LMDI DECOMPOSITION ANALYSIS OF ENERGY EFFICIENCY IN ANDALUSIA (SPAIN) DURING 2003-2011.

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ABSTRACT:

The LMDI decomposition analysis of the evolution of the final energy consumption in Andalusia during the period 2003-2011, leads to the conclusion that the increase of final energy consumption (3%) produced in this period was due to economic growth (83.4%) and the decrease in energy efficiency (16.6%). Industry was the sector that most increased energy efficiency (1.9%), while that of the energy sector reduced by 2.6%. The LMDI decomposition method allowed the analysis of the energy efficiency in Andalusia during 2003-2011. Results show that from 2008, and coinciding with the beginning of the Spanish economic crisis, Andalusia showed an important decline in final energy consumption (- 1406 ktoe) and an improvement in energy efficiency due to declining energy intensity indicators.

KEYWORDS:

LMDI decomposition analysis, energy efficiency, energy intensity, energy policy

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1. Introduction

Energy consumption is one of the main causes of the level of greenhouse gas emissions in industrialised countries, aggravated in some countries by the level of dependency on fossil fuel sources. Thus, the improvement of energy efficiency has become, in its own right, one of the main objectives of energy policies (Pérez Lombard, et al, 2013). Within the sphere of the European Unión (EU), the Europe 2020 Strategy (EC 2010) for a smart, sustainable and inclusive growth, set, among its objectives, a reduction of 20% of the primary energy consumption trend anticipated for 2020.

In the particular case of Spain, the latest Energy Saving and Efficiency Action Plan 2011-2020 (MITC, 2011) set the objective of a reduction of 20% of primary energy, signifying a reduction of 35585 ktoe with respect to 2007. In agreement with the methodology proposed by the European Commission, this objective supposes a reduction of 1.5% of the energy intensity. Regarding the consumption of final energy (FE), the plan anticipates a saving of 17842 ktoe, which translates into a reduction of the final energy intensity of 2%.

In 2011, Andalusia, an autonomous community that represents 17.8% of the Spanish population, had final energy consumption per capita some 21% less than Spain as a whole (1.5 toe/inhabitant versus 1.9 toe/inhabitant, respectively). Conversely, its final energy intensity was 5.8% greater (127 toe/M€ versus the Spanish average of 120 toe/M€), which denotes a smaller energy efficiency index.

The Autonomous Community of Andalusia established an objective of primary energy saving of 4% on the trend of consumption for 2006 through the Andalusian Energy Plan 2003-2006 (PLEAN). Subsequently, the Andalusian Sustainable Energy Plan 2007-2013 (PASENER) anticipated a reduction of 8% of the primary energy consumed and a reduction of 1% of the energy intensity in 2013 with respect to the 2006 situation.

This work has the objective of analysing the evolution of the energy intensity and the energy efficiency in Andalusia for the different economic sectors during the period 2003-2011, discussing the causes that influenced this evolution by means of the application of the Index Decomposition Analysis (IDA) method and the use of the Logarithmic Mean Divisia Index (LMDI) analysis technique following the methodology recommendations of Ang (2004) and Su and Ang (2012).

The present work extends the existing literature in the case of Spain, and of Andalusia in particular, in the following aspects. Firstly, IDA methodology is applied, by means of the LMDI technique, to the analysis of energy consumption and energy efficiency in Andalusia, a region in which this methodology has not been previously applied, thereby completing the existing literature by means of the use of a Social Accounting Matrix (SAM) (Cardenete et al., 2008, 2009, 2012). Secondly, the IDA method is applied to the analysis of the consumption of energy by the primary, services, residential, transport (private and non-private), energy and industrial sectors, which are further broken down into 11 subsectors. The application of this method to the final energy (FE) consumption of the transport sector was novel, because this sector does not have its own Gross Value Added (GVA) attributed, and the FE consumption of this sector must be calculated from its fuel consumption. Thirdly, the analysed period was 2003-2011, in order to discern the possible consequences of the energy saving and efficiency plans implemented in these years in Andalusia.

The work is divided into six sections. After the introduction, the methodology used is explained in detail in the second section. The data base used is described in the third section. The results appear in the fourth section. The fifth section gives a discussion of the results and finally, the sixth section presents the main conclusions.

2. Methodology

The LMDI decomposition approach was used for the analysis of the factors that have affected the evolution of energy consumption and intensity in Andalusia (2003-2011) in its different economic sectors, as recommended in the specialised literature (Ang, 2005, 2006; Su and Ang, 2012).

The seminal works of Ang (1995, 2004 and 2005) and Ang and Liu (2001) in this field have given rise to the development of multiple studies on the decomposition methods which are used in this paper. This technique has recently been applied in works that analyse the evolution of energy consumption and energy efficiency in different countries, such as: Australia (Sandu and Petchey, 2009); China (Ma and Stern, 2008; Liao et al., 2007 and Zhao et al., 2010); Greece (Hatzigeorgiou et al., 2011); Holland (Mulder and Groot, 2013); Lithuania (Balezentis et al., 2011); South Africa (Inglesi-Lotz and Pouris, 2012); Turkey (Ediger and Huvaz, 2006); and the OECD (Mulder and Groot, 2012). However, this same technique has been used for the analysis of the energy consumption and efficiency of some specific economic sectors, as in the following works: the industrial sector (Cahill and Gallachóir, 2010; Salta et al., 2009; Bhattacharyya and Ussanarassamee, 2005); the transport sector (Zhang et al., 2011; Sorrell et al., 2009); the residential sector (Rogan et al., 2012); the services sector (Mairet and Decellas, 2009); the electricity sector (Inglesi-Lotz and Blignaut, 2011); and, the domestic sector (Hojjati and Wade, 2012).

In the case of Spain, the LMDI method has been used for the analysis of the economic-energy structure, comparing the Spanish energy intensity with those of the countries of the EU by Mendiluce (2007), Marrero and Branch-Real (2008), Mendiluce et al. (2010) and Mendiluce (2012). Nevertheless, for the particular case of the evolution of energy intensity in Andalusia, multi-sectoral analysis has only been applied by means of social accounting matrices (SAMs) in Cardenete et al., (2008, 2009, 2012).

The LMDI method allows the energy consumption to be broken down into three factors relating to: the global economic activity; the structure of each economic sector; and the energy intensity or efficiency. The results can be shown in absolute (additive) and relative values (multiplicative).

Specifically, the additive form of the LMDI technique is the following:

$$\Delta E_{tot} = E^T - E^0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \quad [1]$$

$$\Delta E_{saving} = \Delta E_{str} + \Delta E_{int} \quad [2]$$

The different effects can be calculated in the following manner:

$$\Delta E_{act} = \sum_i w_i \ln\left(\frac{Q^T}{Q^0}\right) \quad [3]$$

$$\Delta E_{str} = \sum_i w_i \ln\left(\frac{S_i^T}{S_i^0}\right) \quad [4]$$

$$\Delta E_{int} = \sum_i w_i \ln\left(\frac{I_i^T}{I_i^0}\right) \quad [5]$$

$$w_i = (E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0) \quad [6]$$

Regarding the multiplicative decomposition

$$D_{tot} = \frac{E^T}{E^0} = D_{act} D_{str} D_{int} \quad [7]$$

$$D_{act} = exp\left(\sum_i w_i \, ln\left(\frac{Q^T}{Q^0}\right)\right) \quad [8]$$

$$D_{act} = exp\left(\sum_i w_i \, ln\left(\frac{Q^T}{Q^0}\right)\right) \quad [9]$$

$$D_{str} = exp\left(\sum_i w_i \, ln\left(\frac{I_i^T}{I_i^0}\right)\right) \quad [10]$$

$$w = \frac{(E_i^T - E_i^0)/(lnE_i^T - lnE_i^0)}{(E^T - E^0 \quad)/(lnE^T - lnE^0)} \quad [11]$$

The following variables need to be known for the analysis:

E: final energy consumed

E_i: final energy consumed in the sector i

Q: Total gross value added. Chained volume index reference 2008=100 (henceforth regional GVA)

Q_i: Gross value added of sector i. Chained volume index reference 2008=100 (henceforth sectoral GVA)

The following parameters can be determined from these variables:

S_i: relative weight of sector i on the total of activity (=Q_i/Q)

I: total energy intensity (=E/Q)

I_i: energy intensity of sector i (=E_i/Q_i)

These variables and parameters will be referred to the initial (0) and final period (T) of the study, making it possible to obtain the final energy variation [1]. The analysis allows the quantification of the impact of three factors: the activity effect (ΔE_{act}), the structural effect (ΔE_{str}) and the energy intensity effect (ΔE_{int}). The activity effect [3] refers to the changes of FE consumption due to the variations of the whole economy, measured in terms of the GVA. The structural effect [4] refers to the variation that the FE consumption undergoes due to the modification of the studied economic structure (different participation from each of the economic sectors and subsectors) during a period of time. Finally, the changes of the energy consumption associated with the evolution of the energy intensity of each of the sectors and subsectors, correspond with the intensity effect [5]. The data of ΔE_{int} is identified with the energy efficiency of the sector or subsector, given that it expresses the change produced in the FE consumption per produced unit. A positive value (negative) of the intensity effect will indicate a loss (gain) of energy efficiency.

The sum of the intensity and structural effects corresponds with the energy saving of the period [2], considering this as the improvement or decline of the energy efficiency and the variations of the FE consumption due to changes in the economic structure of the sectors, respectively.

The sectoral analysis of the FE consumption in its different components (activity, structural and intensity effects), is obtained from the following equations:

$$\Delta E_{act} = (\Delta E_{act})_{energ.} + (\Delta E_{act})_{prim.} + (\Delta E_{act})_{serv.} + (\Delta E_{act})_{indust} + (\Delta E_{act})_{residen} + (\Delta E_{act})_{transp} \qquad [12]$$

$$\Delta E_{str} = (\Delta E_{str})_{energ.} + (\Delta E_{str})_{prim.} + (\Delta E_{str})_{serv.} + (\Delta E_{str})_{transp.non-private} \qquad [13]$$

$$\Delta E_{int} = (\Delta E_{int})_{energ.} + (\Delta E_{int})_{prim.} + (\Delta E_{int})_{serv.} + (\Delta E_{int})_{indust} + (\Delta E_{int})_{residen} + (\Delta E_{int})_{transp} \qquad [14]$$

The application of this methodology to the case of Andalusia has required the following considerations:

To make a more detailed analysis of the evolution of the energy consumption and efficiency in the industrial sector in Andalusia, this sector was broken down into 11 subsectors, each of which was studied for its contribution to the activity, structural and intensity effects of the industrial sector derived from the IDA analysis by means of LMDI.

The private transport and residential (domestic) sectors do not have specific GVAs. The regional GVA is used for the calculation of their energy intensity, which is why it is not possible to obtain variations of the structure of these sectors (S_i is equal to one, and therefore its logarithm is zero, nullifying equation [4]).

By not having official statistics that break down the FE consumption of private (associated with the domestic-residential sector) and non-private transport, it has been necessary to adopt a methodology to establish the consumption of each type of transport. The methodology for the case of Spanish transport used by Mendiluce and Shipper (2011) and Monzón and Perez (2008) was adopted for this purpose. Specifically, the consumption of the transport sector was grouped into “private” (that made by people for their personal use) and “non-private” use (transport of passengers, goods, etc.). The latter corresponds with the “Transport and Storage” activity in the Annual Regional Accounts of Andalusia.

To analyse the energy efficiency of the transport sector (Mendiluce, 2010), the FE consumption corresponding to each type of transport within the associated economic sector or subsector (industrial, primary, etc.) were not added, but the relationship was established between the type of fuel used by each means of locomotion and the type of transport (public or private), as shown in Table 1.

Table 1

Relationship between fuels and use of transport.

Fuel Type	Vehicle Type	Use
Kerosene	Aircraft	Non-private
Petrol	Cars/motorcycles	Private
	Vans	Non-private
Diesel A	Cars	Private
	Taxis and others	Non-private
	Buses	Non-private
	Goods lorries	Non-private
	Vans	Non-private

Source: Authors' compilation.

As can be seen in Table 1, maritime and river transport are not taken into account, in accordance with European Union directives (EU, 2013).

The transport type data by province from the Directorate General for Traffic (DGT, 2013) and the report of the Observatory of the transport of goods by road (MF, 2013), provide data from which the distribution of fuel consumed is established, and which is shown in Table 2 (the biofuels are included in petrol and diesel as they are consumed in mixtures).

Table 2

Distribution of the fuel consumption in land transport.

Fuel	Transport Type	% Land Transport
Diesel C	Lorries and vans	44.4%
	Buses	3.3%
	Cars	31.4%
Petrol	Vans	1.4%
	Cars	19.3%
Natural gas	Buses	0.1%

Source: Authors' compilation from the data of the DGT (2013).

Considering transport overall, the total distribution of the fuel consumption by economic sectors is: 53% non-private and 47% private (domestic).

3. Data base

The data used, relative to the annual FE consumption (unit: kilo tonne of oil equivalent, ktoe), is published by the Andalusian Energy Agency (AAE, 2012). The data corresponding to the GVA are those published by the Institute of Statistics and Cartography of Andalusia (IECA, 2013). The series of data of the regional GVA at current prices and the chained volume indices correspond with those published in the Annual Regional Accounts of Andalusia current prices section, Series 1995-2011, base 2008. For the residential sector, the regional total GVA was used, discarding the use of the Gross Domestic Product (GDP), as this includes the net taxes on products and is not broken down by sectors.

In the industrial sector, only the FE consumption coming from energy uses has been attributed. In the energy transformation sector, the consumptions of the activity itself have been attributed and not the fuels (oil, coal, natural gas, etc.) used to produce the different types of energy (electricity, fuels, etc.).

Regarding the eleven industrial subsectors, it must be indicated that a data base of FE consumption does not exist, which is why it has been necessary to produce it from the FE consumption data from the Andalusian Energy Agency (AAE, 2012), and from the Ministry of Industry, Energy and Tourism (MIET, 2012). These data have been corrected taking into account the sectoral evolution and the generated GVA, in order to guarantee their suitable quality.

The period of study for the analysis of the economic sectors was 2003–2011, however, the period of study for the industrial subsectors was restricted to 2003–2010 as the data base used by the IECA (2013) does not offer data broken down into the industrial subsectors for 2011.

4. Results

The results obtained from the application of the LMDI decomposition method allow the identification of three factors or effects which explain the evolution of the FE consumption in Andalusia during the study period.

Table 3 shows the results obtained from the additive and multiplicative LMDI decomposition of the FE consumption in Andalusia between 2003 and 2011. The third and eighth columns show the variation of the consumption attributed to the activity effect; the fourth and ninth columns show that relating to the structural effect; the fifth and tenth columns to the intensity effect; the sixth and eleventh columns show the total net effect; and the seventh column shows the saving in energy consumption for the period in absolute values (ΔE_{ahorro}).

In the period 2003-2011, the FE consumption in Andalusia increased by 399 ktoe (3% of the FE consumption in 2003). The sectors that reduced their FE consumption were: industrial, by 678 ktoe (5%); private transport, by 32 ktoe (0.3%); and non-private transport, by 36 ktoe (0.3%). Conversely, the sectors in which the FE consumption increased were: energy transformation, by 451 ktoe (3.5%); services, by 204 ktoe (1.6%); primary, by 192 ktoe (1.5%); and residential, by 297 ktoe (2.3%).

Table 3

Additive and multiplicative decomposition of the final energy consumption in Andalusia between 2003 and 2011 (ktoe).

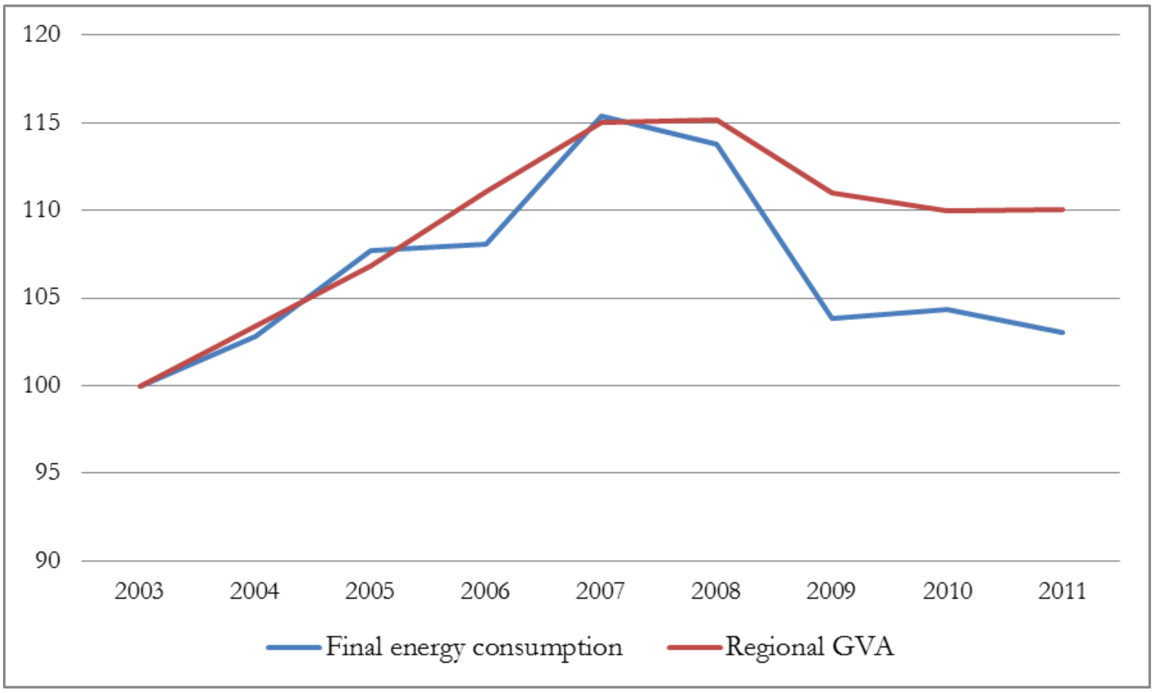
	FE Consumption 2003	**Additive Decomposition (ktoe)**					**Multiplicative Decomposition**			
	(ktoe)	**△E_act**	**△E_str**	**△E_int**	**△E Total**	**△E saving**	**D_ACT**	**D_STR**	**D_INT**	**D_TOTAL**
energy	**1315**	**152**	**- 45**	**345**	**451**	**299**	**1.012**	**0.997**	**1.026**	**1.035**
Services	1001	109	106	- 11	204	95	1.008	1.008	0.999	1.016
Primary	913	100	- 17	109	192	92	1.008	0.999	1.008	1.015
Non-private Transport	2581	254	- 507	216	- 36	- 290	1.019	0.963	1.016	0.997
Private Transport	2289	226	0	- 257	- 32	- 257	1.017	1.000	0.981	0.998
Residential	1597	173	0	124	297	124	1.013	1.000	1.009	1.023
Industrial	3420	304	- 720	- 263	- 678	- 982	1.023	0.947	0.981	0.950
TOTAL	**13115**	**1318**	**- 1182**	**263**	**399**	**- 919**	**1.104**	**0.915**	**1.020**	**1.030**

Source: Authors' compilation.

In the period 2003-2011, the regional GVA increased by 10.4%, changing from 119,780 M€ in 2003 to 132,274 M€ in 2011, giving rise to a strong growth of the FE consumption (Figure 1). As a result of this, the economic activity effect (**Δ E_act**) showed an increase in FE consumption of 1318 ktoe (10.4%) (Table 3). The private and non-private transport, and industrial sectors were among those which most contributed to the growth of the FE consumption due to the economic activity effect with 3.6% and 2.3%, respectively.

Figure 1

Regional final energy consumption and GVA (2003-2011).



Source: Authors' compilation from the AAE (2012) and IECA (2013).

The structural effect (**Δ E_str**), associated with the participation of each of the sectors in the Andalusian economy, shows a saving of FE of 1182 ktoe, equivalent to three times the increase in the FE consumption (Table 3). All the sectors contributed to this saving, except the private transport, residential and services sectors. The increase of FE consumption in the services sector due to the structural effect (106 ktoe) took place as a result of the important increase of its sectoral GVA in this period. Nevertheless, in the case of the private transport and residential sectors, the reason why the structural effect is null is because a GVA for these sectors does not exist, as was previously indicated in the methodology section.

Regarding the intensity effect (**Δ E_int**), that is, the indicator identified as a measure of the energy efficiency, it shows a positive total value (263 ktoe) in Table 3. This increase of FE consumption in the period represents a decline of 2% of the energy efficiency in the 2003-2011 period. However, the sectoral analysis of the energy intensity effect shows that the industrial, private transport and services sectors saw their energy intensity reduced with respect to the situation of 2003 by 2%, 2% and 0.1% respectively, generating a joint FE saving of 531 ktoe. Conversely, a reduction of efficiency in the rest of the economic sectors is observed: energy transformation (2.6%); primary (0.8%); non-private transport (1.6%); and residential (0.9%).

4.1. Interannual LMDI decomposition analysis of energy consumption in Andalusia 2003-2011

Table 4 displays the interannual evolution of the FE consumption in Andalusia, broken down into two sub-periods showing the variation in the total FE consumption. The first includes the period 2003 to 2007 and presents a positive variation in the FE consumption (2017 ktoe), and the second sub-period, from 2008 to 2011, presents a negative variation in the FE consumption of 1406 ktoe. To a large extent, these two sub-periods coincide with the application of the two energy plans approved by the government of Andalusia: the Andalusian Energy Plan 2003-2006 (CEDT, 2003); and the Andalusian Energy Sustainability Plan 2007-2013 (CICE, 2007).

The first of these periods (2003-2007) was characterised by an increase of 2017 ktoe of the FE consumed in the period. Contributing to this increase were the activity effect (1971 ktoe) due to the increase of the regional GVA by 15% and the intensity effect (648 ktoe), whereas the structural effect was reduced (- 603 ktoe) due to the smaller contribution to the regional GVA of the energy transformation, primary, non-private transport and industry sectors.

The second of the periods (2008 – 2011) was characterised by a reduction of 4.2% in the regional GVA and a reduction in the FE consumption of 1406 ktoe. This FE reduction was due to the activity (- 644 ktoe), structural (- 388 ktoe) and intensity (- 373 ktoe) effects, showing an improvement of the energy efficiency in this second period.

Table 4

Additive decomposition for each of the economic sectors of Andalusia in sub-periods 2003-2007 and 2008-2011 (ktoe).

	Consumption	**2003-2007**				**Consumption**	**2008-2011**			
	FE 2003	**ΔE_act**	**ΔE_str**	**ΔE_int**	**Δe Total**	**FE 2008**	**ΔE_act**	**ΔE_str**	**ΔE_int**	**ΔE Total**
ENERGY	1315	186	- 150	- 10	26	1274	- 69	- 8	569	492
SERVICE	1001	155	29	37	221	1291	- 57	75	- 104	- 86
PRIMARY	913	151	- 172	368	348	1119	- 51	159	- 122	- 14
TRANSP. NON-PRIV.	2581	392	- 283	348	457	2930	- 124	69	- 330	- 386
TRANSP. PRIVATE	2289	348	0	57	405	2599	- 110	0	- 232	- 342
RESIDENTIAL	1597	240	0	- 3	237	1895	- 86	0	85	- 1
INDUSTRY	3420	501	- 27	- 150	324	3811	- 148	- 684	- 238	- 1070
TOTAL	**13115**	**1971**	**- 603**	**648**	**2017**	**14919**	**- 644**	**- 388**	**- 373**	**- 1406**

Source: Authors' compilation.

Given the importance of the intensity effect, as a reference of the energy efficiency, its evolution was studied in both periods for each of the economic sectors (Table 4).

For the first period (2003-2007), the intensity effect indicates that three sectors increased their energy efficiency with respect to 2003: Industry (- 150 ktoe); energy transformation (- 10 ktoe); and residential (- 3 ktoe). The primary (368 ktoe) and non-private transport (348 ktoe) sectors stand out in terms of reduced efficiency. The services (37 ktoe) and private transport (57 ktoe) sectors also reduced their efficiency, but to a lesser extent.

In the period 2008-2011, all sectors improved their energy efficiency with respect to 2008, except for those of energy transformation and residential, which experienced an increase of FE consumption measured by the intensity effect of 569 and 85 ktoe respectively. The non-private and private transport sectors experienced a remarkable improvement of their energy efficiencies measured by a reduction of energy consumption due to the intensity effect of 330 and 232 ktoe respectively, followed by the industrial (- 238 ktoe), primary (- 122 ktoe), and services (- 104 ktoe) sectors.

4.2. LMDI decomposition analysis of the energy consumption of the industrial subsectors in Andalusia 2003 - 2010

Table 5 shows the evolution of the FE consumption of all the industrial subsectors in the period 2003-2010. All the subsectors reduced their FE consumption, obtaining a total reduction of 590 ktoe, which represents 17% of the FE consumed by the industrial sector in 2003. Nevertheless, the causes (economic activity, structure of the sector or energy intensity) are very different.

Applying the additive LMDI methodology, in relation to the activity effect (third column Table 5), an increase of 295 ktoe is observed in FE consumption in the set of subsectors. All the subsectors increased their consumption due to this effect, with the main contributing subsectors being: chemicals, 25%; non-metallic minerals, 23%; food, beverages and tobacco, 17%; metallurgy, 12%; and paper pulp and printing with 10%.

With respect to the structural effect (fourth column Table 5), that is, its participation in the GVA of the sector, a reduction of the FE consumption took place in the industrial sector of 620 ktoe, equivalent to 18% of the FE consumption in 2003. The subsectors that contributed more to this reduction were: chemicals; non-metallic minerals; and that of food, beverages and tobacco with 155, 145 and 102 ktoe respectively.

Regarding the intensity effect (fifth column Table 5), in the period 2003-2010 the industrial sector increased its energy efficiency due to a reduction in the FE consumption of 266 ktoe due to this effect. The chemical, non-metallic minerals, and food, beverages and tobacco subsectors are those which most contributed to this reduction with 67, 62 and 44 ktoe respectively.

Table 5

Additive decomposition of the energy consumption of the industrial subsectors in Andalusia for 2003 and 2010 (ktoe).

	FE Consumption 2003	**ΔE_act**	**ΔE_str**	**ΔE_int**	**ΔE Total**
Extractive	30	2	- 5	- 2	- 5
Food, beverages and tobacco	553	49	- 102	- 44	- 97

Textiles, leather and footwear	45	3	- 5	- 2	- 5
Pulp, paper and printing	302	29	- 62	- 27	- 59
Chemical	731	74	- 155	- 67	- 148
Non-Metallic Minerals	894	69	- 145	- 62	- 138
Metallurgy	471	35	- 73	- 31	- 69
Transformed metals	53	5	- 10	- 4	- 9
Transport equipment	112	6	- 14	- 6	- 13
Construction	49	5	- 10	- 4	- 9
Other industry	179	18	- 39	- 17	- 37
TOTAL	**3420**	**295**	**- 620**	**- 266**	**- 590**

Source: Authors' compilation

Finally, the interannual decomposition analysis of the FE consumption variation ratifies the results obtained for the whole period. As in the analysis of the set of sectors, two sub-periods, 2003-2007 and 2008-2010, are also seen in the industrial subsectors in Table 6. In the first period, an increase took place in FE consumption of 323 ktoe, explained by the increase of the FE consumption of the activity effect (499 ktoe), which was partially compensated by the intensity (- 149 ktoe) and structural (+27 ktoe) effects. Conversely, in the second period, the FE consumption was reduced (- 983 ktoe), basically from reductions due to the structural (548 ktoe), intensity (284 ktoe) and activity (151 ktoe) effects

The interannual evolution of the intensity effect by subsectors in Table 6 indicates that, in the period 2003-2007, the improvement of the energy efficiency of the industrial sector was due principally to the non-metallic mineral (- 41 ktoe), chemical (- 35 ktoe), food, beverages and tobacco (- 22 ktoe) and metallurgy (- 18 ktoe) sectors. The other sectors contributed to the reduction of FE consumption due to this effect by 33 ktoe. For the second of the sub-periods, 2008-2010, all the subsectors saw improvement in their energy efficiency. Specifically, the chemical (-77 ktoe), non-metallic minerals (- 64 ktoe) and food, beverages and tobacco (- 49 ktoe) sectors contributed 67% to the reduction of FE consumption due to the intensity effect in the period.

Table 6

Additive decomposition for each of the industrial subsectors of Andalusia in sub-periods 2003-2007 and 2008-2010 (ktoe).

	Consumption	2003-2007				Consumption	2008-2010			
	FE 2003	**Δ E_act**	**Δ E_str**	**Δ E_int**	**ΔE Total**	**FE 2008**	**Δ E_act**	**Δ E_str**	**Δ E_int**	**ΔE Total**
Extractive	30	4	0	- 1	3	22	- 1	- 4	- 2	- 7
Food, beverages and tobacco	553	74	- 4	- 22	48	671	- 26	- 94	- 49	- 169
Textiles, leather and footwear	45	4	0	- 1	3	19	- 1	- 3	- 1	- 5
Pulp, paper and impression	302	44	- 2	- 13	29	331	- 15	- 54	- 28	- 97
Chemicals	731	116	- 6	- 35	75	969	- 41	- 149	- 77	- 267
Non-Metallic Minerals	894	138	- 7	- 41	89	943	- 34	- 125	- 64	- 223
Metallurgy	471	60	- 3	- 18	39	401	- 15	- 56	- 29	- 100
Transformed metals	53	7	0	- 2	4	50, 6	- 2	- 8	- 4	- 14
Transport Equipment	112	13	- 1	- 4	8	51	- 2	- 7	- 4	- 13
Construction	49	11	- 1	- 3	7	138	- 4	- 14	- 7	- 25
Other industry	179	26	- 1	- 8	17	215	- 10	- 35	- 18	- 63
TOTAL	**3420**	**499**	**- 27**	**- 149**	**323**	**3811**	**- 151**	**- 548**	**- 284**	**- 983**

Source: Authors' compilation.

5. Discussion

The results obtained from the application of the LMDI decomposition method allowed the identification of three factors or effects which explain the evolution of the FE consumption in Andalusia in the period 2003-2011: the activity, structural and intensity factors. In the studied period, an increase in FE consumption of approximately 400 ktoe took place. This variation in the FE consumption was broken down into three components. The activity effect caused an increase in the FE consumption in the period of 1318 ktoe due to the increase of the regional GVA, experiencing an increase of 10.4% with respect to 2003. Conversely, the structural effect displayed a reduction in the FE consumption of - 1182 ktoe, which represents a reduction of 8.5% with respect to the 2003 data. Finally, the FE consumption increased by 263 ktoe, due to the intensity effect, involving a loss of efficiency of 2% with respect to 2003.

This last datum calls attention. When analysing the energy efficiency of a sector, the rate of variation of the total energy intensity (I_i) is usually used as an indicator that measures the relative change in FE consumption per unit produced in a period. If this indicator is calculated for the period 2003-2011 in Andalusia, it shows that the FE consumption per produced unit was reduced by 6.7%. This result would indicate that the region of Andalusia gained in efficiency. However, when this data is compared with that obtained from the LMDI decomposition analysis, it shows that a reduction of efficiency of 2% took place.

The apparent contradiction of these results by the fact that the rate of variation of the total energy intensity in the first case shows the variations in the FE consumption per produced unit, including the changes produced by variations in the GVA and the relative weight of each sector in the total. As a result of this, the rate of variation of the energy intensity (I_i) should not be used as an indicator of the energy efficiency, as factors related to the changes in the structural effect, which have not been discounted, have an influence on the calculation of the energy intensity.

Focusing on the analysis of the energy efficiency, in the period 2003-2011, it is observed that the industrial, private transport and services sectors experienced an improvement of efficiency. However, the energy transformation, primary, non-private transport and residential sectors, experienced a decline.

However, the trajectory of each sector is very different. If distinction is made between both analysed sub-periods, 2003-2007 and 2008-2011, the evolution is the following:

The industrial sector displayed a very positive evolution with improvements of efficiency in both sub-periods, and therefore had efficiency gains in the period 2003-2011 (1.9%).

The private transport and services sectors, experienced an improvement of efficiency in the period 2003-2011 (1.9% and 0.1% respectively) due to the improvement of the intensity effect in the second sub-period, partially compensating for the decline experienced in the first sub-period.

The energy transformation sector experienced an improvement of efficiency in the first sub-period, but this was counteracted by the increase of the FE consumption of the second sub-period, causing a decline in the efficiency of the sector in the period 2003-2011 (2.6%).

In the primary sector, although it presented an improvement of efficiency in the second sub-period, this did not compensate for the decline of the first period, which translated into a loss of efficiency of this sector in the period 2003-2011 (0.8%).

The non-private transport sector presented a decline in efficiency in the period 2003-2011 (1.6%), a result of the loss of efficiency experienced in the first sub-period that was not compensated by the slight gain of efficiency in the second sub-period.

The residential sector presented a decline in efficiency in the period 2003-2011 (0.9%), a result of the loss of efficiency experienced in the second sub-period that was not compensated overall by the improvement experienced in the first sub-period.

The LMDI method has been applied to the study of the energy intensity in Spain in various works (Mendiluce et al. (2010) and Mendiluce (2012). These works apply decomposition analysis to the consumption of primary energy for Spain, and the results obtained for period 2003-2011 show a reduction of the energy intensity of 15%. This data is considerably greater than that collected in our work for Andalusia (2%). However, in the case of the calculations made for Andalusia, the evolution of the FE consumption was considered. Also, it can be seen that there is a difference in that in Mendiluce (2010, 2012), the improvement due to energy efficiency in Spain took place from 2005, whereas in Andalusia, this turnaround took place from 2008.

In the case of Spain, the sectors that had the most remarkably influence on the improvement of energy efficiency were the electrical (energy intensity reduction of 44%), followed of non-private transport (22%) and industry (19%). In Andalusia, the sectors which most reduced their FE consumption were industry (1.9%) and non-private transport (1.6%). In our case it was not possible to break down the data of the electrical subsector from that of energy transformation, which is why it was not possible to compare these results.

6. Conclusions

Energy saving and efficiency improvement policies are the main ally in the attempt to fulfil the European, and world-wide, objective of reducing CO_2 emissions, in addition to greatly contributing to reducing the energy dependency of countries that do not have fossil energy resources. In turn, the start-up of actions related to energy saving and efficiency supposes the appearance of new enterprise opportunities, the energy services companies being an example, thereby leading to the creation of employment and wealth.

Establishing an ambitious policy in the field of energy, needs the appropriate mechanisms for its continuous monitoring and evaluation, which allows the reorientation of the policy to obtain its maximum effectiveness and efficiency.

The LMDI decomposition analysis of the final energy consumption for the period 2003-2011 in Andalusia, allows us to conclude the following:

Firstly, an increase of FE consumption of 3.0% took place during the period 2003-2011 in Andalusia, with 83.4% attributable to the economic growth experienced (an increase of 10.4% in regional GVA), and 16.6% attributable to the reduction of energy efficiency.

Secondly, from the point of view of the structural effect, an effective FE saving took place equivalent to 8.5% of that consumed in 2003. The industrial sector contributed to this saving by 5.3%, non-private transport by 3.7%, energy transformation by 0.3% and primary by 0.1%. The services sector was the only sector that increased its FE consumption, by 0.8%.

Thirdly, in relation to energy efficiency, in the period 2003-2011, the industrial and private transport sectors improved by 1.9% and 1.9% respectively, and the services sector by 0.1%. Conversely, the other sectors reduced their energy efficiency: energy transformation (2.6%), non-private transport (1.6%), primary (0.8%) and residential (0.9%).

Fourthly, regarding the 11 subsectors into which the industrial sector was divided, in the period 2003-2010 all of them improved their energy efficiency, with the chemical, non-metallic minerals and food, beverages and tobacco sectors contributing most.

Fifthly, the interannual analysis determined that FE consumption increased by 2017 ktoe in the sub-period 2003-2007, and reduced by -1406 ktoe in the sub-period 2008–2011. In this second period, the reduction in FE consumption due to the activity effect was -644 ktoe, whereas the structural and intensity effects reduced FE consumption by -388 and -373 ktoe respectively. This period was characterised by a recession of the Andalusian economy (a reduction of 4.2% in the GVA), and a significant improvement of energy efficiency. The analysis carried out shows that all the productive sectors improved their energy efficiency with the exceptions of the energy transformation and residential sectors, which experienced increases of FE consumption due to the intensity effect of 569 and 85 ktoe respectively. The sectors that most improved their efficiency were those of non-private transport (- 330 ktoe), industrial (- 238 ktoe), private transport (- 232 ktoe) and primary (- 122 ktoe).

Sixthly, both sub-periods, 2003-2007 and 2008-2011, coincide, to a great extent, with the execution of both of the energy plans approved by the government of Andalusia (CEDT, 2003) (CICE, 2007). The Andalusian Energy Plan 2003-2006 (PLEAN)

(CEDT, 2003) established a saving of 4% of the primary energy on the 2006 consumption trend. Also, the Andalusian Energy Sustainability Plan 2007-2013 (PASENER) (CICE, 2007) set an objective for 2013, of a reduction of 8% of primary energy consumed with respect to that of 2006 and a reduction of 1% of the energy intensity with respect to that of 2006. Although both plans set their objectives in terms of primary energy consumption, and our work analyses the evolution of FE consumption, some conclusions can be established.

In the first sub-period, 2003-2007, an increase of FE consumption took place, basically explained by the activity and energy intensity effects. That is, an increase of the FE consumption took place as a result of both the increase of the GVA, and the loss of efficiency in this period. This analysis shows that the implementation of the PLEAN did not obtain any saving in FE consumption in this period.

In the second sub-period, 2008-2011, the results show a reduction of FE consumption of -1406 ktoe. This data results from the reduction of FE consumption due to the activity, structural and intensity effects. Therefore, a reduction of FE consumption of -373 ktoe can be attributed to the intensity effect, thanks to the good behaviour of the private and non-private transport, industrial, primary and services sectors. Thus, with PASENER being the main energy saving policy for Andalusia in this period, we can intuit the possible repercussion of these political measures on the gain of efficiency of this region and its main sectors.

In later revisions of the present analysis, it would be interesting to analyse a breakdown of the energy transformation sector, thereby obtaining information on its different subsectors (natural gas, coal, electricity, oil) as in the works of Cardenete et al. (2008; 2009; 2012) and Mendiluce (2012).

In the coming years, a decisive factor in increasing the success of the energy policies will be the extension and improvement of the sustainable saving culture among the population. This question is of vital importance in Andalusia due to the low energy efficiency displayed by the domestic sector (residential), which is responsible for good part of the FE consumption. Therefore, it is considered necessary to promote a greater presence in the public and private communication media, of the messages related to saving and good use of energy, to the use of high efficiency domestic electrical goods and lighting and the possibilities offered by renewable energies for the production of hot water and air conditioning in the home. It is also necessary to increase, in regulated primary and secondary education, curricular contents related to the use of energy, efficient technologies and energy resources with lower environmental impact, as well as the knowledge of the native energy resources.

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