\gamma_i}{e}\right) + \mathrm{var}_a\left(\frac{\delta_i}{e}\right) \quad (11)$$

where

$$\mathrm{var}_a\left(\frac{\pi_i}{e}\right) = \mathrm{var}\left(\frac{\pi_i}{e}\right) + \mathrm{cov}\left(\frac{\pi_i}{e}, \frac{\gamma_i}{e}\right) + \mathrm{cov}\left(\frac{\pi_i}{e}, \frac{\delta_i}{e}\right) \quad (12)$$

$$\mathrm{var}_a\left(\frac{\gamma_i}{e}\right) = \mathrm{var}\left(\frac{\gamma_i}{e}\right) + \mathrm{cov}\left(\frac{\pi_i}{e}, \frac{\gamma_i}{e}\right) + \mathrm{cov}\left(\frac{\gamma_i}{e}, \frac{\delta_i}{e}\right) \quad (13)$$

$$\mathrm{var}_a\left(\frac{\delta_i}{e}\right) = \mathrm{var}\left(\frac{\delta_i}{e}\right) + \mathrm{cov}\left(\frac{\delta_i}{e}, \frac{\gamma_i}{e}\right) + \mathrm{cov}\left(\frac{\pi_i}{e}, \frac{\delta_i}{e}\right) \qquad (14)$$

One of the questions open to discussion in this type of analysis is the number of sectors to be considered. A large number of sectors would tend, *ceteris paribus*, to produce high values for the structural factor, to the detriment of other factors. On the other hand, excessive sectoral aggregation would result in greater sectoral similarities and, thus, reduce the empirical value of this component. In our case, the sectoral data on energy consumption and GDP are available for fourteen activity branches. This can be considered a reasonable number of branches for a fruitful sectoral analysis. The availability of this information is restricted to 16 OECD countries and the period 1995–2005[5]. The 16 countries included in this sample account for more than 80% of total energy consumption and GDP of the OECD countries included in the previous section. The lower number of countries and the specific countries included make it less relevant to do a group analysis as in the previous section, so the analysis here is only of the set of countries stated.

The sectors included in the analysis are: basic metals; chemicals and petrochemicals; non-metallic minerals; transport equipment; machinery; mining and quarrying; food and tobacco; paper, pulp and printing; wood and wood products; construction; textile and leather; non-specified (industry); commerce and public services; agriculture/forestry.

[5] The countries considered are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Japan, South Korea, Luxemburg, Netherlands, Portugal, Spain, Sweden, United Kingdom and United States.

Our methodological approach analyse the influence of differences in sectoral structures and in energy efficiency of productive sectors on energy intensity inequalities. Therefore, final energy consumption of transport and domestic sectors are not taken into account[6]. The sectors considered account for 37.0% of total final energy consumption in 1995 and for 35.7% in 2005.[7]

Table 4 shows the results obtained for the decomposition of the weighted variance, on the basis of expression (10), for the sample of OECD countries available and the years 1995 and 2005. Table 5 shows the results after applying the Shorrocks (1983) rule.

**Table 4. Shift-share decomposition of international inequality in energy intensity levels in OECD countries**

| | ***Global*** | ***Structural*** | ***Efficiency*** | ***Allocative*** | **Covariances** |
|---|---|---|---|---|---|

[6] The reason for excluding the energy consumption of transport is that IEA data on transport energy includes not only the energy consumption of transport as productive sector, but also the consumption of private transport and the use of own transport by other economic sectors. Moreover, as we are interested in the analysis of energy uses of final energy, we do not consider non-energy uses that might be relevant in the case of the Chemical and petrochemical sector.

[7] The sum of transport and domestic energy consumption accounts for 35.6% at the beginning of the period and to 36.2 in 2005. Therefore, in order to complete the study of the factors behind the evolution of global energy intensity inequalities, the analysis on productive structures and efficiency developed here should be complemented with future research investigating the differences in transport and household consumption and their influence on global disparities.

| | inequality | Comp. $\text{var}\left(\frac{\pi_i}{e}\right)$ | Comp. $\text{var}\left(\frac{\gamma_i}{e}\right)$ | Comp. $\text{var}\left(\frac{\delta_i}{e}\right)$ | $2Cov\left(\frac{\pi_i}{e},\frac{\gamma_i}{e}\right)$ | $2Cov\left(\frac{\pi_i}{e},\frac{\delta_i}{e}\right)$ | $2Cov\left(\frac{\delta_i}{e},\frac{\gamma_i}{e}\right)$ |
|---|---|---|---|---|---|---|---|
| **1995** | 0,0532 | 0,0189 (35.4%) | 0,0600 (112.8%) | 0,0084 (15.8%) | -0,0271 (-50.9%) | 0,0104 (19.6%) | 0,0174 (-32.7%) |
| **2005** | 0,0385 | 0,0232 (60.2%) | 0,0274 (71.1%) | 0,0054 (13.9%) | -0,0149 (-38.6%) | 0,0049 (12.6%) | -0,0074 (-19.3%) |

Source: own elaboration with IEA and OECD data.

**Table 5. Shift-share decomposition of international inequality in energy intensity levels in OECD countries applying the Shorrocks rule**

| | **Global inequality** | **Structural comp.** $\text{var}\left(\frac{\pi_i}{e}\right)$ | **Efficiency comp.** $\text{var}\left(\frac{\gamma_i}{e}\right)$ | **Allocative comp.** $\text{var}\left(\frac{\delta_i}{e}\right)$ |
|---|---|---|---|---|
| **1995** | 0,0532 | 0,0105 (19.8%) | 0,0378 (71.0%) | 0,0049 (9.2%) |
| **2005** | 0,0385 | 0,0182 (47.3%) | 0,0162 (42.2%) | 0,0041 (10.6%) |

Source: own elaboration with IEA and OECD data.

The results show a clearly differentiated evolution of the different explanatory components of the inequality in energy intensities[8].

Firstly, the data show that the reduction of inequality in energy intensity levels —which, according to the previous section is the main driving force behind the

[8] The difference between the energy intensity inequality value in the first column of Table 4 and the value in the second column of Table 1 is mainly due to the fact that different inequality indexes are employed. The reason for using two different inequality indexes —Theil index in Section 2 and weighted variance in Section 3— is the different type of decomposition that we can obtain with them, as explained in the text.

convergence of energy consumption per capita— must be attributed to the evolution of the energy efficiency component. That is, the reduction in the inequality in energy intensity levels between OECD countries has occurred because of an important convergence in the energy intensity levels of the different countries in different industries. Taking as a reference the results according to the Shorrocks rule (Table 5), the contribution of disparities in the energy efficiency component decreased by 57.1%, a change from 71% of total inequalities to 42.2%.

On the contrary, the structural component has increased its weight in the last decade. It has partly attenuated the important global convergence process in energy intensity levels previously described. After an increase in its contribution by 73.3% at the end of the period, it became the most important factor in total inequalities in energy intensity levels between countries, rising from 19.8% to 47.3%.

As regards the allocative component, it shows a positive value that, although only slightly, has increased in the years considered. This result means there is a tendency to specialise in those industries in which a country is not particularly energy-efficient compared to the other countries. A situation that is unsatisfactory from the point of view of global energy efficiency.

Annex 1 shows the decomposition of individual shift-share factors in the different components. It should be noted that, to calculate the index, the different countries are weighted according to their GDP, which in the case of the United States is greater than 40% for both periods.

According to Greening et al. (1997), the reduction in energy intensity observed in the 10 OECD countries studied in their paper was mainly due to energy efficiency improvements in the different sectors, while sectoral composition of production either supported or undermined the effects of these reductions in the different countries. This paper shows not only that improvements in energy efficiency in the different sectors contributed to reduce energy intensity, but also that they contributed significantly to the trend to equalise energy efficiency between the different OECD countries considered.

The results of this paper are also consistent with Miketa and Mulder (2005), who found evidence of convergence in energy productivity (the inverse of energy intensity) for 10 sectors in 56 countries (24 industrialised and 32 non-industrialised); this convergence being particularly pronounced in the less energy-intensive sectors. However, according to Miketa and Mulder (2005), the convergence process in the energy intensity of these sectors tends to occur between certain groups of countries, while the differences persist between different stationary states to which the different groups of countries would tend. The research presented here shows there is convergence in the use of energy sector by sector, although different specialisation patterns attenuate the equalisation of energy intensity between countries.

## 4. Conclusions

Using a dual approach, this work has analysed inequality in final energy intensity levels between OECD countries. Firstly, the role of energy intensity inequality as a determinant of energy consumption disparities has been evaluated. Secondly, the impact of different sectoral structures and different energy efficiencies on energy intensity inequality has been appraised.

The main results can be divided into two parts. First, the results show that the reduction in the energy intensity differences between countries has played a chief role in the reduction of disparities in energy consumption per capita in the OECD countries. This evolution meant that, in 2006, these differences accounted for less than 15% of global inequality in energy consumption per capita; while differences in the level of GDP per capita have become the factor that accounts for more than 70% of inequality in energy consumption per capita. An analysis by geographical groups (Europe, North America and Pacific) shows the reduction of inequality in energy intensity levels within these groups was more significant than between them, although this also decreased.

Energy intensity constitutes one of the main driving forces of emissions per capita and, so, of the differences in these between countries and groups of countries (Kaya, 1989; Yamaji et al., 1991; Ang, 1999; Roca and Alcántara, 2002; Alcántara and Padilla, 2005; Duro and Padilla, 2006; Raupach et al., 2007). The analysis of the differences in energy intensity is relevant for the analysis of differences in $CO_2$ emissions. However, the connection is not direct as this article analyses final energy and not primary energy. Differences in the primary energy required for a unit of final energy consumption (energy conversion index) and carbon intensity of energy (carbonization index) are other relevant factors in the analysis of emission differences (Hamilton and Turton, 2000).

Secondly, an analysis of the role played by energy efficiency and sector structure in the reduction of energy intensity inequalities, done by means of a shift-share decomposition of the variance, shows the greater relevance of the reduction in the inequalities in energy efficiency in the different countries. Sectoral specialisation has increased inequality, although this has not completely neutralised the first effect. As a consequence, differences in sectoral structures account for almost half of energy intensity inequality in 2005, far beyond the contribution they made in 1995.

From these results it might be interpreted that the technology diffusion and energy-saving strategies, which tend to reduce and equalise the energy intensity levels sector by sector, has had a significant impact on the reduction of energy intensity inequality in the 11 years analysed. It is also the main reason for the reduction in energy consumption per capita inequalities between countries. There is still much to improve in this aspect, as these differences continue to be the most relevant. However, a policy to this effect would not eliminate global disparities in energy intensity due to the existence of different sectoral specialisation patterns. In fact, the results show that specialisation has increasingly contributed to the energy intensity inequality between countries in the last decade. The predictions of economic theory on the effects of globalisation and integration on specialisation patterns and their disparities are inconclusive (Puga, 1999). Finally, one result of the study that shows a negative situation is a tendency by countries to specialise in those industries in which they are less efficient —in terms of energy use *p*er unit of output— compared to other countries, a result which deserves further research.

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## Annex 1

**A1: Components by country of shift-share factor decomposition, year 1995**

| | $(e_i\text{-}e)/e$ | $\pi_i/e$ | $\gamma_i/e$ | $\delta_i/e$ |
|---|---|---|---|---|
| **Austria** | -20.17% | 3.47% | -20.25% | -3.39% |
| **Belgium** | 27.18% | 19.44% | 6.50% | 1.23% |
| **Denmark** | -20.36% | -4.67% | -21.61% | 5.92% |
| **Finland** | 110.15% | 29.15% | 37.92% | 43.08% |
| **France** | -19.94% | -6.85% | -12.20% | -0.89% |
| **Germany** | -20.05% | 4.17% | -21.13% | -3.09% |
| **Greece** | -35.33% | -8.58% | -27.75% | 1.01% |
| **Italy** | -32.49% | 9.09% | -39.32% | -2.26% |
| **Japan** | 2.52% | 7.44% | -4.25% | -0.66% |
| **Korea** | 59.15% | 36.97% | 45.00% | -22.82% |
| **Luxemburg** | 16.25% | 4.28% | -24.27% | 36.24% |
| **Holland** | 11.02% | 5.08% | 0.09% | 5.84% |
| **Portugal** | -19.03% | 12.66% | -31.38% | -0.31% |
| **Spain** | -28.92% | 11.36% | -38.54% | -1.74% |
| **Sweden** | 74.99% | 15.70% | 41.94% | 17.34% |
| **United States** | 7.99% | -9.48% | 21.38% | -3.92% |

Source: own elaboration with IEA and OECD data.

**A2: Components by country of shift-share factor decomposition, year 2005**

| | $(e_i\text{-}e)/e$ | $\pi_i/e$ | $\gamma_i/e$ | $\delta_i/e$ |
|---|---|---|---|---|
| **Austria** | -1.82% | 15.26% | -11.86% | -5.23% |
| **Belgium** | 24.28% | 16.40% | 4.67% | 3.21% |
| **Denmark** | -22.01% | -3.12% | -19.01% | 0.12% |
| **Finland** | 118.75% | 25.24% | 46.98% | 46.53% |
| **France** | -25.71% | -9.77% | -15.10% | -0.83% |
| **Germany** | -14.86% | 10.00% | -20.49% | -4.37% |
| **Greece** | -35.62% | -2.93% | -36.58% | 3.89% |
| **Italy** | -19.26% | 5.01% | -23.76% | -0.51% |
| **Japan** | 12.99% | 11.21% | 5.63% | -3.85% |
| **Korea** | 48.81% | 46.15% | 19.40% | -16.73% |
| **Luxemburg** | -17.02% | -10.74% | -11.16% | 4.88% |
| **Holland** | 15.34% | 0.54% | 9.78% | 5.02% |
| **Portugal** | -0.87% | 4.13% | -6.41% | 1.41% |
| **Spain** | -9.20% | 6.91% | -18.28% | 2.17% |
| **Sweden** | 37.44% | 12.16% | 20.85% | 4.43% |
| **United States** | -0.15% | -10.31% | 13.93% | -3.76% |

Source: own elaboration with IEA and OECD data.