FACTORS INFLUENCING CHANGES IN AGGREGATE ENERGY CONSUMPTION. AN EUROPEAN CROSS-COUNTRY ANALYSIS

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Abstract
A number of previous papers have proposed index-based methods to decompose the change of an aggregate indicator into a series of predefined factors. These approaches range from classical techniques, including Laspeyres/Paasche index-based weighting schemes, to more refined proposals. In this paper we outline and apply a refined method (so-called LMDI), which is exhaustive and uses logarithmic mean weighting. The LMDI framework is then used to decompose the variation of aggregate energy consumption in the EU-27 countries. The decomposition is carried out into three factors, namely, activity, structural and intensity.
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1. Introduction

In the international arena, and from various agencies and institutions, a number of strategies and actions currently being developed seek sustainable growth from the environmental, economic or social standpoints, so that welfare and living conditions of both present and future generations may be improved. The quantification and analysis of environmental variables such as energy consumption or intensity, production and gas emission to the atmosphere, make it easier the analysis and design of action lines that enable control on these magnitudes.

In the last three decades, numerous studies have addressed the decomposition of the variation of a given environmental aggregate in a specific period, trying to analyze the influence of those factors underlying this variation. Authors such as Reitler *et al.* (1987), Boyd *et al.* (1988), Liu *et al.* (1992), Ang and Lee (1994), Ang (1995a), Ang and Choi (1997), Sun (1998) and Albrecht *et al.* (2002) have analyzed index-based decomposition techniques, both from the theoretical and the empirical perspectives. Basic decomposition models include those relying on Laspeyres, Paasche and Marshall-Edgeworth weighting schemes. Other, more refined, methods as LMDI (logarithmic mean Divisia index) exploit variable weight functions that lead to complete (or *exact*) decompositions.

A number of papers have dealt with applications of LMDI (e.g., Ma and Stern, 2008; Sahu and Narayanan, 2010; Zhao *et al.*, 2010, Chung *et al.*, 2011; Shahiduzzaman and Alam, 2012; Zhang *et al.*, 2012). Most of these applications refer to APEC countries. In this paper we exploit this method in order to obtain an exhaustive decomposition (i.e., without residual term) of the change experienced by an indicator referred to the countries in the EU-27. More specifically, our goal is to identify, quantify and explain the factors

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influencing the variation in aggregate energy consumption in the 2001-2008 period.

The decomposition will be implemented through the so-called *energy approach,* which assumes that the variations in aggregate consumption are affected by three determinant factors. These factors are collected in the effects of *(a)* aggregate output *(activity effect), (b)* inter-structural changes *(structural effect),* and *(c)* the proportion of high quality energy inputs and technical changes *(intensity effect)*.

The paper is organized as follows. Section 2 outlines the methodology to be applied in Section 3, and finally the results are discussed.

2. Methodology

Upon the basis of the energy consumption approach, Ang and Lee (1994) derived a multiplicative decomposition of the aggregate energy consumption ratio. We shall rely on this framework, and the following set of variables, evaluated at time *t*, will be considered*:*

E_t : total energy consumption.
$E_{j,t}$: energy consumption in region *j*.
Y_t: total production.
$Y_{j,t}$: production of region *j*.
$S_{j,t}$: fraction of total production from the 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 of region *j* ($I_{j,t} = E_{j,t} / Y_{j,t}$).

In terms of regional disaggregated data, we obtain the following decomposition:

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

where *k is* the number of regions at the considered level of disaggregation.

Taking logarithmic derivatives with respect to *t* in equation (1) and integrating in the time interval [0, *T]*, the resulting expression is obtained:

$$ln\left(\frac{E_T}{E_0}\right) = \sum_{j=1}^{k} \int_0^T w_j(t) \left[\frac{d\,lnY(t)}{dt} + \frac{d\,lnS_j(t)}{dt} + \frac{d\,lnI_j(t)}{dt}\right] dt \qquad (2)$$

where

$$w_j(t) = \frac{Y(t)S_j(t)I_j(t)}{E(t)} = \frac{Y(t)S_j(t)I_j(t)}{\sum_{j=1}^{k} Y(t)S_j(t)I_j(t)} \qquad (3)$$

Applying the exponential operator in (2) above we obtain:

$$\frac{E_T}{E_0} = e^{\left[\sum_{j=1}^{k}\int_0^T w_j(t)\left(\frac{d\,lnY(t)}{dt}\right)dt\right]} e^{\left[\sum_{j=1}^{k}\int_0^T w_j(t)\left(\frac{d\,lnS_j(t)}{dt}\right)dt\right]} e^{\left[\sum_{j=1}^{k}\int_0^T w_j(t)\left(\frac{d\,lnI_j(t)}{dt}\right)dt\right]} \qquad (4)$$

Since in practice the observations are not made in continuous time, discrete approximations to the integrals in equation (4) are usually applied. The following formula is widely accepted:

$$\frac{E_T}{E_0} = e^{\left[\sum_{j=1}^{k}\int_0^T w_j(t^*)ln\left(\frac{Y_T}{Y_0}\right)dt\right]} e^{\left[\sum_{j=1}^{k}\int_0^T w_j(t^*)ln\left(\frac{S_{j,T}}{S_{j,0}}\right)dt\right]} e^{\left[\sum_{j=1}^{k}\int_0^T w_j(t^*)ln\left(\frac{I_{j,T}}{I_{j,0}}\right)dt\right]} \qquad (5)$$

where w_j *(t*)* is a weight function given by the equation (3), evaluated at t^* $[0, T]$. A priori t^* is unknown and it is possible to consider various weight functions. Ang and Choi (1997) suggest the LMDI method, where the weight function is given by the following expression[1]:

$$w_j(t^*) = \frac{L(w_{j,0}, w_{j,T})}{\sum_{j=1}^{k} L(w_{j,0}, w_{j,T})} \qquad (6)$$

where $w_{j,0} = E_{j,0}/E_0$ and $w_{j,T} = E_{j,T}/E_T$. Vartia (1974) and Sato (1976) propose the use of total value added as the argument of the weight function, that is:

$$L\left(\sum_{j=1}^{k} E_{j,0}, \sum_{j=1}^{k} E_{j,T}\right) = L(E_0, E_T) \qquad (7)$$

and

$$\tilde{w}_j(t^*) = \frac{L(E_{j,0}, E_{j,T})}{L(E_0, E_T)} \qquad (8)$$

Substituting equation (8) in (5) we obtain:

[1] This weight function results in much more refined decompositions, as compared with conventional Divisia methods like Laspeyres, Paasche or Marshall-Edgeworth.

$$\frac{E_T}{E_0} = e^{\left[\sum_{j=1}^{k}\int_0^T \tilde{w}_j(t^*) ln\left(\frac{Y_T}{Y_0}\right)dt\right]} e^{\left[\sum_{j=1}^{k}\int_0^T \tilde{w}_j(t^*) ln\left(\frac{S_{j,T}}{S_{j,0}}\right)dt\right]} e^{\left[\sum_{j=1}^{k}\int_0^T \tilde{w}_j(t^*) ln\left(\frac{I_{j,T}}{I_{j,0}}\right)dt\right]} \tag{9}$$

Equation (9) can be rewritten as follows:

$$R_{tot} = R_{act} R_{str} R_{int} \tag{10}$$

$$R_{act} = e^{\left[\sum_{j=1}^{k}\frac{\left(E_{j,T}-E_{j,0}\right)/\left(ln E_{j,T}-ln E_{j,0}\right)}{\left(E_T-E_0\right)/\left(ln E_T - ln E_0\right)} ln\left(Y_T/Y_0\right)\right]} \tag{11}$$

$$R_{str} = e^{\left[\sum_{j=1}^{k}\frac{\left(E_{j,T}-E_{j,0}\right)/\left(lnE_{j,T}-lnE_{j,0}\right)}{\left(E_T-E_0\right)/\left(lnE_T - lnE_0\right)} ln\left(S_{j,T}/S_{j,0}\right)\right]} \tag{12}$$

$$R_{int} = e^{\left[\sum_{j=1}^{k}\frac{\left(E_{j,T}-E_{j,0}\right)/\left(ln E_{j,T}-ln E_{j,0}\right)}{\left(E_T-E_0\right)/\left(ln E_T - ln E_0\right)} ln\left(I_{j,T}/I_{j,0}\right)\right]} \tag{13}$$

where $R_{tot} = E_T / E_0$ is the variation (index) of aggregate energy consumption between years 0 and T (total effect), R_{act} denotes the impact associated with the variation of the production (activity effect), R_{str} reflects the contributions of structural changes (structural effect), and R_{int} denotes the impact of regional energy intensity (so-called intensity effect).

The activity effect is a consequence of the inertia of overall economic growth, whereas the structural effect is affected by changes in trade patterns, the increasing preference of consumers for services and products with high value added and low intensity in materials, as well as improved materials. Finally, the intensity effect is the result of technological change, innovation, substitution between capital, labour and energy, as well as use of higher quality energies.

2.1. Time series decomposition

The decomposition of the variation of an indicator between the initial and final periods can be expressed in terms of changes between the intermediate periods. If we call $(C_{tot})_{T,0}$

the cumulative change in total energy consumption, $(C_{act})_{T,0}$ the cumulative effect of production, $(C_{str})_{T,0}$ the cumulative structural effect, $(C_{int})_{T,0}$ is the cumulative intensity effect, and $(C_{rsd})_{T,0}$ denotes the cumulative residual effect, all of them referred to the period from 0 to *T*, then the multiplicative decomposition may be factored as follows:

$$(C_{tot})_{0,T} = (R_{tot})_{0,1}(R_{tot})_{1,2}...(R_{tot})_{T-1,T} \quad (14)$$

$$(C_{act})_{0,T} = (R_{act})_{0,1}(R_{act})_{1,2}...(R_{act})_{T\text{-}1,T} \quad (15)$$

$$(C_{str})_{0,T} = (R_{str})_{0,1}(R_{str})_{1,2}...(R_{str})_{T\text{-}1,T} \quad (16)$$

$$(C_{int})_{0,T} = (R_{int})_{0,1}(R_{int})_{1,2}...(R_{int})_{T\text{-}1,T} \quad (17)$$

$$(C_{rsd})_{0,T} = (R_{rsd})_{0,1}(R_{rsd})_{1,2}...(R_{rsd})_{T\text{-}1,T} \quad (18)$$

2.2. Multilevel decomposition

The main objective of decomposition studies usually is to estimate the impact of structural change on production. However, the magnitude of change is determined by the grouping considered. This implies that the results of the analysis depend on the disaggregation level (*n*) considered, which in turn is limited by the availability of information.

To investigate this dependency, several authors *(e.g.,* Jenne and Cattell, 1983; Hankinson and Rhys, 1983; Morovic′ *et al.*, 1989, Li *et al.*, 1990; Gardner, 1993; Ang, 1995b) have developed multilevel decompositions. In the above papers *z* levels of disaggregation and only two factors are considered. Here we extend the usual scheme, also considering *z* levels of disaggregation, but introducing a third factor, namely, the activity effect.

Considering *z* disaggregation levels, the multiplicative decomposition in each of these levels may be expressed as follows:

$$R_{tot} = R1_{act}\, R1_{str}\, R1_{int}\, R1_{rsd} \quad (19)$$

$$R_{tot} = R2_{act}\, R2_{str}\, R2_{int}\, R2_{rsd} \quad (20)$$

…

$$R_{tot} = Rz_{act}\, Rz_{str}\, Rz_{int}\, Rz_{rsd} \quad (21)$$

where $R\{h\}_{act}$, $R\{h\}_{str}$, $R\{h\}_{int}$ y $R\{h\}_{rsd}$ are, respectively, the activity, structural, intensity and residual effects, for the *h*-th disaggregation level (h =1,..., z).

By applying the circular property, Equation (19) can be expressed as follows:[2]

[2] Based on Hulten (1973) and Vogt (1978), Liu *et al.* (1992) demonstrated that, when considering discrete differences and under weak homogeneity Divisia indices satisfy the circular property, so:

$Rz_{act} = R1_{act}\, R12_{act}...R\{z-1\}z_{act}$,

$Rz_{str} = R1_{str}\, R12_{str}...R\{z-1\}z_{str}$, and

$Rz_{int} = R1_{int}\, R12_{int}...R\{z-1\}z_{int}$.

$$R_{tot} = \left(R1_{act}\, R12_{act} \ldots R\{z\text{-}1\}z_{act}\right)\left(R1_{str}\, R12_{str} \ldots R\{z\text{-}1\}z_{str}\right) \left(R1_{int}\, R12_{int} \ldots R\{z\text{-}1\}z_{int}\right) Rz_{rsd} \quad (22)$$

where $R\{z\text{-}1\}z$ denotes the estimated effect of going from level $\{z\text{-}1\}$ to a finer level z, and Rz_{rsd} denotes the residual term at z level. Following a similar reasoning, Ang (1995b) shows that estimated effects due to the transition from disaggregation level $\{z\text{-}1\}$ to z can be expressed as follows:

$$R\{z-1\}z_{act} = e^{\left[\sum_{r=1}^{m} \frac{(E_{r,T}-E_{r,0})/(ln\, E_{r,T} - ln\, E_{r,0})}{(E_T - E_0)/(ln\, E_T - ln\, E_0)} ln\left(\frac{Y\{z-1\}z_T}{Y\{z-1\}z_0}\right)\right]} \quad (23)$$

$$R\{z-1\}z_{str} = e^{\left[\sum_{r=1}^{m} \frac{(E_{r,T}-E_{r,0})/(ln\, E_{r,T} - ln\, E_{r,0})}{(E_T - E_0)/(ln\, E_T - ln\, E_0)} ln\left(\frac{S\{z-1\}z_{r,T}}{S\{z-1\}z_{r,0}}\right)\right]} \quad (24)$$

$$R\{z-1\}z_{int} = e^{\left[\sum_{r=1}^{m} \frac{(E_{r,T}-E_{r,0})/(ln\, E_{r,T} - ln\, E_{r,0})}{(E_T - E_0)/(ln\, E_T - ln\, E_0)} ln\left(\frac{I\{z-1\}z_{r,T}}{I\{z-1\}z_{r,0}}\right)\right]} \quad (25)$$

where the subscript r varies from the first to the mth region defined in the dissagregation level z. $S\{z-1\}z_{r,T} = Sz_{r,T} / S\{z-1\}_{j,T}$ and $I\{z-1\}z_{r,T} = Iz_{r,T} / I\{z-1\}_{j,T}$ are the structural and intensity subgroup effects when moving from level *{z-1}* to *z*, where $Sz_{r,T}$, $Iz_{r,T}$, $S\{z-1\}_{j,T}$ and $I\{z-1\}_{j,T}$, denote, respectively, the structural and intensity effects for each region r in level z, and the structural and intensity effects for unit j at level *{z-1}* to which r belongs. In addition, $Y\{z-1\}z_T = Y\{z-1\}z_0 = 1$. In this kind of decomposition we conclude that there is no subgroup effect for the activity factor, that is, the third factor included is not altered by the disaggregation level considered.

3. Variation of aggregate energy consumption in the EU-27

Applying the multiplicative LMDI method, we decompose the change of aggregate energy consumption in the EU-27 between 2001 and 2008, considering two levels of disaggregation.

At level II, 27 spatial units, corresponding to each of the states that make up the EU-27 (country level), are considered.

At Level I, three regions are obtained, by grouping the countries of the EU-27 according to their energy intensities in the final year of study. The resulting breakdown is as follows:

- *Low energy intensity countries:* Denmark, Ireland, the United Kingdom and Austria.
- *Average energy intensity countries:* Italy, Germany, Sweden, Luxembourg, France, Greece, the Netherlands, Spain, Portugal, Malta and Belgium.

- *Energy-intensive countries*:[3] Bulgaria, Finland, Cyprus, Latvia, Czech Republic, Estonia, Romania, Slovenia, Slovakia, Lithuania, Hungary and Poland.

Our choice of energy intensity as the grouping criterion serves a double purpose: *(a)* to analyze the sensitivity of results to changes in the level of disaggregation, and *(b)* to better capture structural movement between groups when homogeneous groups in terms of energy efficiency are formed.

The time series of energy consumption in each country (in thousands of tonnes of oil equivalent) and GDP at current prices in purchasing power parity (in million euros) have been obtained from Eurostat.

3.1. Disaggregation level II

Table 1 shows the results of the analysis on the second level of disaggregation.

Table 1. Results of multiplicative decomposition of the change in aggregate energy consumption in the EU-27, disaggregation level II, 2001-2008. Base 2001.

Year \ Effect	$C2_{act}$	$C2_{str}$	$C2_{int}$	$C2_{rsd}$	C_{tot}
2001	1.00000	1.00000	1.00000	1.00000	1.00000
2002	1.00267	1.00109	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

According to Table 1, between 2001 and 2008 total energy consumption in the EU-27 increased by 2.245% (C_{tot}). Both the pull effect caused by the increase in overall EU production (activity effect) and the effect of inter-structural changes (structural effect) contributed positively to the increase in consumption. Specifically, the activity effect exceeded more than seven times the structural one (14.872% vs. 2.037%). As regards the intensity effect, this contributed by 12.769% to the reduction in aggregate energy consumption. Therefore, the extent of this effect was not enough to offset the impact of

[3] Note that those countries with the highest energy intensity countries seem to correspond to the "Central and Eastern Europe". In this paper, the term "countries of Central and Eastern Europe" applies mainly to former communist members of the EU, whereas the label "Western countries" refers to countries in the former Western block.

the activity and structural effects. It is also checked that the residual effect has value 1 in all cases, showing that, indeed, the method used is exhaustive and has null deviation from the target value[4].

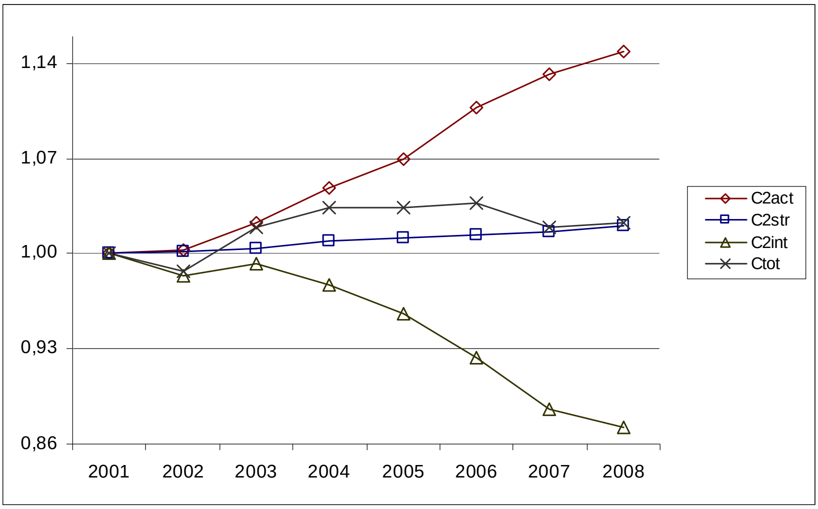

Figure 1. Results of multiplicative time series decomposition of aggregate energy consumption in the EU-27 in 2001-2008 (base 2001)

By analyzing in detail the evolution of the total effect over the entire study period, three phases may be identified: 2001-2002, 2003-2006 and 2007-2008. In the first phase, aggregate energy consumption dropped, with both the structural and activity effects having small positive values and being partially offset by the remarkable influence of the intensity effect, which has negative sign.

During the 2003-2006 period, total energy consumption increased as a result of the structural effect and, especially, the activity effect, both being big enough to counteract the negative intensity. In 2003 the effects with more weight in the decomposition (activity and intensity) appear to suffer some alteration. Specifically, the activity effect begins to grow at higher rates, increasing its contribution to the growth in aggregate energy consumption. On its side, the intensity effect, which continues to maintain its contribution in reducing the aggregate consumption of energy, in 2003 as compared to the previous year, exceptionally, increases consumption. This makes that the annual rate of growth in energy consumption in 2003 is by far the largest in the series. The fall in energy prices during the period caused a sharp increase in consumption that was not accompanied by a significant increase in income.

Finally, in 2007-2008, total energy consumption is still higher than in 2001, but experienced a sharp drop compared to the values from the previous period, making it stand at similar levels to 2003. This decrease was due to the strong impact of the intensity

[4] By definition, the residual term is zero for any exhaustive additive decomposition method.

effect, despite the positive influence of the structural and activity effects. However, in 2008 the growth rates of intensity and activity effects slow down (see Figure 1), losing influence as a result of lower economic growth. In principle, a recession scenario does not favor production, investment in new technologies, the search for alternative energies, and technical innovation.

3.2. Disaggregation level I

At this level, the total and the activity effects obviously maintain their values, whereas the structural and the intensity effects drop (see Table 2). Structural change is having a positive influence on aggregate energy consumption, whereas technical change and R&D maintain their negative impacts. In any case, the difference between these two effects is further reduced in level II. While the cumulative structural effect is 1.691%, the intensity one amounts to 12.473%. From 2001 to 2008, the impact of technological change, innovation and improved use of technology was about ten times bigger than that of the structural changes between groups.

Table 2. Results of multiplicative decomposition of the change in aggregate energy consumption in the EU-27, disaggregation level I, 2001-2008. Base 2001.

Year \ Effect	$C1_{act}$	$C1_{str}$	$C1_{int}$	$C1_{rsd}$	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	1.14873	1.01691	0.87527	1.00000	1.02245

The results at this level continue to show patterns similar to those observed in the previous one, i.e., an increase of the intensity effect in 2003 over the previous year and a significant drop in 2007 compared to the previous phase, although this drop is smaller than in the finest disaggregation level. This points to a milder influence of this effect in level I with respect to level II.

When the subgroup effects of moving from second to first disaggregation level are observed (Table 3), we note that the cumulative structural effect ($C21_{str}$) helped to reduce total energy consumption by 0.339%, whereas the cumulative intensity effect ($C21_{int}$) increased it by 0.34%.

Table 3. Results of time series decomposition of the change in aggregate energy consumption in the EU-27. Transition from level II to I, 2001-2008. Base 2001.

Year \ Effect	$C21_{str}$	$C21_{int}$
2001	1.00000	1.00000
2002	0.99932	1.00068
2003	0.99785	1.00215
2004	0.99667	1.00334
2005	0.99722	1.00278
2006	0.99671	1.00330
2007	0.99689	1.00312
2008	0.99661	1.00340

4. Concluding remarks

In this paper we have outlined-applied a decomposition methodology based on Divisia indices, which relies on the energy consumption approach. The empirical analysis refers to the countries of the EU-27, whose aggregate energy consumption increased by 2.245% between 2001 and 2008. When this variation is decomposed, the following issues are observed:

(a) At the disaggregation level II (27 countries), interregional structural changes, especially the inertia of the global production of the European Union, contributed positively by 2.037% and 14.872%, respectively, to this increase. On the other hand, improved use of technologies, adaptation to more efficient techniques, technical change and innovation contributed negatively by 12.769%.

(b) At the disaggregation level I (3 regions), the positive influence of structural changes and the negative impact of technological change and innovation remain, but the influence of both these factors is reduced. When moving from a higher to a lower disaggregation level, the relevance of structural and intensity effects decreases, although modestly. The effect of between-group movements partially offsets the structural and intensity effects. In any case, we might conclude that results do not appear to be particularly sensitive to changes in the level of disaggregation.

Improved use of technology and the ability to adapt to more efficient techniques, technological change and innovation are factors that, indeed, appear to have contributed to the reduction in aggregate energy consumption in the EU-27 along the studied period. However, the inertia of global production and interregional structural changes have been significant enough to counteract this contribution and eventually cause the growth in aggregate consumption of energy.

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