Departament d'Economia Aplicada

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DOCUMENT DE TREBALL

10.08

Universitat Autònoma de Barcelona
Facultat d'Economia i Empresa

Aquest document pertany al Departament d'Economia Aplicada.

Data de publicació : **Desembre 2010**

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Inequality across countries in energy intensities: an analysis of the role of energy transformation and final energy consumption

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Abstract

This paper analyzes the role of the energy transformation index and of final energy consumption per GDP unit in the disparities in energy intensity across countries. In that vein, we use a Theil decomposition approach to analyze global primary energy intensity inequality as well as inequality across different regions of the world and inequality within these regions. The paper first demonstrates the pre-eminence of divergence in final energy consumption per GDP unit in explaining global primary energy intensity inequality and its evolution during the 1971–2006 period. Secondly, it shows the lower (albeit non negligible) impact of the transformation index in global primary energy inequality. Thirdly, the relevance of regions as unit of analysis in studying cross-country energy intensity inequality and their explanatory factors is highlighted. And finally, how regions around the world differ as to the relevance of the energy transformation index in explaining primary energy intensity inequality.

Keywords: Energy efficiency, energy intensities, energy transformation, Theil index.

JEL code: C69, D39, Q43.

1. Introduction

Energy consumption and CO_2 emissions per capita differ largely across countries and regions around the world. Consequently, people between countries and regions contribute at different degrees to the intensity of the greenhouse effect. Several studies have analyzed such differences using distributive analysis tools and have drawn energy and climatic policy implications (see among others, Heil and Wodon, 1997, 2000; Millimet and Slottje, 2002; Hedenus and Azar, 2005; Padilla and Serrano, 2006; Duro and Padilla, 2006, 2008; Cantore and Padilla, 2010a, 2010b; Groot, 2010).

One of the most commonly used tools to analyze the driving forces of emissions and their evolution is the so-called Kaya identity (Kaya, 1989; Yamaji *et al*., 1991; Alcántara and Padilla, 2005). According to the Kaya identity, the factors explaining the evolution of per capita emissions are the carbon intensity of energy, the energy intensity of GDP, and the affluence, which is usually measured in terms of GDP per capita. In a previous article in this journal, Duro and Padilla (2006) used a Theil index decomposition that allows decomposing inequality into different Kaya factors and two interaction terms to analyze the determinants of cross-country inequality in CO_2 emissions per capita between 1971 and 1999. The authors highlighted the greater importance (although decreasing over time) of income inequality in explaining differences in emissions per capita. Nevertheless, they also highlighted the importance of carbonization index inequalities and energy intensities in globally reducing inequality in per capita emissions. As regards energy intensities, the authors point to the existence of considerable divergence worldwide. However, due to the reduction of energy intensity in some developing countries such divergence has been reduced. Another finding from these authors is the relevance of convergence in energy intensities in reducing CO_2 inequality in the Temperate zone group of countries, which is basically composed of rich countries. Sun (2002) and Alcántara and Duro (2004) also show a downtrend in energy intensity inequality among the OECD countries. Sun (2002) uses mean deviation as a dispersion measure to analyze this inequality. Alcántara and

Duro (2004) analyze this inequality by means of the Theil index. In a recent paper, Duro *et al*. (2010) use a Theil index decomposition which allows the inequality in energy consumption per capita to be decomposed into explanatory factors. They demonstrate that, although differences in affluence are the most significant factor in explaining inequality in energy consumption per capita, the reduction of the inequality in energy intensity levels plays a prominent role in reducing the inequality in energy consumption per capita between 1980 and 2006 among OECD countries.

The reduction in differences in primary energy intensity found in the cited studies may have various causes. It may stem from a more efficient way of transforming primary energy into final energy. Or, it may in contrast be the consequence of convergence in final energy use per GDP unit among countries[1]. That is, such a decline may be attributable to changes in the energy sector or to changes in final energy consumption in the economy.[2] Determining the relative importance of both factors is useful both for analytical purposes and the formulation of policy recommendations. Accordingly, a significant weight of the energy transformation index would suggest a large scope for improvement in countries not efficient in transforming energy. In that vein, energy policies could successfully reduce energy intensity inequalities by converging to greater efficiency levels in energy transformation —either improving the efficiency of energy conversion processes or changing the energy mix. In contrast, a significant weight of the final energy intensity component, would suggest that measures implemented to achieve greater efficiency in final energy

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[1] This second component can in turn be due to two different factors. It could be caused by energy consumption efficiency convergence among countries, or may be due to convergence in production composition. Duro *et al*. (2010) develop a shift-share methodology to analyze these factors for 16 OECD countries. They conclude that the convergence in final energy consumption per GDP unit could be attributed to a convergence in the efficiency in the use of final energy across countries. Meanwhile, the difference in production composition could have increased without offsetting the first effect. Miketa and Mulder (2005) run an econometric analysis of the final energy productivity convergence across 56 countries in 10 manufacturing sectors. They found that the differences in the final energy intensity levels of these sectors diminished across some countries.

[2] The importance of taking into account conversion-efficiency was showed by Hamilton and Turton (2002) who employed a decomposition formula that separated out the effects on emissions growth of changes in population, economic growth, energy intensity, energy transformation index, share of fossil fuels and carbon intensity of fossil fuels. They found that changes in energy transformation contributed to increase emissions in OECD countries over the period 1982–1997.

consumption (from a better use of the different sectors) or to convergence toward sectors that use less energy would be the best ways to reduce differences in energy intensities and lower energy consumption per GDP unit.

This paper complements the literature and makes an original contribution intending to discern the weight of differences within the energy sector and those relative to final energy intensity in determining the differences in energy intensities internationally and its evolution. In that respect, we use the Theil inequality index as the synthetic benchmark index since it allows decomposition by parts. Two types of decompositions will be done: the multiplicative decomposition pioneered by Duro (2003) and implemented in the energy analysis in Duro and Padilla (2006), and group decomposition (Shorrocks, 1980).

The paper is organized as follows. Section 2 lays out the methodology used. In Section 3, we present the empirical results on cross-country energy intensity inequalities for the period 1971–2006. Finally, Section 4 presents some concluding remarks.

2. Methodology

Assessing the role the energy transformation index and final energy consumption per GDP unit have played in the evolution of energy intensity inequalities starts first from a simple bifactorial breakdown of energy intensity in the following way:

$$\frac{PE_{it}}{GDP_{it}} = \frac{PE_{it}}{FE_{it}} * \frac{FE_{it}}{GDP_{it}} \qquad (1)$$

$$e_{it} = f_{it} * w_{it} \qquad (2)$$

where PE_{it} is primary energy consumption of country i in period t, FE_{it} is final energy consumption, GDP_{it} is the gross domestic product. Then, e_{it} is energy intensity, f_{it} is the transformation index, which measures the efficiency of the energy sector in transforming energy[3], while w_{it} captures the final energy consumption per GDP unit (final energy intensity index).

Secondly, to clarify the role of both factors in explaining energy intensity inequalities across countries, we define two hypothetical vectors of primary energy consumption per GDP unit and we let just one of the values of the factors included in (2) diverge from the mean. Accordingly, we obtain the following fictitious factors[4]:

$$e_{it}^{f} = f_{it} * w_{t} \qquad (3)$$

$$e_{it}^{w} = f_{t} * w_{it} \qquad (4)$$

where f_t y w_t are world averages of the factor being considered.

Resorting to Duro's (2003) methodology and Duro and Padilla (2006), using the Theil index (Theil, 1967)[5] as the benchmark inequality index allows a synthetic decomposition of global energy intensity inequalities into three factors:

$$T\left(e,p\right) = T\left(e^{f},p\right) + T\left(e^{w},p\right) + log\left(1 + \frac{\sigma_{f,w}}{e_{t}^{f}}\right) \qquad (5)$$

$$T(e,p) = T_f + T_w + inter_{f,w} \qquad (6)$$

where σ is the covariance (weighted) between the two factors and e_t^f is the world average of the first fictitious factor; *e* is the energy intensity and *p* the weight in global GDP.

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[3] Nevertheless, the index will not only depend on how efficient countries are in the conversion of one or other type of energy but also on their different energy mix. For instance, according to the International Energy Agency, the heat generated by nuclear power plants is considered primary energy while for hydro-electric stations, wind or photovoltaic solar power system, only the energy value of the electricity generated is taken into account. Consequently, the efficiency in transforming nuclear energy is less than in the case of fossil fuels, while it is always greater for renewable energy.

[4] This methodology as developed by Duro (2003) to analyze spatial income inequality.

[5] The Theil index has been used in different works on environmental distribution (Alcántara and Duro, 2004; Duro and Padilla, 2006; Padilla and Serrano, 2006; Padilla and Duro, 2009; Cantore and Padilla, 2010a; Duro *et al.*, 2010). Cowell (1995) highlights its analytical advantages, which include its ability to decompose additively a series of multiplicative factors. This is due to the fact that it is a logarithmic function.

Thus, total inequality is perfectly decomposed into two indices that capture the partial contribution of each multiplicative factor accounted for in global inequality (T_f captures the contribution of energy transformation index and T_w the contribution of final energy intensity index), and an interaction term representing the interfactorial correlation ($inter_{f,w}$)[6]. A positive value of this last component would suggest that countries that are not efficient in energy transformation would also tend to be inefficient in energy use. So, the two inequalities would be self-reinforcing. In turn, a negative value would mean that less efficient countries in energy transformation tend to be more inefficient in final energy consumption.

It should be noted that, as the factors have been formulated in equations (3) and (4), the importance of each factor in the decomposition exercise can be seen as the variation across countries of the factor under analysis, while the remaining factors are set equal to mean.

On the other hand, this factorial decomposition methodology can be extended to subgroup components of inequality. That is, the previous multiplicative factorial decomposition can be combined with subgroup decomposition. This would divide global inequality into an element of inter-group inequality and another of intra-group inequality. The well known Theil index can be easiliy decomposed into population subgroup. We adapt it here for the study of inequalities in energy intensity across countries (Theil, 1967; Shorrocks, 1980)

$$T(e,p) = \sum_{g=1}^{G} p_g T(e)_g + \sum_{g=1}^{G} p_g * \ln\left(\frac{\overline{e}}{e_g}\right) \quad (7)$$

$$T(e,p) = T_{within} + T_{between} \quad (8)$$

[6] Mind that if in addition $\frac{\sigma_{f,w}}{e_t^f}$ is sufficiently small, the decomposition could be approached as:

$$T(e,p) \approx T\left(e^f, p\right) + T\left(e^w, p\right) + \frac{\sigma_{f,w}}{e_t^f}$$

Where p_g is the weight of group g in global GDP; T_g denotes energy intensity inequality within group g; e_g represents group g energy intensity; $\bar{e}$ is the world average energy intensity.

The first term —the intra-group component (T_{within})— is a weighted average of intra-groups Theil indexes. Therefore, a multiplicative decomposition is straightforward according to (5). The second term —the inter-group component ($T_{between}$)— is simply a Theil index evaluating differences among groups. So, the previous multiplicative bifactorial decomposition of equation (5) is also straightforward. Therefore, for the regional analysis we will first apply a decomposition according to equation (6) and at a second stage a decomposition on the basis of equation (5) for each of the inequality components obtained in the first stage.

3. Empirical findings

The data used for the analysis are the energy balances from the International Energy Agency (IEA, 2009a, 2009b). The selected sample includes 116 countries and basically covers the entire world GDP and primary and final energy. For consistency reason, over the entire period we group the countries of the former USSR and also those of the former Yugoslavia. For the countries considered in the analysis per group (whose results are contained in Table 5), we use the IAE classification as a reference. The classification is done according to economic and geographic criteria and considers the following nine world regions: OECD Europe, non-OECD Europe, North America, OECD Pacific, Africa, Latin America, Middle East, Asia and China. Annex 1 gives a detail of the countries included in each group. Table 1 below gives an overview of the statistics of the sample used and for the different regions considered in the analysis.

Table 1. Summary statistics for the different regions, 2006

Group	OECD Europe	North America	OECD Pacific	Non-OECD Europe	Africa	Latin America	Middle East	Asia	China	World total
GDP	12564.17	13312.71	5280.68	2742.90	2168.80	3421.65	1455.53	7617.92	8915.65	57480.01
% PGDP	*21.86*	*23.16*	*9.19*	*4.77*	*3.77*	*5.95*	*2.53*	*13.25*	*15.51*	*100*
Primary energy	1885477	2767869	884077	1125450	610125	528886	522726	1321807	1896936	11543353
% primary energy	*16.33*	*23.98*	*7.66*	*9.75*	*5.29*	*4.58*	*4.53*	*11.45*	*16.43*	*100*
Final energy	1349545	1887103	587732	723159	447575	409961	349102	922848	1213400	7890425
% final energy	*17.10*	*23.92*	*7.45*	*9.17*	*5.67*	*5.20*	*4.42*	*11.70*	*15.38*	*100*
Energy intensity	150.07	207.91	167.42	410.31	281.32	154.57	359.13	173.51	212.76	200.82
Transformation index	1.40	1.47	1.50	1.56	1.36	1.29	1.50	1.43	1.56	1.46
Final use intensity	107.41	141.75	111.30	263.65	206.37	119.81	239.85	121.14	136.10	137.27

Source: Authors' own calculations based on the IEA (2009a, 2009b).

Note: PPP-ajusted GDP in billion US dollars of 2000; Primary energy in thousand tons of oil equivalent; the values for the transformation index vary between 1.01 for Nepal and 3.54 for Brunei (a factor of 3.5). The values for final energy consumption per GDP unit vary between 50.09 for Hong Kong and 901.51 for Iraq (a factor of 18).

Table 2. Cross country energy intensity inequality according to the Theil index and multiplicative factorial decomposition.

	Energy intensity inequality	**Transformation component** T_f	**Final use component** T_w	**Interaction component** $inter_{f,w}$
1971	0.1281	0.0087 (6.8%)	0.1339 (104.5%)	-0.0145 (-11.3%)
1975	0.1270	0.0055 (4.4%)	0.1323 (104.2%)	-0.0108 (-8.5%)
1980	0.1140	0.0051 (4.4%)	0.1217 (106.8%)	-0.0127 (-11.2%)
1985	0.0935	0.0054 (5.8%)	0.0997 (106.7%)	-0.0116 (-12.4%)
1990	0.1051	0.0041 (3.9%)	0.1105 (105.2%)	-0.0095 (-9.0%)
1995	0.0874	0.0049 (5.6%)	0.0899 (102.8%)	-0.0074 (-8.4%)
2000	0.0692	0.0044 (6.3%)	0.0681 (98.5%)	-0.0033 (-4.8%)
2006	0.0599	0.0047 (7.9%)	0.0579 (96.8%)	-0.0028 (-4.7%)

Source: Authors' own calculations based on the IEA (2009a, 2009b). Percentages with respect to global inequality are in parentheses.

The results reveal a clear reduction in cross country primary energy intensity inequality. This is in line with findings from previous studies (Duro and Padilla, 2006; or for the specific case of the OECD countries: Sun, 2002; Alcántara and Duro, 2004; Duro *et al.*, 2010). For the period of analysis, a more than fifty per cent decline in energy intensity differences is observed. According to IEA data, global primary energy intensity level decreases by 25.5% over this period. Therefore, the reduction of energy intensity inequality means convergence to lower values.

The multiplicative factorial decomposition of global inequalities in energy intensities shows that such inequalities are fundamentally attributable to differences in final energy consumption per GDP unit (T_w). Inequalities in final energy intensity are even higher than inequality in primary energy intensity during almost the entire period, although are slightly lower at the end of the period (96.8%). From a dynamic perspective, inequality in final energy consumption per GDP unit has declined considerably. Its contribution has basically halved at the end of the period. Given its relative weight, this huge decline explains the strong reduction observed in global inequality in primary energy intensity. Moreover as —according to IEA data— global final energy intensity decreased by 42.4%, the reduction in final energy intensity inequality means convergence to lower final energy intensity values.

The contribution of the transformation component (T_f) to global energy intensity inequalities is not negligible, although it is much lower than that of the final intensity. In relative terms this contribution declines until 1990. It starts increasing from this year on to reach a maximum of 7.9% in 2006. That is, something less than one tenth of cross country energy intensity inequality would be due to efficiency differentials in transforming primary energy into final energy in the energy sector of the different countries.

The interaction coefficient indicates a negative correlation of the two components considered. Its contribution is not very important, particularly at the end of the period. In any case, it reveals that countries that are less efficient in energy transformation also tend to be the ones that consume less final energy per GDP unit. That is, global inequalities would tend to compensate one another. This explains why for some years differences in final energy consumption per GDP unit are greater than differences in energy intensity.

The evolution of final energy intensity inequalities also explains the observed changes in energy intensity inequalities during the period. Policy wise, there is a lot a ground to cover to bring energy intensity down to the low values. Implementing measures that encourage a more efficient use of final energy in less efficient countries could bring down the inequality in energy intensity[7]. On the other hand, although there exist differences in energy transformation efficiency across countries, they are of lower magnitude. However, these results could be concealing different patterns among the different regions of the world, which could distort the previous interpretations. In that vein, we extended the previous decomposition to group components when accounting for the nine groups of countries defined by the IAE. Table 3 below gives the results for inequality among the different countries considered.

Table 3. Multiplicative factorial decomposition of inter-group global inequalities of energy intensity.

	Energy intensity inequality	**Transformation component** T_f	**Final use component** T_w	**Interaction component** $inter_{f,w}$
1971	0.0765	0.0026	0.0823	-0.0084
	(59.7%)	(3.4%)	(107.6%)	(-10.9%)
1975	0.0824	0.0016	0.0855	-0.0047
	(64.9%)	(2.0%)	(103.8%)	(-5.7%)
1980	0.0706	0.0014	0.0763	-0.0072
	(61.9%)	(2.0%)	(108.2%)	(-10.2%)
1985	0.0565	0.0015	0.0600	-0.0050
	(60.4%)	(2.7%)	(106.1%)	(-8.8%)
1990	0.0742	0.0009	0.0769	-0.0036
	(70.6%)	(1.2%)	(103.7%)	(-4.9%)
1995	0.0591	0.0008	0.0582	0.0001
	(67.6%)	(1.4%)	(98.5%)	(0.1%)
2000	0.0452	0.0006	0.0406	0.0039
	(65.2%)	(1.4%)	(89.9%)	(8.7%)
2006	0.0368	0.0013	0.0308	0.0048
	(61.5%)	(3.5%)	(83.6%)	(12.9%)

[7] However, the impact of these measures on global energy intensity inequality could be limited if there were an increasing sector specialization of countries. Duro *et al*. (2010) found that sector specialization becomes increasingly important in explaining the inequality of energy intensity.

Source: Authors' own calculations based on the IEA (2009a, 2009b). The percentages in the first column show the weight of inter-group inequality in global inequality, while in the remaining columns the weight of the different components in inter-group inequality is given.

From the above it is evident that inter-group inequality is more important than intra-group inequality for the world regions considered. The weight of the former varies between 60 and 70%, being at around 60% at the beginning and at the end of the period (first column of Table 3). This high weight of the inter-group component suggests that the group classification operated —according to economic and geographic criteria— happens to be quite relevant in explaining existing differences among countries[8].

Again, the final energy consumption per GDP unit component (T_w) is the most relevant in explaining such differences. Its relative weight is even greater than what was recorded for global inequalities, being above 100% throughout the period. As in the global inequality, the reduction in disparity by 51.9% is fundamentally due to the reduction in final energy consumption inequalities per GDP unit. This reduces by 62.6%.

The transformation index plays a limited role with a 3.5% contribution. It follows the same downward tendency as the final energy consumption component. In contrast, the behaviour of the interaction component is quite remarkable. This changes sign by 1990. That is, contrary to the global inequality case, since 1995 there is a positive correlation between transformation efficiency and final energy consumption. And this reinforces both inter-group inequalities.

Table 4. Multiplicative factorial decomposition of intra-group global inequalities of energy intensity.

[8] In fact, the weight of the intra-group component in global inequality can be construed as an indicator of the induced error due to this type of aggregation, with a regional and economic criterion (Esteban *et al*., 1999).

	Energy intensity inequality	Transformation component T_f	Final use component T_w	Interaction component $inter_{f,w}$
1971	0.0516	0.0060	0.0516	-0.0060
	(40.3%)	(11.6%)	(100.0%)	(-11.6%)
1975	0.0446	0.0043	0.0467	-0.0065
	(35.1%)	(9.6%)	(104.9%)	(-14.5%)
1980	0.0434	0.0042	0.0453	-0.0061
	(38.1%)	(9.6%)	(104.4%)	(-14.0%)
1985	0.0370	0.0041	0.0398	-0.0069
	(39.6%)	(11.0%)	(107.5%)	(-18.5%)
1990	0.0309	0.0034	0.0336	-0.0060
	(29.4%)	(10.9%)	(108.6%)	(-19.5%)
1995	0.0283	0.0039	0.0317	-0.0072
	(32.4%)	(13.7%)	(111.7%)	(-25.4%)
2000	0.0241	0.0036	0.0275	-0.0071
	(34.8%)	(15.0%)	(114.5%)	(-29.5%)
2006	0.0230	0.0035	0.0271	-0.0076
	(38.5%)	(15.2%)	(117.9%)	(-33.1%)

Source: Authors' own calculations based on the IEA (2009a, 2009b). The percentages in the first column show the weight of intra-group inequality in global inequality, while in the remaining columns the weight of the different components in intra-group inequality is given.

As to the intra-group inequality component, this varies between 30 and 40%, being approximately 40% at the end of the period (first column of Table 4). This component also experiences a huge decrease, which helps to explain the global decline, and reduces at less than 50% its contribution to inequality.

The most relevant component is again final energy consumption per GDP unit (T_w). In fact, inequalities in this factor are even greater than in global inequalities in energy intensity. However, in this case the importance of the differences in transformation indices is greater than for inter-group inequalities. This component (T_f) represents up to a 15.2% of intra-group inequality at the end of the period. Two thirds of the total differences in transformation indexes occur within the regions considered. That is, the greater contribution to global differences in energy transformation efficiency occurs particularly within the relatively homogenous groups of countries taken into account.

The interaction factor plays a very important role in intra-group global inequalities of energy intensity, particularly at the end of the period. The negative sign on this factor suggests that countries that are more efficient in energy transformation are most likely the more intensive ones in final energy consumption, and this tends to offset inequalities.

Table 5. Multiplicative factorial energy intensity inequality decomposition by region for 1971, 1990 and 2006.

	Energy intensity inequality	**weight**	**Transformation component T_f**	**Final use component T_w**	**Interaction component $inter_{f,w}$**
OECD Europe					
1971	0.0635	30.5%	0.0048 (7.5%)	0.0477 (75.2%)	0.0110 (17.3%)
1990	0.0372	26.8%	0.0029 (7.8%)	0.0297 (79.9%)	0.0046 (12.3%)
2006	0.0148	21.9%	0.0030 (20.4%)	0.0107 (71.8%)	0.0011 (7.7%)
North America					
1971	0.0243	25.8%	0.0002 (0.7%)	0.0232 (95.7%)	0.0009 (3.7%)
1990	0.0052	25.3%	0.0006 (11.1%)	0.0063 (121.2%)	-0.0017 (-32.3%)
2006	0.0038	23.2%	0.0005 (12.7%)	0.0072 (189.7%)	-0.0039 (-102.4%)

OECD Pacific					
1971	0.0036	9.6%	0.0004 (10.6%)	0.0019 (51.0%)	0.0014 (38.5%)
1990	0.0141	11.3%	0.0001 (0.6%)	0.0132 (93.7%)	0.0008 (5.6%)
2006	0.0119	9.2%	0.0003 (2.2%)	0.0117 (98.4%)	-0.0001 (-0.6%)
Non-OECD Europe					
1971	0.0078	10.6%	0.0010 (12.4%)	0.0096 (122.3%)	-0.0027 (-34.7%)
1990	0.0135	8.3%	0.0005 (3.9%)	0.0157 (116.8%)	-0.0028 (-20.7%)
2006	0.0313	4.8%	0.0009 (2.8%)	0.0309 (99.0%)	-0.0005 (-1.8%)
Africa					
1971	0.2491	4.4%	0.0183 (7.3%)	0.3127 (125.6%)	-0.0819 (-32.9%)
1990	0.1320	4.0%	0.0230 (17.4%)	0.1975 (149.5%)	-0.0884 (--66.9%)
2006	0.1151	3.8%	0.0270 (23.5%)	0.1873 (162.7%)	-0.0993 (-86.2%)
Latin America					
1971	0.0346	6.6%	0.0192 (55.6%)	0.0305 (88.1%)	-0.0151 (-43.7%)
1990	0.0504	6.3%	0.0051 (10.1%)	0.0339 (67.3%)	0.0114 (22.6%)
2006	0.0641	6.0%	0.0033 (5.1%)	0.0599 (93.4%)	0.0010 (1.5%)
Middle East					
1971	0.0802	2.6%	0.0643	0.1267	-0.1107

			(80.1%)	(157.9%)	(-138.0%)
1990			0.0086	0.0762	-0.0305
	0.0543	2.3%	(15.9%)	(140.3%)	(-56.2%)
2006			0.0210	0.0952	-0.0360
	0.0803	2.5%	(26.2%)	(118.6%)	(-44.8%)
Asia					
1971			0.0084	0.1246	-0.0242
	0.1088	7.2%	(7.7%)	(114.5%)	(-22.2%)
1990			0.0093	0.0654	-0.0280
	0.0467	9.9%	(20.0%)	(139.9%)	(-59.9%)
2006			0.0069	0.0457	-0.0175
	0.0350	13.3%	(19.6%)	(130.3%)	(-49.9%)
China					
1971			0.0006	0.0663	-0.0080
	0.0590	2.7%	(1.1%)	(112.5%)	(-13.6%)
1990			0.0005	0.0507	-0.0066
	0.0446	5.9%	(1.1%)	(113.7%)	(-14.8%)
2006			0.0000	0.0096	0.0095
	0.0095	15.5%	(0.0%)	(101.2%)	(-1.2%)

Source: Authors' own calculations based on the IEA (2009a, 2009b). The percentages in the second column show the weight of GDP relative to global GDP while in the remaining columns the weights of the different components in intra-group inequality are given.

The first column shows the cross country inequality within each of the regions considered. The factorial decomposition analysis for the different regions provides a much more detailed and interesting information. For instance, it allows identifying in which groups the weight of both the transformation index and the interaction component are relevant enough to have increased their importance in the intra-group component analyzed previously. This way, we are able to identify certain divergent patterns that are reflected in the behaviour of the different factors at regional level.

Firstly, the results show that, contrary to the global tendency, energy intensity inequalities have increased in four among the nine regions considered. These are OECD Pacific, non-OECD Europe, Latin America —where inequality has almost doubled— and the Middle East. This tendency has however been more than offset by the downward trajectory of some regions with greater relative weight (with respect to global GDP).

A common feature to all the regions is the pre-eminence of differences in final energy consumption intensity as determinants of the differences in energy intensity. This occurs despite the significant differences in the contribution of this factor observed among the groups of countries analyzed —from 71.8% in the case of OECD Europe to 189.7% in North America. Across the board, the evolution of the differences in final energy consumption per GDP unit is what determines the evolution of energy intensity inequalities. That is, the observed increases or declines in inequalities in final energy consumption per GDP unit predominate the evolution of the remaining factors that determine the energy intensity inequality tendency.

The factor that captures the weight of the differences in the transformation index, which represents almost 8% of the explained global differences (see Table 2), is much more relevant in some of the regions considered. This is the case for Asia (19.6%), the Middle East (26.2%), Africa (23.5%), and even OECD Europe (20.4%). As to Africa, where the weight of this component is greater, it has even increased substantially during the period of analysis. Within these regions, among countries economically and geographically relatively homogenous, there are important differences in efficiency of the energy sector in transforming primary energy into final energy.

The interaction factor also exhibits a very different pattern across the regions, being even positive in the case of OECD Europe and Latin America. However, in the former it decreases substantially throughout the period while in the latter the behaviour is somewhat erratic, increasing between 1970 and 1990 to decrease afterwards. Anyway, and contrary to the other regions, in OECD Europe and Latin America the interaction component reinforces global inequality. That is, inequalities in the transformation indices and final energy consumption per GDP unit would reinforce each other. This is so because the countries with worse efficiency level in energy transformation tend also to be those that consume more energy per GDP unit. At the other extreme are regions like North America or Africa, where the negative and significant value of the interaction factor has been increased throughout the period. This largely compensates the inequalities in final energy consumption in both cases.

4. Conclusions

As shown by previous studies, energy intensity inequality is a determining factor in the unequal energy consumption and emissions per capita among countries. The observed decline in energy intensity inequality in the past decades has been one of the main causes of the reduction in inequalities in emissions per capita. Several studies have focused on the importance of different factors in the evolution of final energy intensity differences. However, primary energy inequalities and their evolution can be conditioned by differences in final energy intensity and differences in efficiency in transforming primary into final energy alike. The present paper contributes to the literature by illustrating the role of the differences in the internal component of the energy sector and the one of the differences in final energy intensity in the evolution of primary energy intensity inequalities through synthetic indicators.

We analyzed the evolution of energy intensity inequalities using the Theil index. The methodology, which is developed by the authors, allows decomposing inequality into three components. One that captures the partial contribution of energy transformation indexes; one that calculates the role of final energy consumption per GDP unit; and finally an interaction factor. The methodology also permitted the decomposition of the factors by groups of countries and within the groups considered (following the IEA classification).

In line with previous studies the findings clearly reveal an important decline in cross country energy intensity inequality. For the groups of countries considered, inter-group inequality is more important than intra-group inequality (60%–40%). This shows the relevance of the grouping we made. However, inequality is not reduced in all the regions. In four of the nine regions considered inequality actually increased.

The factorial decomposition allowed to identify the unequal final energy consumption per GDP unit as the most relevant factor in cross country energy intensity inequalities. The observed reduction in final energy intensity inequality can be attributed to either a convergence in final energy consumption efficiency across countries or a greater similarity in sectoral production structures. In that respect, Duro *et al*. (2010) show that, for a sample of OECD countries, the reduction in final energy intensity inequalities is fundamentally due to a convergence in consumption efficiency from sector to sector and not to a greater similarity in production composition, which have become more unequal during the period of analysis. Nevertheless, this evidence cannot however be extrapolated to the rest of the regions. In fact, the present paper shows that in some regions there has been increasing divergence in final energy consumption per GDP unit.

The transformation factor has been less relevant in determining cross country energy intensity inequalities, although its role is far from being negligible. Its contribution to inter-group inequality is even more moderate. However, it is very relevant in explaining the existing differences within some of the regions considered. It represents one fourth of regional inequalities in energy intensity in some regions. Important differences still exist in the efficiency in transforming primary energy into final one. Clearly, the differences in energy conversion efficiency cannot be neglected. In some regions (e.g. Africa) such differences go up while the overall trend is downward. However, through the implementation of pertinent measures, there could still be scope to reach greater convergence toward higher efficiency level in energy transformation.

The interaction component is quite relevant, particularly with respect to within group energy intensity inequalities for some countries. However, in terms of global inequality its contribution is moderate and negative. This negative correlation suggests that inequalities in the two factors considered tend to compensate one another. Nevertheless, this behaviour changes depending on whether we consider inter-group or intra-group inequality.

Acknowledgements

The authors acknowledge support from projects ECO2009-10003 (Ministerio de Ciencia e Innovación), 2009SGR-600 and XREPP (DGR).

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Annex 1. Countries included in the sample:

OECD Europe: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Island, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom.

North America: Canada, Mexico, United States.

OECD Pacific: Australia, Japan, Korea, New Zealand.

Non-OECD Europe: Albania, Bulgaria, Cyprus, Gibraltar, Malta, Rumania, Former USSR, Former Yugoslavia

Africa: Algeria, Angola, Benin, Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Egypt, Ethiopia, Gabon, Ghana, Kenya, Libya, Morocco, Mozambique, Nigeria, Senegal, South Africa, Sudan, Tanzania, Togo, Tunisia, Zambia, Zimbabwe, Others Africa.

Latin America: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, Others Latin America.

Middle East: Bahrain, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen.

Asia: Bangladesh, Brunei Darussalam, Chinese Taipei, India, Indonesia, Dem. People's Rep. of Korea, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Others Asia.

China: People's Republic of China, Hong Kong.

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