MULTILEVEL LMDI DECOMPOSITION OF CHANGES IN AGGREGATE ENERGY CONSUMPTION. A CROSS COUNTRY ANALYSIS IN THE EU-27

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Abstract

This paper aims at analyzing the factors behind the change in aggregate energy consumption in the EU-27, also identifying differences between member states. The logarithmic-mean Divisia index method (LMDI) is applied to multiplicatively decompose, at the country level, the variations in aggregate energy consumption of the EU-27 member states in the 2001-2008 period. We also analyze the sensitivity of results when several aggregation levels are considered, with energy intensity used as the criterion to aggregate countries. This allows us to check robustness of results and improve understanding of both inter and intra-unit effects. Results indicate that improvements in energy efficiency in the EU-27 were not enough to override the pressure of European economic activity on aggregate energy consumption. Mediterranean, and especially former communist countries, increased their energy consumptions, most of them being favoured by structural change. The analysis also reveals that the impact of intra-group movements on aggregate energy consumption is partially offset when moving from higher to lower aggregation levels.

Keywords: Multilevel decomposition, Energy consumption, European studies.

1. Introduction

The United Nations designated 2012 as the Year of Sustainable Energy for All. At the Rio20Summit (2012) it was recognized the significant role of energy in economic growth and pointed out the need for urgent measures. The EU-27 itself is increasingly dependent on energy imported from Non-EU Member States, thus creating -among others- political, social and economic risks for the Union. In 2009, this high dependence on energy imports and the shrinkage of traditional energy resources -added to the insufficient expansion of renewable resources and the concern on greenhouse gas emissions and climate change- led to the design of a European energy policy. The main objectives of this policy are: (1) reduction of import dependence, (2) security of supply and (3) sustainable development. Several actions are put into operation, including: Intelligent Energy for Europe 2003-2006 (a multiannual programme for action in the field of energy), Action Plans for energy efficiency 2000-2006 and 2007-2013 (including measures to reduce energy consumption and improve energy efficiency), and the Green Paper on Energy Efficiency 2005 (in order to relaunch energy saving). In this agreement, the Member States made a commitment to reduce energy consumption by 20% for 2020[1] (compared to energy consumption forecasts for that year). This undertaking also encouraged the signing of an international agreement which obliges developed countries to reduce their greenhouse gas emissions by 30% -compared with 1990 levels- for year 2020.

Although the EU as a whole is one of the largest energy consumers and polluters, and despite their considerable concern about this issue, there are no decomposition studies available that explore the change in aggregate energy consumption (AEC) with a view to analyse the driving forces behind them. Many empirical studies addressing this objective refer to APEC

[1] This is a European initiative published by the European Commission (2005) in its Green Paper.

countries (Ma and Stern, 2008; Liao and Wei, 2010; Sahu and Narayanan, 2010; Chung et al., 2011; Shahiduzzaman and Alam, 2012; Xu et al., 2012; Zhang et al., 2013). In this paper we deal with decomposing the change in aggregate energy consumption between two benchmark years for each of the 27 European Member States. Our study aims at identifying and analysing the influence of the factors underlying that change at the macroeconomic level.

Instead of using alternative techniques as Structural Decomposition Analysis (SDA) and econometric analysis, we shall rely on Index Decomposition Analysis (IDA). This technique imposes milder requirements in terms of data availability (this being particularly interesting in international studies), as well as using sector level data and allowing for multiplicative decompositions. Relying on IDA, we multiplicatively decompose variations in the aggregate into the contributions from several determinant factors, namely, activity, structural and intensity. Said otherwise, we will apply a so-called energy consumption approach (Ang and Lee, 1994).

The activity effect measures the impact on energy consumption due to changes in overall activity level. The structural effect involves changes in energy consumption arising from changes in the sectoral (resp., regional) production structure. Lastly, the intensity effect relates to changes in both sectoral (resp., regional) activity mix and sectoral (resp., regional) energy intensities. This analysis will allow us to understand the behaviour patterns of the aggregate, its driving forces, and to derive action lines in order to achieve a reduction in energy consumption.

On the other hand, a large proportion of prior studies have focused on a single, fixed aggregation level. This is particularly evident in international studies, where data collection at several aggregation levels becomes a difficult issue. Nevertheless, it is well known that a given methodology may lead to different final results depending on the aggregation level specified by the researcher. In this regard, a sensitivity analysis of how results are affected by the specific aggregation level becomes important in order to check the robustness of results. In this paper we shall carry out a decomposition analysis at three different aggregation levels. This will allow us to properly assess the effects of disaggregation. In addition, application of a specific aggregation criterion can enable more accurate measurement of some specific aspects, also allowing for isolation and control of others.

The highest level includes the 27 countries, whereas in the medium one, the EU states are grouped into 8 spatial units. Only three regions are considered in the lowest level. These levels are constructed with a view to compose homogeneous groups in terms of energy intensity. This aims to check whether, after controlling for the energy intensity factor, there still exists a significant impact of geographical differences in production structure and market size.

Afterwards, returning to the country level decomposition, we analyse each country, comparing results and deriving a number of strategies and policy implications in order to achieve reductions in energy consumption.

Summing up, the objectives of the paper are threefold: (*a*) identification, quantification and explanation of the driving forces behind the change in aggregate energy consumption, (*b*) analysis of the findings at several regional levels, and (*c*) comparison analysis of results across countries. Our findings will be helpful in order to understand how the aggregate is affected by a number of driving forces, also allowing us to design strategies and policy recommendations to reduce aggregate energy consumption in these countries. This will favour energy saving, costs reduction, competitiveness of these regions, increased exports, higher growth rates and, in other matters, fulfilment of international agreements and, by and large, being part of a sustainable growth.

In Section 2 we outline the LMDI-based methodology to multiplicatively decompose changes in aggregate energy consumptions into the contributions from activity, structural and intensity factors. More precisely, Subsection 2.1 briefly reviews single-period (*periodwise*) and time series decomposition, while Subsection 2.2 focuses on multilevel decompositions.

Section 3 reports an application of the above methodology in order to study AEC changes in the 27 European member states along the 2001-2008 period. We begin by reporting decomposition results at three different aggregation levels, and then looking for differences in the results that may be explained by so-called subgroup effects. Then, focusing on the decomposition results at the country level, a comparison analysis across member states is carried out.

In Section 4 we review the political actions adopted by the European Union in order to reduce European energy consumption. Effectiveness of these measures is also discussed in the light of results presented in the previous section.

Finally, we draw some conclusions. We find that overall EU-27 aggregate energy consumption increased by 2.245% between 2001 and 2008, pushed up by the influence of inter-regional structural changes, and particularly by the inertia of overall production. This increase took place in spite of improvements in energy efficiency in the same period.

2. LMDI-based decomposition analysis

A large number of decomposition techniques are now available in the energy and environmental literature. Among them, Index Decomposition Analysis (IDA) is widely used, in both energy and environmental economics, for the analysis of energy consumption and emissions. Methodological and practical aspects of this technique have been studied by Jenne and Cattell (1983), Reitler et al. (1987), Boyd et al. (1987), Liu et al. (1992a), Ang and Lee (1994), Ang (1995a), Ang and Choi (1997), Sun (1998) and Albrecht et al. (2002), among others. Numerous specific methods exist, ranging from those based on Laspeyres (Liu et al., 1992b; Unander, 2007), Paasche and Marshall-Edgeworth indices (Boyd and Roop, 2004) to extended and refined models (Ang and Choi, 1997; Sun, 1998; Fernández and Fernández, 2008).

We will focus on the logarithmic mean Divisia index -or LMDI- method introduced by Ang and Choi (1997). According to Ang (2004; 2005), multiplicative LMDI is the preferred index decomposition method, both from the theoretical and applied perspectives[2].

2.1. The energy consumption approach

We begin by considering the following variables in period *t*:

[2] From a theoretical standpoint, LMDI provides an exhaustive decomposition (i.e., decomposition with no deviations from target values). It also fulfils time and factor reversal tests, as well as being able to handle zero values and being applicable when several levels of disaggregation are available (Ang, 2004). From a practical perspective, a direct relationship exists between additive and multiplicative decompositions -which is useful when interpreting results-, and the expressions for the effects have the same mathematical forms irrespective of the number of factors considered (this being useful in order to implement the method in applications).

E_t : Aggregate energy consumption.

$E_{j,t}$: Energy consumption in region j.

Y_t: Total production.

$Y_{j,t}$: Production of region j.

$S_{j,t}$: Production share of region j ($S_{j,t} = Y_{j,t} / Y_t$).

I_t: Energy intensity ($I_t = E_t / Y_t$).

$I_{j,t}$: Energy intensity for region j ($I_{j,t} = E_{j,t} / Y_{j,t}$).

In terms of disaggregated regional data, we have:

$$E_t = \sum_{j=1}^{k} E_{j,t} = \sum_{j=1}^{k} Y_t \left(Y_{j,t} / Y_t\right)\left(E_{j,t} / Y_{j,t}\right) = \sum_{j=1}^{k} Y_t S_{j,t} I_{j,t} \tag{1}$$

where k is the number of regions in the considered disaggregation level.

Following the energy consumption approach (Ang and Lee, 1994), the change in aggregate energy consumption between two periods 0 and T (or total effect $R_{tot}= E_T/E_0$) may be expressed in terms of indices, as follows:

$$R_{tot} = R_{act} R_{str} R_{int} \tag{2}$$

where R_{act}, R_{str} and R_{int} are the activity, structural and intensity effects, respectively.

The effects resulting from the LMDI decomposition can be calculated as follows (Ang and Choi, 1997):

$$R_{act} = e^{\left[\sum_{j=1}^{k} \frac{\left(E_{j,T} - E_{j,0}\right)/\left(\ln E_{j,T} - \ln E_{j,0}\right)}{\left(E_T - E_0\right)/\left(\ln E_T - \ln E_0\right)} \ln\left(Y_T / Y_0\right)\right]} \tag{3}$$

$$R_{str} = e^{\left[\sum_{j=1}^{k} \frac{\left(E_{j,T} - E_{j,0}\right)/\left(\ln E_{j,T} - \ln E_{j,0}\right)}{\left(E_T - E_0\right)/\left(\ln E_T - \ln E_0\right)} \ln\left(S_{j,T} / S_{j,0}\right)\right]} \tag{4}$$

$$R_{int} = e^{\left[\sum_{j=1}^{k} \frac{\left(E_{j,T} - E_{j,0}\right) / \left(ln\, E_{j,T} - ln\, E_{j,0}\right)}{\left(E_T - E_0 \right) / \left(ln\, E_T - ln\, E_0 \right)} ln\left(I_{j,T} \,/\, I_{j,0}\right) \right]} \qquad (5)$$

When data for intermediate periods are available, time series decomposition becomes possible. Its results may be expected to be more accurate than those of periodwise decompositions as it exploits greater amounts of information. In addition, detection of different phases or time patterns (including potential structural breaks) also becomes feasible in this setting.

If the cumulative change in aggregate energy consumption is denoted as $(C_{tot})_{0,T}$, the cumulative production effect as $(C_{act})_{0,T}$, the cumulative structural effect as $(C_{str})_{0,T}$, the cumulative intensity effect as $(C_{int})_{0,T}$, and the cumulative residual term[3] as $(C_{rsd})_{0,T}$, all of them from periods 0 to T, then the multiplicative time series decomposition for the cumulative effects may be expressed as follows:

$$(C_{tot})_{0,T} = (R_{tot})_{0,1}\,(R_{tot})_{1,2} \cdots (R_{tot})_{T-1,T} \qquad (6)$$

$$(C_{act})_{0,T} = (R_{act})_{0,1}\,(R_{act})_{1,2} \cdots (R_{act})_{T\;\;1,T} \qquad (7)$$

$$(C_{str})_{0,T} = (R_{str})_{0,1}\,(R_{str})_{1,2} \cdots (R_{str})_{T-1,T} \qquad (8)$$

$$(C_{int})_{0,T} = (R_{int})_{0,1}\,(R_{int})_{1,2} \cdots (R_{int})_{T-1,T} \qquad (9)$$

$$(C_{rsd})_{0,T} = (R_{rsd})_{0,1}\,(R_{rsd})_{1,2} \cdots (R_{rsd})_{T-1,T} \qquad (10)$$

where $(R_m)_{t\text{-}1,t}$ is the m-type effect (m=*tot, act, str, int, rsd*) from periods t-1 to t (t=1, 2,…,T).

[3] By definition, in exact (or exhaustive) decomposition methods there is no deviation from the target value, so the residual term is identically null (resp., unity) for any additive (resp., multiplicative) technique. Although the residual component is technically redundant, it is computed in this paper in order to check that our calculations are correct.

2.1. Multilevel decomposition

Usually, the main goal of decomposition studies is to estimate the impact of structural change on production. However, structural change is influenced by the grouping considered, so the results of the analysis usually are closely related to the disaggregation level considered –i.e., the specific set of *a priori* defined regional groups- at which the decomposition has been carried out. In order to avoid this undesired dependence, several authors (e.g., Morović et al., 1989; Jenne and Cattell, 1983; Gardner, 1993; Hankinson and Rhys, 1983; Li et al., 1990; Ang, 1995b) have carried out multilevel decompositions. Previous works have generally considered z disaggregation levels and only two factors (namely, structural and intensity effects). In this paper we extend multilevel analysis in order to allow for a set of three pre-defined factors, with an additional factor (namely, the *activity effect*) now being included in the analysis.

Ang (1995b) derived the following expressions for the structural and intensity subgroup effects -$R\{z\text{-}1\}z_{str}$ and $R\{z\text{-}1\}z_{int}$, respectively- when passing from level $\{z\text{-}1\}$ to z:

$$R\{z-1\}z_{str} = e^{\left[\sum_{r=1}^{m} \frac{\left(E_{r,T}-E_{r,0}\right)/\left(ln\ E_{r,T}-ln\ E_{r,0}\right)}{\left(E_T-E_0\right)/\left(ln\ E_T-ln\ E_0\right)} ln\left(\frac{S\{z-1\}z_{r,T}}{S\{z-1\}z_{r,0}}\right)\right]} \tag{11}$$

$$R\{z-1\}z_{int} = e^{\left[\sum_{r=1}^{m} \frac{\left(E_{r,T}-E_{r,0}\right)/\left(ln\ E_{r,T}-ln\ E_{r,0}\right)}{\left(E_T-E_0\right)/\left(ln\ E_T-ln\ E_0\right)} ln\left(\frac{I\{z-1\}z_{r,T}}{I\{z-1\}z_{r,0}}\right)\right]} \tag{12}$$

where r varies from the first to the m-th region at the z-th disaggregation level. $S\{z\text{-}1\}z_{r,T} = Sz_{r,T}/S\{z\text{-}1\}_{j,T}$ and $I\{z-1\}z_{r,T} = Iz_{r,T}/I\{z-1\}_{j,T}$ are the structural and intensity subgroup effects when going from level $\{z\text{-}1\}$ to z, with $Sz_{r,T}$, $Iz_{r,T}$, $S\{z\text{-}1\}_{j,T}$ and

$I\{(z\text{ - }1)_{j,T}\}$, being, respectively, the structural and intensity effects for region r at level z and the structural and intensity effects for unit j in level $\{z\text{-}1\}$ at which r belongs.

Following an analogous reasoning, we now introduce the activity subgroup effect:

$$R\{z-1\}z_{act} = e^{\left[\sum_{r=1}^{m} \frac{(E_{r,T} - E_{r,0}) / (\ln E_{r,T} - \ln E_{r,0})}{(E_T - E_0) / (\ln E_T - \ln E_0)} \ln \left(\frac{Y\{z-1\}z_T}{Y\{z-1\}z_0} \right)\right]} \tag{13}$$

By definition, $Y\{z\text{ - }1\}z_T = Y\{z\text{ - }1\}z_0 = 1$, so the activity subgroup effect is identically one in the multiplicative case (resp., null for the additive decomposition), and consequently the activity effect is invariant to changes in the aggregation level.

3. Decomposition analysis of changes in aggregate energy consumption in the EU-27

In this section we apply LMDI decomposition to multiplicatively[4] decompose the variation in aggregate energy consumption in the EU-27 economy between 2001 and 2008. First, considering three different levels of regional aggregation, we carry out a multilevel decomposition. Then, focusing on a country aggregation level, we analyse the results separately for each country and each effect, assessing the differences between them.

Time series for gross inland energy consumption in each country (in thousand tonnes of oil equivalent) and Gross Domestic Product at current prices using purchasing power parity (in millions of euro) were obtained from Eurostat (European Commission, 2011 and 2012). Production shares in the EU-27 total production and energy intensities for each country

[4] As a consequence of the additive property, a simple relationship exists between multiplicative and additive decompositions (Ang *et al.*, 1998), which makes the latter technically redundant.

(measured as ratio between gross inland consumption of energy and GDP) were constructed, in order to obtain balanced data and avoid any error from unbalanced data.

3.1. Decomposition at several disaggregation levels

Consideration of several regional disaggregation levels involves the consideration of the so-called intra-group (or *subgroup*) effects and enables a sensitivity analysis of results. When energy intensity is used as the aggregation criterion, countries are grouped into a set of relatively homogeneous –in terms of energy efficiency- areas, thus making it possible a deeper analysis of structural changes between groups with different technological levels.

At the finest disaggregation level (i.e., level III), 27 spatial units -each corresponding to one Member State of the EU-27- are considered.

At level II, the following 8 spatial units or regions are defined[5]:

- Region 1: Denmark, Ireland and the United Kingdom.
- Region 2: Italy, Austria, Germany and Sweden.
- Region 3: Luxembourg, France, Greece, the Netherlands, Spain and Portugal.
- Region 4: Malta and Belgium.
- Region 5: Finland, Cyprus and Latvia.
- Region 6: Lithuania, Hungary and Poland.
- Region 7: Czech Republic, Estonia, Romania, Slovenia and Slovakia.
- Region 8: Bulgaria.

[5] Countries were classified according to their energy intensities, measured in kilograms of oil equivalent per EUR 1,000 of GDP. Region 1: Below 125, Region 2: 125-155, Region 3: 155-190, Region 4: 190-210, Region 5: 210-310, Region 6: 310-425, Region 7: 425-625, and Region 8: Above 625.

In the above classification Western EU-27 member states are mainly grouped in the first regions, reflecting their lower energy intensities, while Central and Eastern countries are classified in the latter groups.[6] Consequently, the aggregation criterion generates a grouping that roughly corresponds to a political/geographical division.

At level I we consider 3 spatial units made up of countries with similar energy intensities at a level higher than II. We have[7]:

- Low intensity countries (LIC): Denmark, Ireland and the United Kingdom.
- Medium intensity countries (MIC): Italy, Germany, Sweden, Luxembourg, France, Greece, the Netherlands, Spain, Portugal, Malta and Belgium.
- High intensity countries (HIC): Finland, Cyprus, Latvia, Lithuania, Hungary, Poland, Czech Republic, Estonia, Romania, Slovenia, Slovakia and Bulgaria.

Again, LIC and MIC countries correspond to Western EU Member States while HIC countries mostly comprise Central and Eastern EU members. Naturally, a number of specific factors - including the great importance of heavy industry, technological underdevelopment, absence of entrepreneurship and private property, and non-cost-reflected energy- explain that these former centrally planned economies have historically been more energy-intensive than Western capitalist countries.

[6] In this paper the denomination "Central and Eastern countries" basically applies to ex-communist EU countries, whereas the label "Western countries" mainly refers to former European members of the Western block.

[7] Energy intensity is measured in kilograms of oil equivalent per EUR 1,000 of GDP. LIC: Below 125, MIC: 125-210, HIC: Above 210.

3.1.1. Disaggregation level III (country level)

First of all, according to Table 1, the EU-27 aggregate energy consumption (C_{tot})[8] increased by 2.245% in the 2001-2008 period. Both overall production -the activity effect ($C3_{act}$)- and inter-regional structural changes -the structural effect ($C3_{str}$)- were positive, contributing to this increase by 14.872% and 2.037%, respectively. In other words, the increase in overall economic activity in the EU-27 –i.e., the inertia of EU production growth- involved a 14.872% increase in aggregate energy consumption. However, the change in production structure -likely from less to more energy-intensive sectors in those countries where changes occurred- only led to a 2.037% increase in aggregate energy consumption, seven times smaller than the activity effect.

On the other hand, the intensity effect ($C3_{int}$) had a negative contribution to increase the aggregate (12.769%). This means that changes in energy efficiency -probably induced by improved use of technologies, adaptability to more efficient techniques, technical change, innovation, and modifications in the energy mix- had a relevant contribution to reduce aggregate energy consumption. However, this impact was not enough to override the accumulated effect of all the other factors. Indeed, the influence of the increase in total EU production induced so strong an increase in the aggregate that improvements in energy efficiency failed to reverse the situation.

[8] By definition, the total change in aggregate energy consumption for the EU-27 is the same under any disaggregation level considered, so $C1_{tot} = C2_{tot} = C3_{tot} = C_{tot}$.

Table 1. Multiplicative decomposition of changes in aggregate energy consumption in the EU-27 at level III, period 2001-2008. (Base year 2001).

Year	$C3_{act}$	$C3_{str}$	$C3_{int}$	$C3_{rsd}$	C_{tot}
2001	1.00000	1.00000	1.00000	1.00000	1.00000
2002	1.00267	1.00109	0.98396	1.00000	0.98766
2003	1.02330	1.00425	0.99258	1.00000	1.02001
2004	1.04811	1.00928	0.97693	1.00000	1.03344
2005	1.07011	1.01118	0.95603	1.00000	1.03450
2006	1.10767	1.01409	0.92387	1.00000	1.03776
2007	1.13186	1.01632	0.88594	1.00000	1.01912
2008	1.14872	1.02037	0.87231	1.00000	1.02245

Results, displayed in Figure 1 below, suggest three different periods in the evolution of aggregate consumption. More specifically, a detailed analysis of the total effect indicates three phases: 2001-2002, 2003-2006 and 2007-2008.

During the first phase, aggregate energy consumption dropped in the EU-27. In those years, the impact of growing overall activity was modest, although positive. On the one hand, former EU-15 Member States were subject to restrictions and economic conditions imposed by the Maastricht Treaty (1992). On the other hand, former communist countries were slowed their growth due to the financial and economic crisis in Russia in 1999. Meanwhile, the energy efficiency improvement was the unique contributor to the decrease of that aggregate. Some determinants of this behaviour were the economic transition from centrally planned economies, the growing private sector share in GDP, liberalization of interest rates, adjustment of electric tariffs, creation of competition policy, and price liberalisation.

On the contrary, between 2003 and 2006, aggregate energy consumption increased as both the structural -and especially the activity- effects were positive, and strong enough as to override the negative influence of the intensity effect. More specifically, in 2003 the activity and the intensity effects -the biggest contributors to aggregate energy consumption- changed their behaviour. The former started growing at faster rates (with this high activity being maintained along the time). The latter shows a similar behaviour, but in the opposite direction. However, the positive activity effect, reinforced by a positive structural effect, lead to an overall increase in aggregate energy consumption. During these years, the inertia of the growing overall EU-27 activity, added to the influence of structural changes -still persistent preponderance of agriculture and industry sectors in many of the new EU-Member States, inherited from the Soviet domination- contributed to increasing aggregate energy consumption. Furthermore, changes in production from less to more energy-intensive countries reinforced this contribution. On the other hand, as shown by the negative intensity effect, significant energy efficiency improvements were made, contributing to decreasing aggregate energy consumption. However, these improvements were not important enough as to offset the joint effects of all the other impacts.

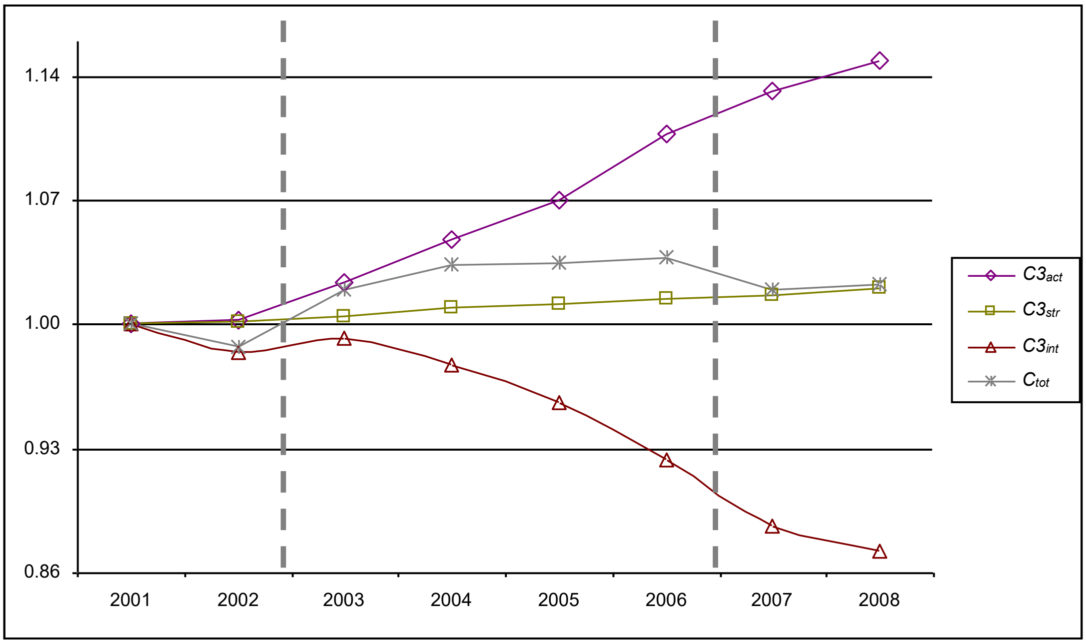

Figure 1. Multiplicative decomposition of changes in aggregate energy consumption in the EU-27, period 2001-2008. (Base year 2001).

Finally, in the 2007-2008 period, aggregate energy consumption dropped with respect to the second phase (although it still exceeded the 2001 data), actually coming back to 2003 values. This reduction was a consequence of the remarkably negative impact of the intensity effect. Nevertheless, the last year of the series, 2008, is particularly interesting as both the intensity and activity effects appear to reduce their influence (see Figure 1 above). Neither national production nor the intensity effect were favoured by lower economic growth in 2008 as a consequence of the global economic and financial crisis. On the one hand, consumers (households and businesses) are spending less on new durable goods and delaying deployment of more efficient buildings and equipment. As their disposable income decreases, they are also less willing to pay the premium for more efficient goods. Besides, they are using less goods. On the other hand, companies are now finding it much harder to obtain credit than in the past -especially for the riskiest projects- and new investments in production facilities are less profitable as prices of oil and other forms of energy have sharply decreased since mid

2008 as a consequence of weak demand and lesser need for capacity. Some ongoing projects are being slowed, and other planned projects are postponed or even cancelled due to lack of finance and downward revisions in expected profitability.

3.1.2. Disaggregation level II

In order to test for sensitivity of the above results to changes in disaggregation level, we carried out a decomposition of the change in aggregate energy consumption at an additional level (namely, level II). The total (C_{tot}) and activity ($C2_{act}$) effects obviously remain the same as in level III, as they are independent of the aggregation level.

Table 2. Multiplicative decomposition of changes in aggregate energy consumption in the EU-27 at disaggregation level II, period 2001-2008. (Base year 2001).

Year	$C2_{act}$	$C2_{str}$	$C2_{int}$	$C2_{rsd}$	C_{tot}
2001	1.00000	1.00000	1.00000	1.00000	1.00000
2002	1.00267	1.00076	0.98429	1.00000	0.98766
2003	1.02330	1.00329	0.99353	1.00000	1.02001
2004	1.04811	1.00810	0.97808	1.00000	1.03344
2005	1.07011	1.00999	0.95716	1.00000	1.03450
2006	1.10767	1.01252	0.92530	1.00000	1.03776
2007	1.13186	1.01463	0.88742	1.00000	1.01912
2008	1.14872	1.01828	0.87410	1.00000	1.02245

Again, the structural effect ($C2_{str}$) had a positive influence of 1.828% on aggregate energy consumption in 2008 (see Table 2). Nevertheless, this contribution is slightly reduced as compared with the previous disaggregation level.

As for the intensity effect ($C2_{int}$), it has now a negative impact of 12.59% on aggregate energy consumption in 2008 (see Table 2). This impact is just slightly smaller than that obtained for disaggregation level III.

3.1.3. Disaggregation level I

At this disaggregation level we observe the same patterns as in previous levels. Both structural and intensity group effects ($C1_{str}$ and $C1_{int}$) maintain their respective (positive the former, negative the latter) contributions (see Table 3). However, their impacts are now 1.691% and 12.473%, respectively, slightly lower than those obtained at levels III and II.

Table 3. Multiplicative decomposition of the change in aggregate energy consumption in the EU-27 at disaggregation level I, period 2001-2008. (Base year 2001).

Year	$C1_{act}$	$C1_{str}$	$C1_{int}$	$C1_{rsd}$	C_{tot}
2001	1.00000	1.00000	1.00000	1.00000	1.00000
2002	1.00267	1.00041	0.98463	1.00000	0.98766
2003	1.02330	1.00209	0.99471	1.00000	1.02001
2004	1.04811	1.00592	0.98020	1.00000	1.03344
2005	1.07011	1.00837	0.95869	1.00000	1.03450

2006	1.10767	1.01075	0.92691	1.00000	1.03776
2007	1.13186	1.01316	0.88870	1.00000	1.01912
2008	1.14872	1.01691	0.87527	1.00000	1.02245

3.1.4. The subgroup effects

In this subsection we compare the decomposition results at the three different aggregation levels, looking for differences between them. The analysis involves both quantification and explanation of the corresponding subgroup effects.

Table 4 shows the structural ($C32_{str}$ and $C31_{str}$) and intensity ($C32_{int}$ and $C31_{int}$) subgroup effects when shifting from disaggregation level III to levels II and I, respectively.

When going from the 27-country to the 8-region setting, the structural subgroup effect contributes to reduce aggregate energy consumption by 0.248% while the intensity one increases it by 0.205%. In addition, when moving from 27 countries to the 3-area grouping, the structural subgroup effect has a positive contribution of 0.339% whereas the intensity effect shows a negative influence of 0.34%[9].

On the one hand, when reducing the fineness of the disaggregation level, both the structural and intensity effects lose some of their influence. Since this loss is not very significant, the initial decomposition results would be robust to the aggregation level.

On the other hand, when considering higher-order spatial units –i.e., more homogeneous groups in terms of energy intensity-, the meagre intra-group influences do not only indicate a similar technical development into groups but also inter-country movements in production

[9] By definition, the subgroup effects have zero sum in additive models (or equivalently, unit average in multiplicative decompositions), as the total effect remains the same at any disaggregation level.

structure.

Table 4. Subgroup effects when decomposing the change in aggregate energy consumption in the EU-27, moving from level III to levels II and I, period 2001-2008 (base year 2001).

Year	$C32_{str}$	$C32_{int}$	$C31_{str}$	$C31_{int}$
2001	1.00000	1.00000	1.00000	1.00000
2002	0.99890	1.00033	0.99932	1.00068
2003	0.99794	1.00096	0.99785	1.00215
2004	0.99835	1.00118	0.99667	1.00334
2005	0.99853	1.00118	0.99722	1.00278
2006	0.99760	1.00155	0.99671	1.00330
2007	0.99911	1.00167	0.99689	1.00312
2008	0.99752	1.00205	0.99661	1.00340

Figures 2 and 3 show the structural and intensity group effects at each disaggregation level. Theirs impacts are similar, independently of the level, but a loss in their respective influences is observed when moving from level III to II or I[10]. Then, when shifting from the country level to a coarser spatial division, the activity effect maintains its impact, while the structural and intensity effects reduce their contributions. From this perspective, the overall increase in economic activity in the EU-27 has a bigger influence on the aggregate than changes in economic structure or improvements in energy efficiency.

[10] Although visual differences between Figures 2 and 3 are observed, these are merely scale effects, as the impact loss was the same for both effects.

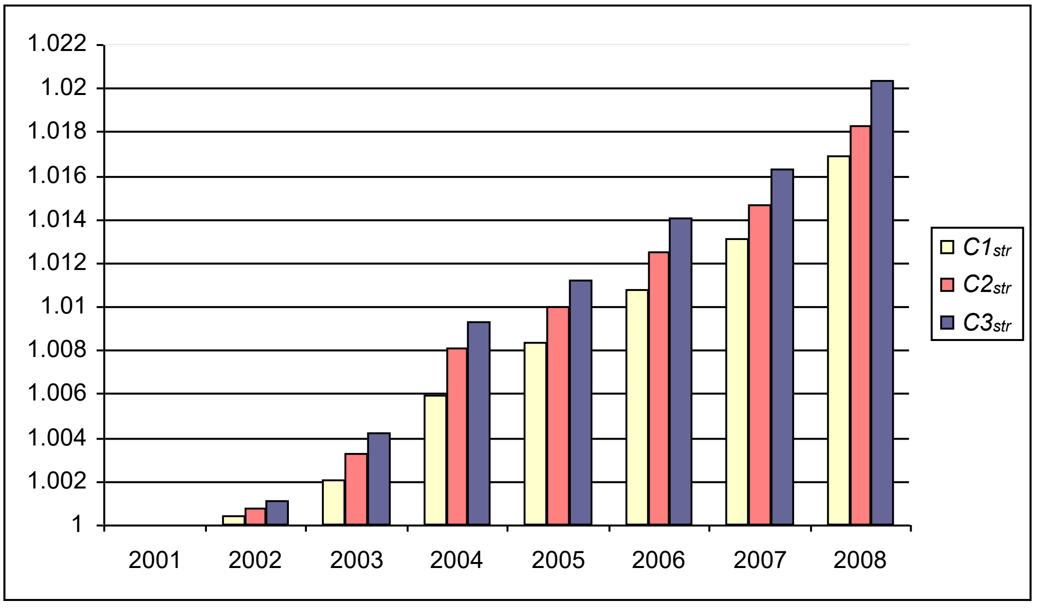

Figure 2. Cumulative structural effects for EU-27 energy consumption. LMDI decomposition, at three disaggregation levels, period 2001-2008.

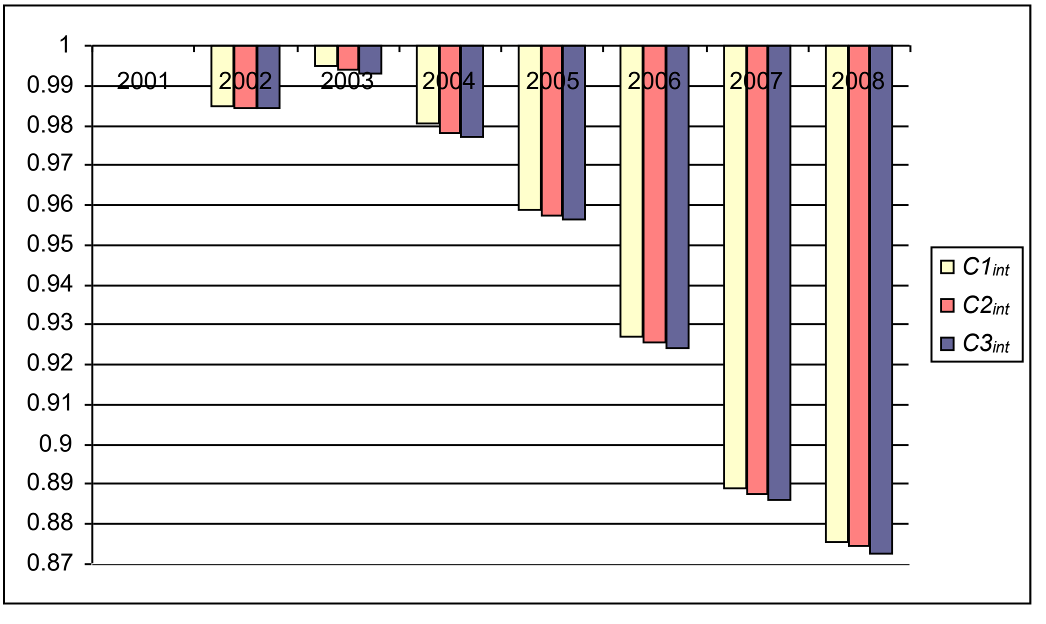

Figure 3. Cumulative intensity effects for EU-27 energy consumption. LMDI decomposition at three disaggregation levels, period 2001-2008.

3.2. A European cross-country study

Now we apply the LMDI method to decompose aggregate energy consumption for specific countries, quantifying and analysing the forces that underlie these changes. Decomposition results suggest some ideas and strategies to control the aggregate.

Results appear in Table 5. As commented above, in the EU-27 as a whole, both overall production ($C3_{act}$) and structural change factors ($C3_{str}$) contributed to increase aggregate energy consumption, whereas the intensity effect ($C3_{int}$) was not big enough as to override them. Consequently, the total effect indicates an overall increase of 2.245%.

Table 5. Multiplicative LMDI decomposition of aggregate energy consumption by countries, period 2001-2008.

~~Qué hacemos con la columna de Ctot?.~~

Countries	$C3_{act}$	$C3_{str}$	$C3_{int}$	C_{tot}
Austria	1.00318	1.00023	0.99844	1.08561
Belgium	1.00453	0.99952	0.99447	0.95448
Bulgaria	1.00113	1.00269	0.99704	1.11415
Cyprus	1.00022	1.00013	0.99988	1.15870
Czech Republic	1.00306	1.00312	0.99498	1.05431
Denmark	1.00182	1.00010	0.99853	1.03461
Estonia	1.00033	1.00076	0.99929	1.17640
Finland	1.00309	1.00111	0.99727	1.06925
France	1.01871	0.99175	0.98886	0.99302
Germany	1.02675	0.99513	0.97882	1.00034

Greece	1.00247	1.00238	0.99691	1.10610
Hungary	1.00208	1.00102	0.99742	1.03493
Ireland	1.00144	1.00278	0.99758	1.18876
Italy	1.01590	0.98781	0.99826	1.01583
Latvia	1.00048	1.00129	0.99876	1.17136
Lithuania	1.00053	1.00178	0.99854	1.25784
Luxembourg	1.00050	1.00037	0.99966	1.16937
Malta	1.00005	1.00006	0.99996	1.19221
Netherlands	1.00611	0.99745	0.99637	0.99685
Poland	1.00693	1.00983	0.98843	1.10682
Portugal	1.00220	0.99907	0.99889	1.00988
Romania	1.00290	1.00575	0.99300	1.08031
Slovakia	1.00127	1.00299	0.99556	0.97865
Slovenia	1.00057	1.00069	0.99930	1.14561
Spain	1.01123	1.00697	0.99226	1.14372
Sweden	1.00398	1.00050	0.99420	0.95467
United Kingdom	1.01816	1.00513	0.97161	0.95768
EU-27	1.14872	1.02037	0.87231	1.02245

Naturally, the contribution of each determinant factor was different among countries. This would reflect differences in risk, market and owner structures, level of leverage, local credit markets and economic perspectives. However, there is a common pattern in both the activity and intensity effects: the first positively influenced energy consumption in all the analysed countries -this being a result of a growing economy- and the latter had a negative influence in order to improve energy efficiency. In addition, the structural effect exhibits a great deal of variability depending on the member state, ranging from 0.983% for Poland to -0.1219% for Italy.

Most Member States -including Bulgaria, Austria, Czech Republic, Denmark, Estonia, Finland, Poland, Germany, Romania, Italy, Luxembourg, Greece, Hungary, Portugal and, to a greater extent, Lithuania, Ireland, Estonia, Latvia, Malta, Cyprus, Slovenia and Spain- experienced increases in their energy consumptions. Nevertheless, among these countries the contribution of the structural factor has different sign depending on the country. In this regard, a structural reform of mining is still pending in Estonia. Slovenia has a strong pharmaceutical and electrical consumer products industry. Cyprus has suffered a serious degradation as a consequence of tourism (even without considering future problems following its recent financial crisis). Malta has a very strong shipyard sector (50% of employed labour force). Romania passed its first national plan of action in the field of energy efficiency in 2007 (the year when the country joined the EU). Spain hardly has oil or gas and they are currently used on its increasing transportation sector needs and on electricity production. All those countries had positive contributions from change in production structure. On the other hand, Germany, Italy and Portugal had negative contributions from the structural factor, although these were not strong enough to offset the positive sign of their activity effects. In particular, members as Germany and Italy were labour receptors in the period and their populations increased. So did the demand of goods and services in these countries, to such an extent that the activity effect became too large to be overridden.

Other states -namely, some Western countries as the United Kingdom, Sweden, Belgium, France and the Netherlands, and Slovakia as an Eastern exception- achieved reductions in their energy consumptions. In the cases of France, Belgium and the Netherlands this drop was mainly due to both negative intensity and structural effects. On the contrary, only the intensity factor intervened in the United Kingdom and Sweden, where changes in their production structures contributed to increase their energy consumption as in these countries, particularly the United Kingdom, the industry (more energy-intensive than other sectors) gained prominence over the other sectors.

Focusing on each specific factor, a positive activity effect is observed for all the EU-27 member states, this being particularly relevant in large economies as Germany, France, the United Kingdom, Italy and Spain. The population increase in these big Western economies, as a consequence of immigration, as well as economic growth itself with the greater satisfaction of needs have involved an increase in aggregate energy consumption. Hajko (2012) also reports the activity effect as the most significant one, pointing out that the average activity effect of old EU-15 countries was about 1.13 times bigger than the average of EU-27.

Regarding the structural effect, it was positive or negative depending on the member state. In most countries, changes in inter-regional productive structure contributed to significantly increase aggregate energy consumption. This was particularly remarkable in Poland, Spain, Romania and the United Kingdom. On the contrary, in other countries (namely, Italy, France, Germany, the Netherlands, Belgium and Portugal) the structural effect contributed to decreasing energy consumption. The change in the structural component was mainly due to a transformation process in which the importance of the industry in the economy as a whole drops, while the opposite holds for services (which are generally less energy-intensive than industry, excepting transport). Western countries generally have relatively bigger and growing tertiary sectors than Central and Eastern member states that have inherited the primacy of agriculture and industry from the Soviet domination. Additionally, Mediterranean countries have lower energy intensities in tertiary and residential sectors due to moderate temperatures.

The intensity effect had a negative impact on energy consumption in all the EU-27 member states. This effect was mild in Cyprus, Malta, Luxembourg, Slovenia and Estonia, whereas a strong influence is observed for big economies as France, Spain, Poland, and especially the United Kingdom and Germany. A number of factors -including more efficient industrial processes and transport systems, minimum efficiency requirements for energy-using equipment, tougher standards and better labelling on appliances, coherent use of taxation, improving energy performance of buildings and, more generally, innovation and adaptation to more efficient technologies led to significant reductions in energy consumption. This was especially remarkable in large Western economies as Germany and the United Kingdom, and in Poland. These results are in line with the findings published in a communication by the European Commission in 2007.

4. Policy implications

The spectacular worsening of European energy dependence, the growing need to ensure more competitiveness in an increasingly globalized world, as well as the commitments made by the EU on climate change (Kyoto, 1998), led the European institutions to overview the actions taken by the European Union in the energy field and to present, in 1999, the first proposal that takes account of all energy problems. In the Communication *An overall view of energy policy and actions* (1997), the European Commission aims at covering both cooperation with the Member States -through promotion of energy co-operation between Member States- and direct actions taken by the Union. Its objectives and actions[11] set include: (a) integration of European energy markets –through standardisation, energy taxation, competition policy and promotion of trans-European energy net-works-, (b) promotion of sustainable development – encouraging rational and efficient use of energy resources, promotion of new and renewable energy sources-, (c) development of energy technologies -through promotion of energy research, dissemination of energy technology, and nuclear research- and (d) security of supply and strengthening of international energy co-operation, through bilateral agreements, diversification of energy supply through energy sources and relations with supplier countries, and preparation of new Member States (i.e., Central and Eastern European countries).

Afterwards, the Community was taking several specific measures such as the Directive on large plants (1998), the Disposal of diffused offshore oil and gas installations (2001), new taxation of energy products, waste incineration, or polluting emissions from motor vehicles (Auto-oil Programme, 2000b). Member States have the main responsibility to act, and regional and local authorities also play a role in energy management. Nevertheless, their activities should be reinforced and complemented by a number of actions at Community level.

In year 2000, the Commission presented an Action Plan for a six year period (2000-2006) aiming at reducing energy consumption by improving energy efficiency. This plan strengths and expands previous measures. It proposed a label system for domestic appliances and office equipment (EU Eco-Label system), energy certification of buildings, promotion of new infrastructures and inter-modality in the transport sector, decentralisation of energy

[11] The main sources of finance for those Community actions were programmes as THERMIE (for actions management and implementation), PHARE (cooperation with Central Europe), EURATOM loans (for nuclear research), European Investment Bank loans (for financing energy investments), JOULE (to promote energy research), ALTENER (for renewables strategy), *et cetera*.

management at both local and regional levels, stimulation of demand for energy-efficient technologies from the public procurement, tax exemptions for investments in energy efficiency, harmonisation of efficiency standards, energy audits, promotion of green attitudes, increase of combined production of heat and power, and protocols on minimum energy-efficient processes and production methods.

In 2006 the Commission adopted a new Action Plan for energy efficiency (2007-2012) aimed at achieving a 20% reduction in energy consumption by 2020 (compared to the energy consumption forecasts for that year). The Plan proposes a number of short and medium-term actions to achieve this objective, also strengthening and updating previous measures. Finally, in 2007, the European Union approved a real European Energy Policy with the following priority energy objectives: sustainability, security of supply and competitiveness. It set up many different actions to achieve these objectives (from diversifying energy mix to promoting relations with producer countries). Focusing on measures related to energy consumption reduction, the following ones are included: accelerating the use of fuel efficient vehicles for transport, tougher standards and better labelling of appliances, improving the energy performance of the EU´s existing buildings, coherent use of taxation in order to achieve more efficient use of energy, improving the efficiency of heat and electricity generation, transmission and distribution, developing biofuels -particularly second generation biofuels- in order to get fully competitive alternatives to hydrocarbons, increasing investments in order to take advantage of economies of scale in renewables, and an international agreement to promote a common effort.

Concerning the definition of the specific factors (activity, structural and intensity) considered in the decompositions presented in this paper, most of the measures taken by the European

Union are oriented to improving energy intensity via energy efficiency, that is, they directly relate to the intensity effect. However, at the same time, a large proportion of these actions - such as funding renewables or some taxation- involve changes in the market that lead to readjustment in agent decisions. So, this intervention is likely to affect the production structure, directly related to the structural effect. Indeed, our results show global changes from less energy-intensive to more energy-intensive sectors. Finally, other kinds of measures would boost economic growth, so affecting the activity effect.

It is generally known that energy efficiency programmes may lead to some undesirable results. Moreover, some voices argue that technological innovation has been occurring for centuries without any need of specific policies, with the evolution of energy prices being what moves decision-makers to act (Jaffe and Stavins, 1994; Sutherland, 2003). On the one hand, the rebound effect may erode energy savings (Brookes, 1992; Inhaber, 1997). When service costs decline, the demand for energy services like heating, refrigeration or lighting increases. On the other hand, the economy-wide effect may also erode energy savings. Gains in energy efficiency imply an increase in economic growth (pushing up energy consumption) and an increase in energy use, as it appears relatively cheaper than other inputs (Saunders, 1992).

In the United Kingdom, the government provided grants to stimulate energy efficiency improvements in houses. Shorrock (1999) found the programme cost-effective in terms of saving energy, even after accounting for free rider effects. In the Netherlands, the government provided technical and financial assistance to participating companies in order to implement and develop energy efficiency improvements. Reitbergen et al. (1998) and Van Luyt (2001), after adjusting energy savings, also showed the strategy as cost-effective to reduce energy consumption.

In any case, in the EU-27 as a whole, the efforts done through energy actions and programmes to increase energy efficiency clearly were not sufficient to reduce aggregate energy consumption. In most countries the growing overall economic activity and some changes from less to more energy-intensive sectors were strong enough to offset the expected results of these programmes.

5. Conclusions

The measures included in the Action Plans (1999 and 2006) and the European Energy Policy (2007) contributed to improving the use of technologies, adaptation to more efficient techniques, innovation, technical change, R&D and substitution for higher quality energies. However, although the EU-27 made a remarkable effort to reduce aggregate energy consumption, this magnitude increased by 2.245% between 2001 and 2008. Our findings indicate that the impact of improvements in energy efficiency (12.629%) was not enough to offset the joint influence of growing overall activity (14.872%) and changes in the production structure (2.037%).

When considering coarser aggregation levels -eight regions or three areas (i.e., high, medium and low energy intensity zones)- we arrive at a similar conclusion: the structural and intensity effects maintain the same sign, although both of them reduce their contributions. The meagre intra-group influences reveal a similar technical development and production structure movements within the groups.

Analysing the situation at the country level, aggregate energy consumption increased in most of them, particularly in Eastern and Central countries, Spain, Ireland and Greece[12]. This increase was due to the influence of European economic growth, but also was a consequence of changes in their production structures. Only a few Western countries (Belgium, France, Germany and the Netherlands) reported reductions in energy consumption, achieved through a combination of energy efficiency and structural changes in that period.

Regarding each individual effect, European economic growth contributed to increasing energy consumption in all the countries, particularly in large economies as Germany, the United Kingdom, France, Italy and Spain. On the contrary, improvements in energy efficiency contributed to decreasing the aggregate in all the member states, particularly in Germany and Poland. However, the influence of structural change differs among countries. With the exceptions of Belgium, France, Germany, Italy, the Netherlands and Portugal, the influence of structural change helped increase energy consumption, so inter-sectoral production changes did not favour energy savings.

The above results suggest a number of energy and environmental actions potentially helpful in order to reduce energy consumption. The following policies (most of them already considered by the European Commission) aim at reinforcing the intensity effect, although the structural impact is also taken into account: (a) to promote change in consumer choices (towards higher value added products), (b) to encourage "green consumption" attitudes (recycling, conserving energy in lighting, heating and air conditioning at both private and public levels), (c) to improve energy efficiency (particularly in countries with energy-intensive economic structures as Spain, Poland and other Eastern and Central European member states), (d) to use higher quality inputs and energies, (e) to stimulate nuclear and hydrological energies (instead

[12] Malta and Luxembourg have also increased their energy consumption. However, the estimated effects were modest and nearly unity.

of fossil fuels) for electricity generation, (f) to promote a structural change towards less energy-intensive goods and services, (g) to research and innovate (looking for more efficient technologies), (h) to adapt and install proper equipment in order to improve energy efficiency (as an instance, the construction sector in Eastern and Central European countries might greatly improve its efficiency).

All these actions will be helpful in order to reduce aggregate energy consumption, making it possible for the EU-27 to address a number of challenges concerning sustainability, security of supply and competitiveness, as well as complying with international agreements.

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