Energy efficiency's key role in explaining the performance of energy consumption in Andalusia (Spain)

Rocío Román-Collado[a,b*] and María José Colinet Carmona[a,c]

[a] Universidad de Sevilla (Spain).

[b] Universidad Autónoma de Chile (Chile).

[c] Agencia Andaluza de la Energía (Spain)

*corresponding autor

Contact details:

Email: rroman@us.es

Address:
Facultad de Ciencias Económicas y Empresariales. Departamento de Análisis Económico y Economía Política.
Avda. Ramón y Cajal, 1.
41018 Sevilla.
Tel.: +34 954557522

Abstract

The EU commitment to improve energy efficiency will help the EU economies to reduce energy consumption and achieve the desired decoupling between economic and energy consumption growth. For that aim, not only are the member states' commitments important, the role that the European regions adopt when they develop their own energy policies is also paramount. Among them, the Andalusia region (south of Spain) has been chosen as a case study due to its economic and energy characteristics. This paper aims to inform about the role played by energy efficiency, explaining the energy consumption behaviour in Andalusia and in comparison with the Spanish average for the period 2000-2015, through the Logarithmic Mean Divisia Index (LMDI) decomposition method.

Key words

Energy efficiency; energy decoupling; European decarbonisation; LMDI; energy policy; European regions.

1. Introduction.

The aim of the decarbonisation of the European economy in 2050 according to the Paris Agreements (United Nations, 2015) has led the European Union (EU) to focus on the importance of reducing energy consumption besides Green House Gas (GHG) emissions. The EU has set objectives for these aims in the medium and long term in order to guarantee final decarbonisation in 2050. These objectives are a reduction of 20% in GHG and energy consumption in 2020 (European Commission, 2010) and 40% in GHG and 32.5% in energy consumption in 2030 (European Commission, 2014).

Recently, with the publication of the European Green Pact (European Commission, 2019a), the European Union has assumed the commitment to achieve a neutrality of GHG emissions by 2050, establishing as pillars to achieve this situation the reduction of energy consumption by increasing energy efficiency and the modal changes that bring about a change of habits in the use of energy, as well as a drastic reduction in the use of fossil fuels and a determined commitment to improve renewable energy.

To reduce energy consumption, the EU has opted for improvements in energy efficiency. In particular, the EU has put into place concrete measures to increase the energy efficiency of different economic sectors and citizens (National Energy Efficiency Fund, Energy Efficiency Obligations System, etc.). The commitment to improve energy efficiency additionally expected the EU economies to achieve the desired decoupling between economic and energy consumption growth, allowing these economies to continue growing and developing without moving away from the decarbonisation objective of 2050 (Economidou & Román-Collado, 2019).

The balance of achievements of European policy for the period 2005-2016 has determined that the final reduction of energy consumption is due to a reduction in energy intensity that has been partially offset by an increase in energy consumption because of the economic growth of the period (European Commission, 2019b). Concretely, there are numerous factors which can contribute to a reduction of the energy intensity, such as aspects related with the sectoral economic structure, living standards, productivity and technological development, which also have an effect on the degree of energy decoupling (Mureau & Vuille, 2018).

Yet, to achieve energy decoupling in the EU, not only are the member states' commitments important, the role that the European regions adopt is also paramount, as they develop their own energy policies as well, thus contributing to the EU's global objectives through the Committee of the Regions (European Union, 2018). Among the member states, the case of Spain stands out, as it is made up of 17 autonomous regions with competences to develop their own policies of driving their economies and of improving their energy efficiency and environment. Andalusia is one of the largest Autonomous Communities in Spain, having 17% of the country's territory and 18% of its population (INE, 2015). It is highly vulnerable to global warming because it belongs to the Mediterranean area where the temperature increases are expected to be higher than the European average, putting pressure on the future energy consumption demand (PNACC, 2006, European Environment Agency, 2017). On the other hand, with 14% of the total Spanish energy consumption, Andalusia has a higher energy intensity (5.9%) than the Spanish economy (5.1%) (AAE, 2015), though some energy efficiency plans have been implemented in the last decades. The main financial source of Andalusia's energy policy has been through the EU ERDF funds.

The Andalusian energy policy is linked to the EU objectives and is established following the different ERDF financing frameworks, such as the Andalusian Energy Plan (PLEAN) 2003-2006, the Andalusian Energy Sustainability Plan (PASENER) 2007-2013 and the Energy Strategy of Andalusia (ESA) 2014-2020. The aim of the Andalusian Energy Plan 2003-2006 (PLEAN) (CEDT, 2003) and the Andalusian Sustainable Energy Plan 2007-2013 (PASENER) (CICE, 2007a) was to promote the production and use of renewable sources (solar, wind, biomass etc.) and encourage measures to promote energy efficiency. Also, Andalusia has had the financing of the Spanish General Administration, which in the period analysed, and until 2010, comes from the national budgets assigned to the Renewable Energy Plan (Spanish Ministry of Industry, 2005) and the Energy Savings and Efficiency Strategy (Spanish Ministry of Industry, 2007). The main measures to promote energy efficiency have been subsidies for projects that implement more efficient technologies and renewable energy in industries, buildings, lighting, services, agriculture and transport services.

With these previous considerations, the aim of this paper is to analyse the explanatory role of energy efficiency in the energy consumption changes that have occurred in Andalusia, taking into consideration its social, economic and energy characteristics, as well as the differences in energy consumption between Andalusia and the Spanish average between 2000 and 2015. In view of the results, some energy policy recommendations will be provided on how the energy efficiency measures implemented in Andalusia have contributed to Spain's and the EU's energy targets.

The paper is structured in five sections. After this introduction, the second section presents the revision of the literature research. The methodology is explained in the third section. The fourth section indicates the database used. In the fifth section the results achieved are displayed. The sixth section summarises the main discussion points. The seventh section concludes and provides some energy policy recommendations.

2. Literature review.

To better capture the role played by energy efficiency in the energy consumption changes in Andalusia, the Logarithmic Mean Divisia Index (LMDI) decomposition method, based on the advantages highlighted by the previous specialised literature, such as Ang (1995; 2004; 2005), Ang and Liu (2001), Ang et al. (2010) and Ang (2015), has been applied under three perspectives.

Firstly, a temporal LMDI decomposition and a decoupling analysis have been applied to the energy consumption changes in Andalusia in order to inform about the role played by energy efficiency in the energy decoupling values of Andalusia, differentiating the results by sectors and energy sources. Our approach had been previously introduced by Diakoulaki and Mandaraka, (2007) and made widely known by the previous research literature, contributing to supplement the results coming from temporal LMDI decomposition analysis (Zhang & Da, 2015; Roinioti & Koroneo, 2017; Román-Collado et al., 2018; Engo, 2018; Bai et al., 2019; Cansino et al., 2019). Considering this region's low GDP per capita and high unemployment rate in comparison to the Spanish average, the results of this analysis will shed light on the relative importance that energy efficiency and economic growth have on this region's energy consumption changes. Energy intensity is also an inhibiting factor for greenhouse gas emissions from energy consumption, along with the energy carbonisation factor (Fatima et al., 2019).

Secondly, a spatial-temporal LMDI-I decomposition analysis is applied to the differences between the energy consumption in Andalusia and the Spanish average in order to analyse to what extent energy efficiency has driven these differences over the timespan considered. The spatial decomposition analysis is useful in comparing differences in energy consumption and emissions between regions within a country, not only in one year (SP-IDA) (Ang et al., 2015;

Román-Collado & Morales, 2018) but also, as Ang et al. (2016) suggest, during a period (ST-IDA), such as (Li et al., 2017; Chen et al., 2019; Shi et al. 2019). Therefore, the spatial temporal (ST) IDA analysis will let us study how the gaps between Andalusia and the average of Spanish regions have changed during a period and how energy efficiency has driven these changes.

And thirdly, the traditional factors considered for energy consumption analysis are the energy intensity effect, the structural effect and the activity effect. The energy intensity effect, calculated as the relation between energy consumption and the GVA (IEA, 2016) is the usual indicator for measuring the energy intensity from a monetary point of view (Proskuryakova & Kovalev, 2015). However, Patterson (1996) points out that this indicator can be affected by other factors, such as the market, labour or others linked to the economic activity and economic production as a consequence of using the GVA as an indicator of the activity. For this reason, Patterson (1996) suggests using a physical unit as a proxy of the economic activity instead of the GVA and, therefore, defining a physical energy intensity indicator. In order to test the differences that arise when these two approaches are used, the traditional final energy consumption decomposition using a monetary energy intensity effect is supplemented with a second decomposition using a physical energy intensity effect. A physical unit has been previously used in the decomposition analysis of energy consumption changes based on the LMDI approach, such as Ang et al. (2010), Cahill and Ó Gallachóir (2012), Xu (2013), Xu and Ang (2014) and Ang (2015). With this latter approach, the efficiency effect - that is, the rate at which the energy use per unit of physical production has changed - provides a better indicator of true energy efficiency improvements as it is cleansed of price effects (Román-Collado & Colinet, 2018b). Considering the special characteristics of Andalusia in terms of labour productivity and unemployment, the physical unit chosen has been the number of hours worked (labour).

The previous research literature has chosen Andalusia as a case study for analysing energy intensity (Cardenete et al. 2008, 2009 and 2012), the impact of some energy technologies on its economy (Cansino et al., 2013 and Cansino et al., 2014) and the main drivers of energy consumption changes (Colinet & Román, 2016). This paper contributes to the research literature as follows. Firstly, the traditional temporal decomposition of energy consumption changes in Andalusia is supplemented with a second step in the decomposition, analysing the key drivers of the energy decoupling. Secondly, to the best of our knowledge, this is the first time that a spatial-temporal decomposition analysis has been applied to the energy consumption differences between Andalusia and the average of Spanish regions, contributing to identifying the role played by the sole characteristics of the Andalusian economy. And, thirdly, the explanatory role played by the workforce in the energy consumption changes in the past, used as a physical indicator instead of a monetary energy intensity indicator is also tested for this region.

3. Methodology.

3.1 Drivers of the decoupling process based on the LMDI approach.

The main aim of this section is to analyse the driving effects that lead to the change of energy consumption in Andalusia and the decoupling progress between the output and the energy consumption growth.

Firstly, the energy consumption from productive sectors *E* is decomposed in equation (1):

$$E = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} \frac{E_i}{Q_i} \cdot \frac{Q_i}{Q} \cdot Q = \sum_{i=1}^{n} I_i \cdot S_i \cdot Q = I \cdot S \cdot Q \qquad (1)$$

E_i being the final energy consumption by productive sectors (*i=1…n*), Q_i the gross value added (GVA) produced by each productive sector and Q the total GVA. Therefore, the total energy consumption of productive sectors is decomposed into three factors: I the energy intensity, S the structural and Q the activity factors.

By applying the additive Logarithmic Mean Divisia Index (LMDI-I) as the specialised literature recommends (Ang et al., 2010; Ang, 2015), the change in the final energy consumption between period *0* and *T* is defined in equation (2) as follows:

$$\Delta E = E^{T} - E^{0} = \Delta I + \Delta S + \Delta Q \qquad (2)$$

The energy consumption change is decomposed into three effects that are the intensity (ΔI), the structural (ΔS) and the activity (ΔQ) effects. The calculation of these effects, following the LMDI-I approach, as was recommended by Ang (2015), is presented in Annex A (eqs. A1-A4).

This same methodology has been applied to analyse the energy consumption changes by each *k* energy source (*k=1…m*): carbon, oil, natural gas, nuclear and renewable energies.

$$E = \sum_{i=1}^{n} E_{i,k} = \sum_{i=1}^{n}\sum_{k=1}^{m} \frac{E_{i,k}}{Q_{i,k}} \cdot \frac{Q_{i,k}}{Q_k} \cdot Q_k = \sum_{i=1}^{n}\sum_{k=1}^{m} I_{i,k} \cdot S_{i,k} \cdot Q_k = I \cdot S \cdot Q \qquad (3)$$

The calculation of these effects following the LMDI-I methodology, as was recommended by Ang (2015), can be seen in Annex A (eqs A5-A8).

Secondly, to analyse the energy decoupling process of the Andalusian region during the period 2000-2015 a decoupling index based on the LMDI decomposition analysis is proposed following the research literature (Diakoulaki & Mandaraka, 2007, Zhang & Da, 2015; Roinioti & Koroneo, 2017; Román-Collado et al., 2018). This decoupling index enables us to assess the degree of dissociation between economic growth and energy consumption from a base year 0 to year t.

Let us define the energy efficiency measures' (ΔEE_t) effect as the energy efficiency measures undertaken in Andalusia during the period analysed. Accordingly, this effect only shows the energy consumption changes attributed to the structural and intensity effects, excluding those caused by the activity effect. Similarly to Wang & Jiang (2016), reordering equation (2), the ΔEE_t effect for each period *t=1…h* is defined as follows:

$$\Delta EE_t = \Delta E - \Delta Q = \Delta S + \Delta I \qquad (4)$$

If ΔEE_t is negative, that means that the sum of the structural and intensity effects is negative and, therefore, the efficiency measures have been effective. But if ΔEE_t is positive this means that the efficiency measures have not been effective, the sum of the structural and intensity effects being positive.

When $\Delta Q \geq 0$, in order to assess the degree to which the efforts mentioned above are effective in terms of decoupling the economic growth from energy consumption changes, a decoupling index μ_t, is calculated as follows:

$$\mu_t = -\frac{\Delta EE_t}{\Delta Q} = -\left(\frac{\Delta E}{\Delta Q} - \frac{\Delta Q}{\Delta Q}\right) = -\left(\frac{\Delta S}{\Delta Q} + \frac{\Delta I}{\Delta Q}\right) = \mu_{str} + \mu_{\text{int}} \qquad (5)$$

Here, as the energy efficiency measures will be effective, it is expected that the sum of the structural and intensity effects will be negative and therefore the index μ_t will display positive values.

Also, unlike what was suggested by the seminal paper on this decoupling index (Diakoulaki & Mandaraka, 2007), this paper provides a different equation in the case of $\Delta Q < 0$, as follows:

$$\mu_t = \frac{\Delta EE_t}{\Delta Q} = \frac{\Delta E}{\Delta Q} - \frac{\Delta Q}{\Delta Q} = \frac{\Delta S}{\Delta Q} + \frac{\Delta I}{\Delta Q} = \mu_{str} + \mu_{\text{int}} \qquad (6)$$

Here, it can be deduced that if the economic growth promotes the energy consumption reduction, the decoupling index is thus determined by the additional efforts towards reducing energy consumption in excess of the reduction caused by the negative economic activity effect. As the energy efficiency measures would be effective, the sum of the structural and the intensity effects would surpass the energy consumption reduction of the economic activity and the decoupling index μ_t will offer positive values.

As is indicated, besides the total decoupling index μ_t, both equations (5) and (6) enable us to calculate the decoupling indices derived from the different effects: μ_{str} (structural decoupling index) and μ_{int} (energy intensity decoupling index).

The values of the decoupling indices can be understood as follows. When energy policy efforts have been effective, the decoupling index will provide positive values, using either equation (5) or (6). If the index value is $\mu_t \geq 1$, this denotes strong decoupling efforts; that is, the ΔEE_t effect is more significant than the activity effect. If the decoupling index is between $0 < \mu_t < 1$, this denotes weak decoupling efforts; that is, the ΔEE_t effect is weaker than the activity effect. When efforts carried out are not effective, the decoupling index will provide negative values showing that there have been no decoupling efforts (Diakoulaki & Mandaraka, 2007; Wang & Jiang, 2016).

3.2 Spatial and spatial-temporal IDA of energy consumption differences between Andalusia and Spain.

The spatial (SP) IDA model supplements the temporal monetary IDA approach since it lets us analyse the effects that contribute to performance gaps among regions (Ang et al., 2015). Concretely, Andalusia is going to be compared with the average of Spanish regions. Additionally, the spatial-temporal (ST) IDA has also been applied as it goes a step further than the previous one because it enables an analysis of changes in regional disparities over time (Ang et al., 2016). This analysis has been developed using the same reference region for the whole period instead of changing the reference region as usually happens in a static spatial analysis (Bartoletto & Rubio, 2008; Gingrich et al., 2011; Román-Collado & Morales, 2018).

Following Ang et al. (2016), the spatial models are classified into bilateral-region (B-R), radial-region (R-R) and multiregional-region (M-R). In the B-R model, each pair of regions in a group is compared, but this is difficult to implement when the number of regions is large. As a result of this, the alternative models R-R and M-R overcome this difficulty. In the R-R model each region is compared with a reference region and in the M-R model, after each region comparison with the reference region (direct comparison), two regions are compared (indirect comparison).

This paper follows the R-R model in order to compare Andalusia with the reference region. At this stage, no further comparisons have been carried out for the rest of the Spanish regions, but this might contribute to a future analysis. Therefore, a reference region has to be chosen. In this paper, a strategy B-1 is followed, as Ang et al. (2016) recommend.

The ST-IDA model implemented is based on equation (1), which is defined as the final energy consumption for the productive sectors (*i=1…n*) of Andalusia (named Region 1). Now, a reference region to be compared with has to be defined following strategy B-1 (Ang et al., 2016). The arithmetic average of the *R* regions of Spain (*R* is equal to the 17 Spanish autonomous regions) in all the years analysed is chosen in order to present a neutral and fair picture of the reference region performance. Following this approach, the energy consumption of the reference region (R_μ) is decomposed similarly to equation (1):

$$E^{R\mu} = \sum_{i=1}^{n} E_i^{R\mu} = \sum_{i=1}^{n} \frac{E_i^{R\mu}}{Q_i^{R\mu}} \cdot \frac{Q_i^{R\mu}}{Q^{R\mu}} \cdot Q^{R\mu} = \sum_{i=1}^{n} I_i^{R\mu} \cdot S^{R\mu} \cdot Q^{R\mu} = I^{R\mu} \cdot S^{R\mu} \cdot Q^{R\mu} \tag{7}$$

$E_i^{R\mu}$ being the average energy consumption of sector i (*i=1…n*) for all regions during the period analysed (*t=1…h*), $Q_i^{R\mu}$ is the average of the gross value added of each sector i (*i=1…n*) for all the regions during the period analysed (*t=1…h*), and $Q^{R\mu}$ is the average of the total production of productive sectors for *R* regions during the period analysed (*t=1…h*).

Taking Andalusia as region *1* (R_1) and the reference region (R_μ) as the average of Spanish regions for the period analysed (*t=1…h*), the direct comparison of Andalusia and the reference region for year 0 is as follows:

$$E^{R1,0} - E^{R\mu} = \Delta I^{R1,0-R\mu} + \Delta S^{R1,0-R\mu} + \Delta Q^{R1,0-R\mu} \tag{8}$$

Where $\Delta I^{R1,0-R\mu}$ $\Delta S^{R1,0-R\mu}$ and $\Delta Q^{R1,0-R\mu}$ represent the intensity, structural and activity effects. These effects indicate the contributions to the overall difference in aggregate energy consumption arising from the differences between region 1 and the reference region in intensity, structural and activity effects.

Additionally, the temporal change of Andalusia's (R_1) energy performance compared to the Spanish regions between the year *0* and *T* can be expressed as follows:

$$E^{R1,T} - E^{R1,0} = (E^{R1,T} - E^{R\mu}) - (E^{R1,0} - E^{R\mu}) \tag{9}$$

$$\Delta I^{R1,T-R1,0} = (\Delta I^{R1,T-R\mu}) - (\Delta I^{R1,0-R\mu}) \tag{10}$$

$$\Delta S^{R1,T-R1,0} = (\Delta S^{R1,T-R\mu}) - (\Delta S^{R1,0-R\mu}) \tag{11}$$

$$\Delta Q^{R1,T-R1,0} = (\Delta Q^{R1,T-R\mu}) - (\Delta Q^{R1,0-R\mu}) \tag{12}$$

The effects of the spatial-temporal decomposition (ST-IDA) are calculated based on Ang et al. (2016), following the additive LMDI-I method (the formulation can be seen in Annex B).

3.3 LMDI additive decomposition of energy consumption changes using the intensity refactorisation (IR) approach.

The two previous IDA models carried out for the analysis of the energy consumption changes in Andalusia consider three decomposition effects that are energy intensity, structural and activity. In the case of the energy intensity effect, the factor was defined as the energy consumption per unit of output produced, following a monetary approach.

There are alternative approaches for analysing energy efficiency trends (Ang et al., 2010). Ang and Xu (2013) analysed the two different approaches to incorporating physical activity indicators in energy studies: intensity refactorisation (IR) and activity revaluation (AR). The first technique relies on monetary values to measure economic activity, though including a preliminary refactorisation of the energy intensity indicator. The second incorporates only physical indicators for both energy intensity and output.

Our paper follows the IR approach and therefore combines physical indicators for energy intensity with monetary output data following Ang and Xu's (2013) proposal. The advantage of this approach is that the results can be compared with those coming from the monetary decomposition carried out in previous sections because, in the IR approach, the monetary intensity effect, that is, the energy consumption per unit of value added, is decomposed into two effects: a physical intensity effect and a materialisation effect. The final aim of this approach is twofold. First, this decomposition provides an alternative indicator of energy efficiency improvements through a physical intensity effect cleansed of price effects as the research literature suggests. Second, the materialisation effect quantifies the extent to which changes in prices of products have influenced the aggregate energy intensity of each productive sector (Ang et al., 2010; Cahill & Ó Gallachóir, 2012; Belzer, 2014). Therefore, the decomposition is carried out with four effects: the activity, structural, materialisation effects and the energy intensity in physical terms.

As is recommended by Román-Collado and Colinet (2018b), the hours of labour worked is a suitable physical unit to use, as it can be applied in all sectors, avoiding the disadvantage of choosing different physical units depending on the productive sector and it is also linked to the economic activity of the productive sectors. This indicator has been previously used in several papers related to the analysis of industrial energy consumption and labour productivity (Taylor, 2008, von Arnim & Rada, 2011, Camarero et al., 2015). It has also been recommended for the analysis of energy efficiency by some international organisations, such as the International Energy Agency (IEA, 2017) and the Sustainable Energy Authority of Ireland (SEAI, 2017).

Nonetheless, the main limitation of this approach occurs when the capital-labour intensity of the sectors increases during the period analysed. In those cases, this physical energy intensity based on the labour force does not properly display the energy efficiency gains of these sectors. To avoid this limitation, a previous analysis of the capital-labour intensity of sectors is recommended. In the case of Andalusia, during 2000-2015, the productive sectors reduced the capital/labour ratio around 30% due to an important growth of the labour force, with the exception of the primary sector, although this is a highly intensive labour force sector (IECA, 2015). Additionally, as Doménech et al. (2018) explain, the specific institutional configuration of the labour market in Spain, and also in Andalusia, has led this to be used as an adjustment mechanism, both in booms and in recessions (countercyclical changes in working hours). Therefore, since no labour substitution is identified during this period and as a consequence of the specific characteristics of the labour market in this economy, the labour force has been chosen as a physical reference variable linked with the economic activity.

So, the physical energy Intensity is defined as the energy use per unit of labour (L) (number of hours worked) and the dematerialisation effect is the inverse of labour productivity. This latter effect is particularly relevant in the case of Andalusia due to this ratio having changed significantly in this economy during the period analysed.

Another advantage of using the IR approach is that the results for Andalusia can be compared with those arising for the Spanish case (Román-Collado & Colinet, 2018b) and then can supplement the results coming from the spatial decomposition approach.

Following the IR approach, the energy consumption for all productive sectors (*i=1…n*) is now decomposed into four factors:

$$E=\sum_{i=1}^{n}E_i=\sum_{i=1}^{n}\frac{E_i}{L_i}\cdot\frac{L_i}{Q_i}\cdot\frac{Q_i}{Q}\cdot Q=\sum_{i=1}^{n}I_{Li}\cdot P_i\cdot S_i\cdot Q=I_L\cdot P\cdot S\cdot Q \qquad (13)$$

Where E_i is the energy consumption of sector *i* (*i=1…n*), L_i is the number of hours worked in sector *i* (*i=1…n*), Q_i is the gross value added of sector *i* (*i=1…n*) and Q is the total production of the productive sectors. Therefore, I_L is the physical energy intensity factor which is the energy use per unit of hour worked, P is the materialisation factor or, in this case, the inverse of the labour productivity factor, S is the structural factor and Q is the activity factor.

Applying the LMDI-I additive decomposition method as the specialised literature recommends (Ang et al., 2010; Ang, 2015), from equation (13), the variation of the consumption of energy in a period of time (*0,T*) is defined by the following expression:

$$\Delta E=E^T-E^0=\Delta I_L+\Delta P+\Delta S+\Delta Q \qquad (14)$$

Therefore, the change in energy consumption is decomposed into four effects that are: the physical energy intensity (ΔI_L), the inverse of labour productivity (ΔP), the structural (ΔS) and the activity (ΔQ) effects. The calculation of these effects, following the LMDI-I methodology as was recommended by Ang (2015), can be seen in Annex C.

4. Database.

For the Andalusian economy, the economic data (the regional GVA) comes from the Statistic and Cartography Institute of Andalusia (IECA, 2015). The regional and sectorial GVA data have used constant prices (base year 2010) calculated from the GVA at current prices and the chained-linked volume measures published by the Andalusian Annual Regional Accounts (IECA, 2015).

The energy consumption data comes from the Andalusian Energy Agency (AAE, 2004 and 2015). The energy consumption data does not include the non-energetic uses and therefore only includes the energy consumption data of the productive sectors and the self-consumption of the energy transformation sector. In the specific case of the transport sector, the energy consumption data come from the application of the methodology provided by Román-Collado and Colinet (2018a). Also, the physical unit chosen for calculating the physical energy intensity indicator has been the number of hours worked for each productive sector (INE, 2016).

For the ST-IDA approach, the data for the Spanish economy are considered. The Spanish GVA and the sectorial GVA at constant prices (base year 2010) are calculated from the GVA at current prices and the chained-linked volume measures published by the Spanish National Institute of Statistics (INE, 2015). The energy consumption data comes from the Spanish Energy Balance (MINETUR, 2015; IDAE, 2015).

All the variables are available for the period analysed: 2000-2015. The productive sectors considered in the three decomposition approaches are primary, industry, construction, transport and services. For the first decomposition, the Andalusian energy consumption has also been disaggregated by energy sources: coal, oil, natural gas, nuclear and renewable energies.

5. Results.

5.1 A LMDI-I monetary decomposition and a decoupling analysis (2000-2015).

The analysis of the energy consumption change for the whole period 2000-2015 lets us distinguish the decomposition effects by sub-periods as presented in Table 1. Globally, the energy consumption increased between 2000 and 2015, due to the activity effect, only partially compensated by the intensity and structural effects.

Table 1. Decomposition effects of energy consumption changes in Andalusia (2000-2015).

	2000-2008	**2008-2015**	**2000-2015**
Intensity effect	1,459	-1,588	-103
Structural effect	-1,470	238	-1,089
Activity effect	2,111	-603	1,339
Total	2,100	-1,953	147

Source: Own elaboration

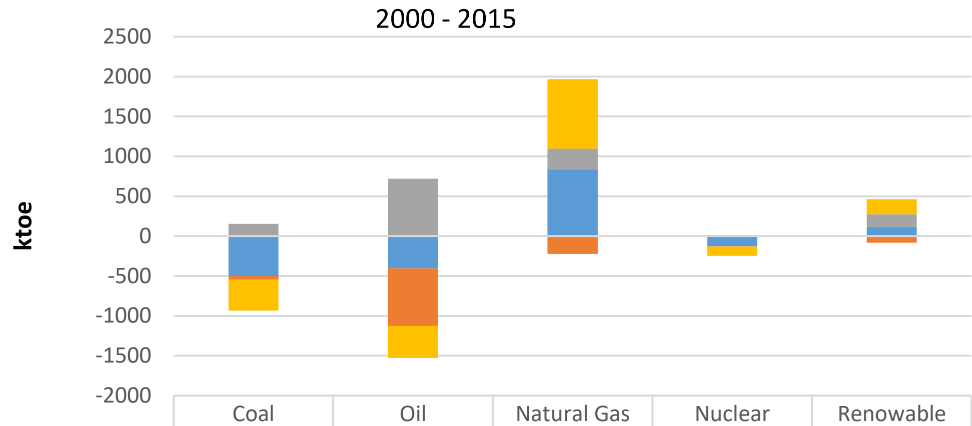
During the expansion period, 2000-2008, the energy consumption increased. The main drivers were the activity and the sectoral intensity effects that were partially compensated by the structural effect. The structural effect indicates that the more energy intensive sectors, such as industry and transport, reduced their relative weight in the total GVA. This result is corroborated by the official statistics data that reveal how the service and construction sectors increased their relative weight between 2000 and 2008 (2.8 and 1.6 percentage points, respectively), while the weights of the others were reduced. Similarly, during the recession period, the main inhibitor effects were the activity and the intensity. Again, these effects seem to be coupled with the economic activity and are partially compensated by the structural effect. In this sub-period, the structural effect increases energy consumption mainly due to the transport and services sectors, which increased their weight in the total GVA around 7.5 percentage points each compared with the reduction of construction and industry sectors by 7.4 and 0.5 percentage points, respectively (Table D1 in Annex D).

Related to the energy consumption change by energy sources, natural gas and renewable energies are the only ones that increase, mainly as a result of the intensity effect, while the others (coal, oil and nuclear energy) reduce their weight in the final energy consumption during the period 2000-2015. Additionally, the activity effect contributes to the increase of all energy sources and the structural effect reduces all energy sources except in the services sector, where it increases, indicating that the relative importance of this latter sector rises in the Andalusian economy (Figure 1).

The temporal decomposition effects by energy sources show that for the period 2000-2015 the energy consumption increased mainly due to natural gas and renewable energies, partially compensated by the other energy sources (coal, oil and nuclear). The explanatory effects for the diminishing of coal, oil and nuclear are the intensity and structural effects, while the increase in natural gas and renewable is driven by the intensity effect (Figure 1). During the sub-period 2000-2008, coal diminished considerably (-579 ktoe), through the intensity effect that acts as an inhibitor, mostly in the industry and services sectors. On the contrary, natural gas increases (2282 ktoe), specifically in these same sectors, because of the intensity effect representing a loss in energy efficiency. Additionally, the oil consumption change (485 ktoe) is driven by the activity effect -mainly in the transport and primary sectors- and is inhibited by the intensity effect in the industry sector and by the structural effect in the industry, primary and transport sectors. The renewable energies increased in the period analysed (26 ktoe), mainly driven by the activity effect, specifically in the industry sector (see Table D.1 in Annex D).

Related to the second sub-period, 2008-2015, the activity effect is an inhibitor of all energy sources. The diminishing of oil in the transport sector and natural gas in the industry sector is especially significant. On the other hand, the energy intensity effect also inhibits the oil and natural gas energy consumption in most sectors, significantly affecting oil in the transport and primary sectors and natural gas in the services and industry sectors (see Table D.1 in Annex D).

Figure 1. Decomposition effects by energy sources



	Coal	Oil	Natural Gas	Nuclear	Renowable
Total	-391	-404	871	-117	189
Activity effect	152	720	261	14	160
Structural effect	-43	-721	-225	-3	-85
Sectoral intensity effect	-501	-403	835	-128	113

Source: Own elaboration

The previous results make it possible for us to identify the main driver and inhibitor effects of energy consumption changes in Andalusia during the period analysed. Additionally, the efforts carried out in order to achieve a decoupling process are also considered, using the decoupling index suggested by Diakoulaki and Mandaraka (2007) for the period 2000-2015. The value of the total decoupling index shows a weak decoupling (0.89). Similar values, lower than 1.0, are indicated for the primary, construction and services sectors, although the industry sector presents a strong decoupling (Table 2).

During the sub-period 2000-2008, the decoupling index μ_t reveals no decoupling for most sectors except industry and transport, which offer a weak decoupling. During this expansion period, the Andalusian economy did not take advantage of the economic growth and did not accordingly reduce the energy consumption due to the intensity effect. Additionally, the structural decoupling index presents no decoupling for the construction and services sectors, considered to be essential for the economic growth of this region. On the other hand, during the second sub-period, when the recession took place, the energy consumption decreased and the decoupling index displays a strong decoupling. In this case, the decoupling index for all sectors also shows a strong decoupling (see Table 2). The intensity decoupling index indicates that the Andalusian economy made significant efforts to reduce energy consumption in addition to the activity effect. When the structural decoupling index is analysed this only happens in the industry and construction sectors.

Table 2. Decoupling indices by sectors

2000-2008				
	μ_{int}	μ_{str}	μ_t	
Industry	-0.35	0.62	0.26	WD
Construction	-2.79	-0.39	-3.18	ND
Services	-0.52	-0.17	-0.69	ND
Primary	-1.42	0.95	-0.47	ND
Transport	-0.86	1.08	0.22	WD
Total	-0.69	0.70	0.01	WD
2008-2015				
	μ_{int}	μ_{str}	μ_t	
Industry	2.19	0.63	2.83	SD
Construction	4.56	8.11	12.67	SD
Services	2.45	-1.43	1.02	SD
Primary	3.04	-0.77	2.28	SD
Transport	3.03	-1.30	1.73	SD
Total	2.63	-0.39	2.24	SD
2000-2015				
	μ_{int}	μ_{str}	μ_t	
Industry	0.37	1.11	1.48	SD
Construction	-2.09	2.65	0.56	WD
Services	0.24	-0.80	-0.56	ND

Primary	-0.77	1.02	0.24	WD
Transport	-0.01	1.00	0.99	WD
Total	0.08	0.81	0.89	WD

Source: Own elaboration

The efforts for the decoupling process can be also analysed differentiating by energy sources. The total decoupling index for the period 2000-2015 shows a strong decoupling for the coal, oil and nuclear energy sources, considering that they are linked to the industry sector. Additionally, for the first sub-period, coal and nuclear exhibit a strong decoupling value while natural gas presents no decoupling. Also, although the Andalusian economy is very dependent on oil, the decoupling index indicates that there is a weak decoupling for the oil source, besides renewable sources, as the total consumption did not largely change during the period analysed. Nevertheless, in the second sub-period, coal, nuclear and renewable energy sources reveal no decoupling, except natural gas and oil that have a strong decoupling (see Table 3).

Table 3. Decoupling indices by energy sources

2000-2008				
	μ_{int}	μ_{str}	μ_t	
Coal	3.89	0.30	3.89	SD
Oil	-0.38	0.94	-0.38	ND
Natural gas	-4.04	0.47	-4.04	ND
Nuclear	6.37	0.26	6.37	SD
Renewable	0.44	0.44	0.44	WD
2008-2015				
	μ_{int}	μ_{str}	μ_t	
Coal	-5.31	-0.42	-5.73	ND
Oil	2.79	-0.85	1.96	SD
Natural gas	6.29	0.20	6.51	SD
Nuclear	0.09	-0.52	-0.43	ND

Renewable	-3.34	-0.11	-3.45	ND
2000-2015				
	μ_{int}	μ_{str}	μ_t	
Coal	3.29	0.28	3.57	SD
Oil	0.56	1.00	1.56	SD
Natural gas	-3.20	0.86	-2.34	ND
Nuclear	8.87	0.21	9.07	SD
Renewable	-0.70	0.53	-0.18	ND

Source: Own elaboration.

5.2 The SP-IDA and ST-IDA approaches for energy consumption in Andalusia.

The SP-IDA model applied to the Andalusian region enables us to explain the differences of energy consumption between Andalusia and the average of Spanish regions (reference region) for the period 2000-2015, based on three effects: activity, intensity and structural.

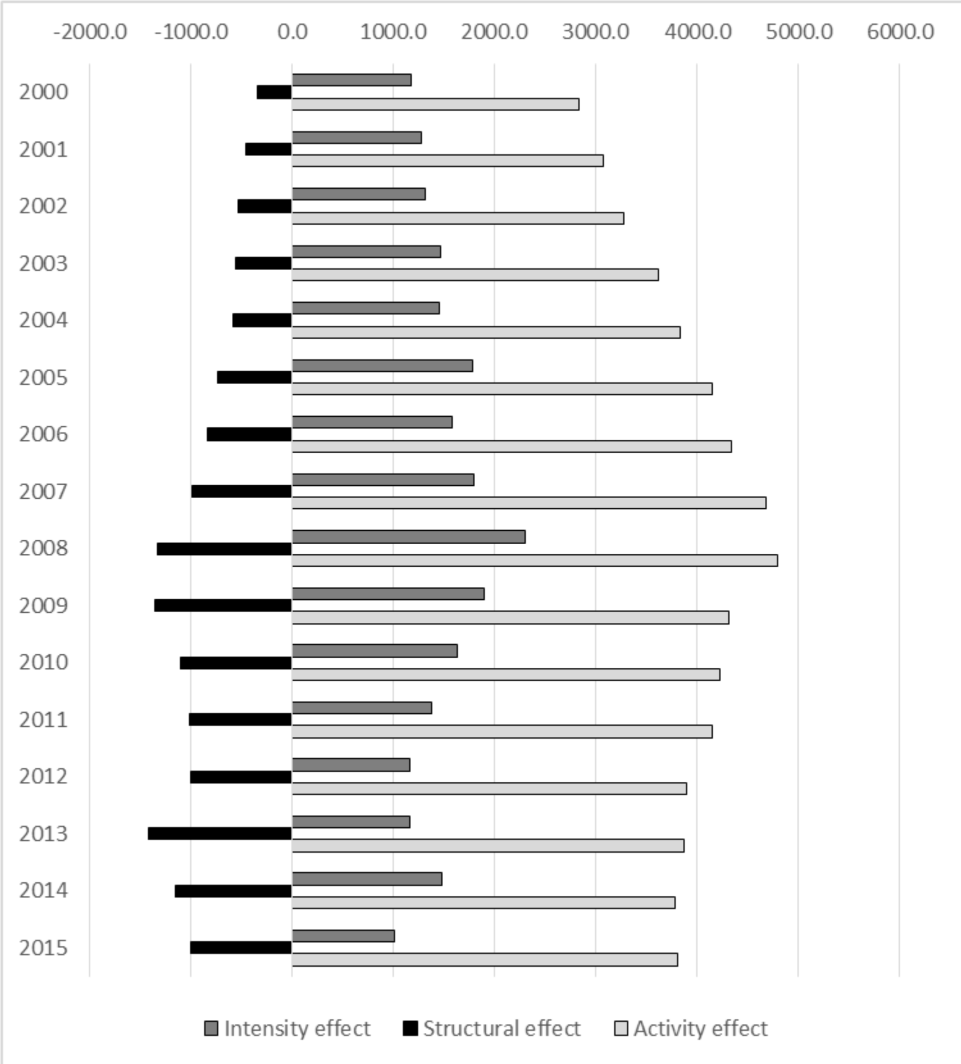
The SP-IDA results show that there is always a positive difference between energy consumption in Andalusia and the reference region during the period 2000-2015 (see Figure 2). This positive difference is explained by the activity and energy intensity effects, partially offset by the structural effect. These results highlight the economic features of the Andalusian economy that affect the energy consumption of this region. Concretely, this region being specialised in less energy intensive sectors than the average of the Spanish regions contributes to reducing the energy consumption while, on the other hand, Andalusia has a higher energy intensity ratio than the average of the Spanish regions, presenting a lower energy efficiency.

The behaviour of energy consumption in Andalusia with regard to the reference region is different when the expansion and recession periods of the economy are considered. During the expansion period 2000-2008, the positive difference between the energy consumption in Andalusia and the reference region increased because of increasing activity and intensity effects.

The Andalusian economic growth and energy intensity drove the energy consumption in this region more than these same effects did in the average of the Spanish regions. On the contrary, the structural effect inhibited the energy consumption difference between Andalusia and the average of the Spanish regions during this same period, indicating that there was an increase in the share that the low energy intensive sectors had in the total Andalusian output in comparison with what happens in the average of Spanish regions (Figure 2).

During the recession period, 2008-2015, the difference between the energy consumption in Andalusia and the reference region was also positive but was progressively reduced. The main explanatory effects were again the activity and intensity effects that, although positive, had been diminishing since 2008-2009. Also, the structural effect was an inhibitor effect reducing its importance throughout this sub-period (Figure 2).

Figure 2: SP-IDA effects of Andalusian energy consumption differences with the reference region

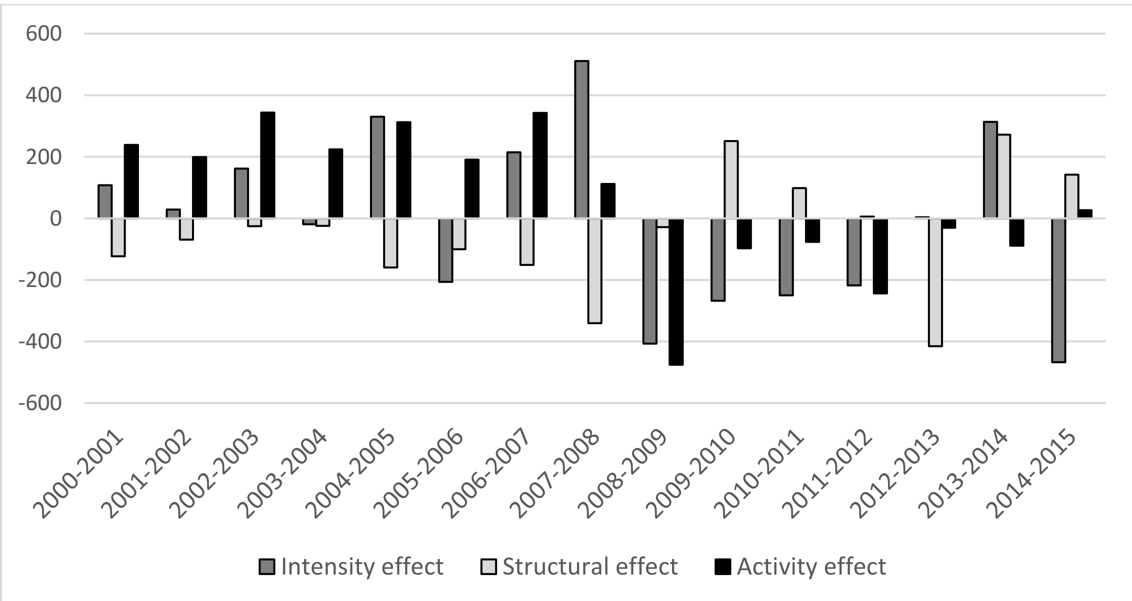


Source: Own elaboration

Similarly, these two sub-periods can be analysed through the ST-IDA approach that enables us to study the changes in the energy consumption differences between Andalusia and the same reference region during a period of time. The results are coherent with the monetary temporal decomposition carried out, in accordance with what was expected (Ang et al., 2016). The energy consumption change between 2000 and 2008 was positive and driven by the activity and intensity effects, while between 2008 and 2015 it was negative due to these same effects. Finally, the energy consumption increased between 2000 and 2015 as a result of the activity effect, partially offset by the other two effects (Table D.2 in Annex D).

The inter-annual change of Andalusian energy consumption following the ST-IDA approach enables us to further analyse the behaviour by sub-periods and effects (Figure 3). The activity effect acts as a driver of the energy consumption change in Andalusia during the expansion period and during 2014-2015. Also, the sub-period 2014-2015 is the first one after the economic recession that drove the energy consumption change. The intensity effect was a driver of the Andalusian energy consumption changes during most of the sub-periods corresponding to the expansion period. This loss of energy efficiency also occurs during the period 2013-2014. The recession period was accompanied by an improvement of energy efficiency. The structural effect was an inhibitor effect of the energy consumption changes during most of the sub-periods, except during 2009-2012 and 2013-2015. These results demonstrate that the economic growth in the Andalusian economy during the expansion period was concentrated in low energy intensive sectors (Table D.3 in Annex D).

Figure 3. ST-IDA energy consumption in Andalusia by periods (ktoe).



Source: Own elaboration

5.3 The Intensity refactorisation (IR) approach for energy consumption changes in Andalusia (2000-2015).

The additive LMDI-I analysis of the energy consumption changes in Andalusia considering the Intensity refactorisation approach (IR) for the period 2000-2015 lets us identify the following effects: physical energy intensity, productivity, structural and activity.

The comparison between the decomposition effects coming out from the two approaches considered, the monetary and the physical, reveals that the structural and the activity effects are the same. Therefore, the differences arise when the energy intensity is considered. In the monetary decomposition approach, all the changes in energy consumption that are not a consequence of the structural and activity effects are summarised in the monetary intensity effect.

However, in the IR approach, all the changes in energy consumption apart from those explained by the structural and activity effects are now to be seen in two effects, the physical energy intensity and the materialisation factor. In our analysis, the physical energy intensity effect offers the energy consumption per hour of labour worked and the materialisation effect is the inverse of labour productivity.

The IR approach permits us to identify that the physical energy intensity effect was an inhibitor (-446), partially offset by the inverse of labour productivity (343 ktoe) of the energy consumption change during the period 2000-2015 (Table 4). From the perspective of the IR decomposition approach, there was an improvement in energy efficiency during this period which is larger (-446 ktoe) than that measured by the monetary decomposition (-103 ktoe) (see Tables 1 and 4).

Table 4. Decomposition effects using the IR approach for the analysis of energy consumption changes in Andalusia (ktoe)

	2000-2008	2008-2015	2000-2015
Intensity effect (physical)	544	-1008	-446
Inverse labour productivity effect	915	-580	343
Structural effect	-1470	238	-1089
Activity effect	2111	-603	1339
Total	2100	-1953	147

Source: Own elaboration.

The analysis by sub-periods enables us to identify different key effects. Table 4 indicates that during the expansion period (2000-2008), activity is the main driver effect of the energy consumption change (2,100 ktoe), partially offset by the structural effect (-1,470 ktoe). This latter result shows that during this sub-period the changes in the productive structure of the Andalusian economy contribute to reducing the energy consumption. Also, the intensity effects present an improvement in energy efficiency parallel to a decrease in labour productivity. Table 5 provides us with some further information by sectors. The industry, primary and transport sectors are those that most reduce their energy consumption due to the structural effect.

During the second period 2008-2015, the negative energy consumption change in Andalusia (-1953 ktoe) is explained by the physical energy intensity, the inverse of labour productivity and the activity effects (see Table 4). Therefore, there was a lower energy consumption because of a lower energy intensity measured in terms of hours worked, higher labour productivity and lower economic activity. Additionally, the structural effect has an increase in energy consumption driven by some productive sectors, such as services, primary and transport, being partially compensated by the other sectors (Table 5).

Table 5. IR decomposition effects of energy consumption changes by sectors in Andalusia 2000-2015 (ktoe)

Sectors	Effects	2000-2008	2008-2015	2000-2015
Industry	Intensity (physical)	524	-221	254
	Productivity	-213	-299	-455
	Structural	-540	-150	-603

	Activity	876	-237	545
	Total	647	-907	-260
Construction	Intensity (physical)	65	0	37
	Productivity	-4	-29	-18
	Structural	9	-52	-24
	Activity	22	-6	9
	Total	92	-88	4
Services	Intensity (physical)	46	127	145
	Productivity	483	-86	377
	Structural	46	127	145
	Activity	274	-89	181
	Total	848	80	847
Primary	Intensity (physical)	459	-224	220
	Productivity	-114	0	-100
	Structural	-231	57	-157
	Activity	244	-74	154
	Total	358	-241	116
Transport	Intensity (physical)	-164	-430	-536
	Productivity	764	-166	540
	Structural	-754	256	-450
	Activity	696	-197	450
	Total	541	-537	4

Source: Own elaboration.

The results of the IR approach by sectors show us that there was an increase in physical energy intensity in the primary, industry and construction sectors during 2000-2015, which is a loss of energy efficiency. The main explanatory reason is the diminishing of the employment rate in those sectors that led to a positive energy intensity effect. Additionally, these sectors also have a negative productivity effect as a result of the higher labour productivity.

6. Discussion.

The temporal decomposition analysis of energy consumption changes in Andalusia during the period 2000-2015 makes it possible for us to highlight some important issues. The Andalusian economy faced significant changes in energy consumption but, specifically, these were conditioned by the economic activity of this region similar to what happened in the rest of Spain (Román-Collado & Colinet, 2018a; Lima et al., 2017). Besides the activity effect, the energy consumption changes in Andalusia were also driven by the intensity effect. During the expansion period this effect was a driver and in the recession it was an inhibitor.

Andalusia contributed significantly to the Spanish energy and climate objectives, and consequently those of the EU, in the 2008-2015 sub-period in which it reduced its energy consumption by 21.3% and contributed by 18.6% (AAE, 2004 and 2015) to the consumption of renewable energies, while the Spanish energy consumption was reduced by 14.3% and renewable energies were equivalent to 14.4% of total energy consumption (IDAE, 2015). The recession period also led to a reduction in the energy intensity of around 19.9%, similar to what happened in the Spanish economy (15.5%) (AAE, 2015). This energy intensity change was accompanied by the implementation of several energy policy measures that aimed to promote energy efficiency improvements during this period. Concretely, the Spanish Energy Saving and Efficiency Strategy (Spanish Ministry of Energy, 2007) developed a large number of measures to reduce energy consumption and thus meet the European Union's energy and emissions targets. These measures, aimed at different economic sectors and households, were co-managed between the Spanish General Administration and the Regional Governments of the Autonomous Communities in Spain. In the particular case of Andalusia, the Sustainable Energy Plan (PASENER) (CICE, 2007a) established additional and more ambitious savings and renewable energy objectives than for the rest of the Spanish regions. For this purpose, specific funds (from the Regional Government and the ERDF) were applied for the promotion of renewable energies, the increase in energy efficiency and the commitment to more sustainable mobility (CICE, 2007b).

The decoupling index permits us to understand the role played by the energy efficiency measures defined by the structural and intensity effects. During the recession, the index displays a strong decoupling, this being the most relevant period from the energy efficiency perspective as a result of the energy efficiency measures being completely compensated by the activity effect. Similarly, Guevara and Domingos (2017) indicate a decoupling process in the Portuguese economy in the period 2008-2010 due to the structural and intensity effects. When the whole period is analysed, the decoupling results show that there was a weak decoupling, meaning that the increase in energy consumption as a result of the activity effect was partially compensated by the structural and intensity effects. So, these results insist on the important role played by the activity effect but are also coherent with the energy decoupling process observed in Europe, where the tertiarisation of the economies and the improvement of energy efficiency partially enabled the reduction of final energy consumption (Moreau et al., 2019).

As was stated by O´Mahony and Dufour (2015), the application of a macro-energy intensity indicator is useful in analysing the overall progress of the development pathway but this indicator does not include the analysis of other factors that can be linked to social, cultural and political drivers (O'Mahony et al., 2013). When the results coming from the two temporal decompositions (the monetary and IR approaches) are compared for the whole period (2000-2015), it can be concluded that the monetary approach has a lower intensity effect (-103 ktoe) than the IR approach (-446 ktoe). This comparison lets us highlight the importance of considering a materialisation effect in the decomposition because the physical energy intensity effect presents a more accurate value of the energy consumption change produced by the energy intensity change. Then, for the whole period, the improvement in energy efficiency in Andalusia was larger than what was measured by the monetary effect. These different results for the physical and monetary intensity effects are similar to those observed by Román-Collado and Colinet (2018b) and O´Mahony and Dufour (2015) for the Spanish economy during the period 2000-2013 and 1995-2011 respectively.

Additionally, the use of the physical energy intensity indicator has allowed us to analyse the influence of the labour productivity. Yet, between 2000 and 2015, there was an effective increase in the energy consumption as a result of the inverse of labour productivity or, in other words, due to a diminishing of the Andalusian economy's labour productivity. This result also permits us to conclude that the labour productivity is an important effect as well. The data for Andalusia show that during the expansion period, the labour productivity in Andalusia did not improve, with the exception of some sectors such as primary, industry and construction where it improved significantly (13.1%, 6.6% and 5.3%, respectively) (IECA, 2015). On the contrary, during the economic recession, there was an improvement in the labour productivity that led to a reduction in energy consumption. But, this factor was followed by an increase in the unemployment rate in Andalusia from 17.7% to 31.5 % between 2008 and 2015, respectively (IECA, 2018). This situation was fundamentally alarming in the construction and industry sectors, where the hours worked were reduced by 63.6% and 19.3%, respectively, between these two years (IECA, 2015). This situation makes it possible for us to identify that in addition to the energy policy measures established for the improvement of energy efficiency between 2008 and 2015, the energy consumption might have also diminished due to the labour productivity improvement. Therefore, the Incentive Programme for the Promotion of Innovation and Business Development 2007-2013, financed with ERDF and destined to the modernisation of Andalusian companies should be considered because a labour productivity improvement was one of the key aims (ADIA, 2019).

The SP-IDA decomposition has also allowed us to compare the energy consumption in Andalusia with the average of the Spanish economy. The results indicate that the energy consumption in Andalusia was higher than the average of the Spanish regions during all the years analysed, being driven by the activity and intensity effect. The lower energy efficiency of the Andalusian economy can explain why the energy consumption in this region was higher than the average of Spanish regions. Also, the Andalusian economic growth was concentrated in lower energy intensive sectors than the average of the Spanish regions, which can be deducted from the negative values of the structure effect in the spatial decomposition.

Concretely, the results from the ST-IDA analysis are coherent with those coming from the temporal decomposition according to Ang et al. (2016). Most of the periods that have a structural effect lower than the average match with the first sub-period, when the Andalusian economy expanded and the economic activity was focused on less energy intensive sectors. Additionally, most periods which have higher structural effects than the Spanish average match with the second sub-period, when the Andalusian economy experienced a significant recession. However, it can be demonstrated that the differences between energy consumption in Andalusia and in the Spanish average diminished during the period thanks to the energy intensity effect. Therefore, the energy efficiency policies implemented in the period analysed, mainly the Andalusian Energy Sustainability Plan (PASENER), contributed to reducing the regional differences between Andalusia and the rest of Spain. This result is corroborated by Costa-Campi et al. (2015), who indicated that, in general, adopting energy efficiency measures makes it possible to reduce the differences of the energy intensities between regions. This reduction in the energy consumption difference between Andalusia and the Spanish average contributes to the reduction of the Spanish energy consumption and therefore enables this country to approach the objectives established by the EU. In fact, the energy intensity was also the main inhibitor effect in Spain during the period 2000-2013 (Román-Collado & Colinet, 2018a), although the decrease in energy intensity was larger in Andalusia (15.4%) than in Spain (12.8%).

Additionally, the analysis of energy consumption by productive sectors demonstrates that the services sector in Andalusia contributed to increasing the energy consumption differences with the average of Spanish regions. Specifically, the activity and structural effects of the services sector drove the energy consumption and favoured the tertiarisation of the Andalusian economy (Mendiluce, 2013; Fernández, 2015; Colinet & Román, 2016). However, the energy intensity of the services sector was an inhibitor, contributing to reducing the energy consumption in Andalusia and bringing the region closer to the Spanish average. The Andalusian energy efficiency measures adopted for the services sector (CICE, 2007b) were focused on the energy rehabilitation of buildings (through the incorporation of renewable energies, the improvement of the epidermis, the use of high efficiency windows, low consumption lighting etc.). Also, some energy measures were implemented to improve energy management and to execute the projects through energy services companies (ESCOs).

On the other hand, Andalusia has negative differences of energy consumption in the industry sector, mainly as a consequence of the lower relative weight of this sector in the total GVA compared to Spain (12% and 18%, respectively, in 2000, reduced to 10% and 17%. respectively, in 2015) and the effects that the recession period had on this sector. In fact, the industry sector is the only one that has a strong decoupling for the whole period, this being explained by the loss of energy intensity during the recession period provided by the monetary decomposition approach. Nevertheless, when the IR decomposition approach is applied, the results indicate that the improvement in labour productivity in the industry sector is an alternative explanation.

The transport sector should be taken into consideration as it represents around 33% of the total energy consumption in Andalusia. The decoupling index values for the recession period reveal that the energy efficiency improvements in the transport sector are the main path towards the decoupling process between energy consumption and this sector's economic activity growth. In the period 2008-2015, Andalusia contributed significantly to reducing energy consumption in the transport sector in Spain (21%). With the main objective of reducing energy consumption in the transport sector, the measures implemented in Andalusia during this period were municipal mobility plans and efficient driving courses (CICE, 2009) that complemented the policy measures aimed at promoting the acquisition of less polluting and more efficient vehicles (PIVE, MOVEA, MOVES, MOVALT) (IDAE, 2019). The results for the transport sector are similar to those obtained by Colinet and Román (2016) for the sub-periods 2003-2008 and 2008-2012 in Andalusia, where the intensity effect acts as a driver in the first sub-period and an inhibitor in the second.

The analysis of the energy sources shows that natural gas and renewable energies increased. Concretely, in the first sub-period, 2000-2008, there was a significant growth of natural gas. Several reasons explain this, such as the start-up of electricity production with this fuel and the energy diversification experienced by the Andalusian industry that led to a greater use of natural gas compared to other, petroleum-derived fuels. Also, the commitment to the use of natural gas in the Spanish National Energy Plan 1991-2000 (Spanish Parliament, 1991) allowed the establishment of an extension network of gas pipelines that permitted access to the consumption of this fuel by different types of users (electricity generation, industries, households and other sectors) and promoted the use of this energy source. On the other hand, during the second sub-period, 2008-2015, the ceasing of combined cycle electricity production and the industrial recession brought about a lower gas consumption, presenting a strong decoupling index.

Also, the greater use of renewable energies during the second sub-period is explained by the significant promotion of these resources for power generation (Ministry of Industry, 2007) that undoubtedly contributed to Andalusia and Spain being closer to the EU's renewable energy objectives. In 2015, the renewable energy consumption in Andalusia was equivalent to 18.6% of the primary energy consumed (in Spain this was equivalent to 14.4%), displaying a growth of 13 percentage points in the last ten years. Additionally, renewable energies in Andalusia contributed to the development of a business network, fundamentally related to the use of solar energy. This has a high presence in community and non-EU countries. However, the decoupling indices for energy sources show that the growth of renewable energies was partially compensated by the structural effect between 2000-2015. The reduction of the relative weight of industry in Andalusia in this period has also affected the decrease in the consumption of renewable energies in this sector. In general, the industrial sector has adopted measures to improve the energy efficiency of the processes and has opted for energy diversification by increasing the consumption of natural gas. This was because energy conversion equipment with natural gas (boilers, furnaces, dryers, etc.) had a more advanced technological state than that of biomass. This experience can be transferred to EU countries with similar climatic conditions, mainly with high solar resources, such as the countries of southern Europe and the Mediterranean.

The temporal decomposition indicates that the intensity and activity effects drove the oil consumption during the first sub-period, although they were partially compensated by the structural effect, showing a weak decoupling. On the contrary, during the second sub-period, the oil energy consumption diminished and presented a strong decoupling, this being linked to the economic activity but also to a lower energy intensity. The Andalusian economy's high dependency on petroleum derivatives was partially corrected in the second sub-period when the intensity effect denotes a reduction of the energy consumption in the transport sector, which is extremely dependent (95.5%) on these fuels (AAE, 2015). The regional and Spanish political measures implemented during this sub-period, relating to aids for investment in more efficient vehicles and the promotion of efficient driving for individual and professional transport, could also have contributed to these results (CICE, 2007a).

7. Conclusions.

The importance of energy efficiency for the region of Andalusia considering the Spanish and EU energy targets has been highlighted with the three decomposition approaches. The energy measures established by the national government and co-managed by each one of the Spanish regions, concretely Andalusia and the specific programmes developed by the regional government have been analysed, taking into consideration these decomposition results.

Firstly, the decoupling analysis shows us that if the activity effect is not taken into consideration, the energy consumption in Andalusia would have been reduced between 2000 and 2015. This result indicates that the energy efficiency measures (equivalent to the intensity and structural effects) implemented in Andalusia during that period were effective. Specifically, the energy efficiency measures implemented there were more effective during the second sub-period (2008-2015), when the energy consumption was greatly reduced (-1350 ktoe), than during the expansion period, when the energy consumption was moderately reduced (-11 ktoe). This energy consumption change contributed to reducing Spanish energy consumption, while the final energy intensity was lower in Andalusia than in Spain.

Secondly, the spatial decomposition analysis has highlighted that Andalusia always had a positive energy consumption difference with the Spanish average, although this progressively diminished during the period analysed. Therefore, although the energy efficiency measures have been globally effective in terms of reducing the energy intensity between 2000 and 2015, Andalusia still has a higher energy intensity than the Spanish average and more efforts should be made in order to reduce it and to contribute to Spain's energy consumption targets. The main efforts to reduce energy intensity should be focused on the industry and primary sectors (agriculture and livestock). The first because of the special characteristics of Andalusian industry, which is very polarised in a large chemical and petrochemical industry and has SMEs from different sectors, mainly agri-food. The latter industries are highly atomised in Andalusia and, as a result of being small, they sometimes encounter difficulties accessing new technologies and their financing. Something similar happens with the primary sector that accounts for small industries but, additionally, has a double relative weight in the Andalusian economy compared to Spain's, occupying a large part of the Andalusian territory. These energy efficiency improvements will contribute to bringing Andalusia closer to the Spanish average energy intensity, allowing a more efficient energy use.

Thirdly, the activity revaluation approach has shown us that the energy intensity effect in physical (labour force) units provides a more accurate measure of the energy intensity changes that have to be supplemented with the information provided by the materialisation effect. As a consequence, the activity revaluation approach indicates that the energy efficiency improvements between 2000 and 2015 are larger (-446 ktoe) than those measured by the traditional decomposition (-103 ktoe). Also, the activity revaluation approach demonstrates that the first period was accompanied by an increase in energy intensity (544 ktoe) that is counteracted by the decrease produced in the second period (-1008 ktoe). It can be seen from these results that the development of physical statistics at the sectoral level both in Andalusia and in Spain would contribute to providing more accurate measures of energy intensity changes.

Related to the productive sectors, the IR and the ST-IDA approaches show that the services sector drove the energy consumption in Andalusia between 2000 and2015 in spite of the energy efficiency improvements. As the services sector is becoming a key sector in the Andalusian economy, political measures should be focused on this sector in order to improve the energy decoupling process without reducing the economic growth.

Regarding the energy sources, there is a strong decoupling process in the case of coal, nuclear and oil when the whole period is considered. In this case, the energy efficiency measures (measured by the structural and intensity effects) contributed to reducing those energy sources between 2000 and 2015. The diminishing of fossil fuels, coal and oil also contribute to reducing emissions in the region. On the contrary, natural gas and renewable energies experienced no decoupling because they were highly used by the industry and other production sectors. The measures to adopt in Andalusia must complete and boost those developed by the national government, which have been directed at fostering technologies with a greater energy efficiency and the production of electricity with natural gas and renewable energies.

In short, Andalusia has a double challenge. On the one hand to bring the economic situation of Andalusia closer to the Spanish average and therefore to reduce energy intensity. On the other hand, the energy consumption must be decoupled from economic growth, thus contributing to a reduction in CO_2 emissions and in the external dependence on fossil fuels, which also have a significant impact on the Andalusian economy. These characteristics of this region might help other EU regions to understand the importance of energy efficiency and energy decoupling to achieve a diminishing of the energy consumption growth.

Likewise, the regional energy-economic policy will have to promote not only the use of the energy resources existing in the region (in the case of Andalusia only renewable energies), but also the adoption of an environmental regulation which fosters the use of these energies rather than more contaminating fuels, and the development of more expeditious administrative procedures which facilitate the implementation of projects with cleaner technologies.

The energy efficiency measures implemented in Andalusia during the period analysed were highly dependent on the availability of European funds (ERDF). These funds were deployed through grants for energy efficiency and renewable energy projects. The results suggest that it would be convenient to complement those funds with other types of measures that could impact the improvement of energy efficiency but that do not need the availability of funds, such as the development of EU-wide dissemination platforms of good energy practices for companies, administrations and citizens.

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ANNEX A

EFFECTS OF THE TEMPORAL ADDITIVE LMDI-I DECOMPOSITION BY SECTORS

$$\Delta I = \sum_i w_i \ln\left(\frac{I_i^T}{I_i^0}\right) \qquad \text{A.1}$$

$$\Delta S = \sum_i w_i \ln\left(\frac{S_i^T}{S_i^0}\right) \qquad \text{A.2}$$

$$\Delta Q = \sum_i w_i \ln\left(\frac{Q^T}{Q^0}\right) \qquad \text{A.3}$$

$$w_i = L(E_i^0, E_i^T) = \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \qquad \text{A.4}$$

EFFECTS OF THE TEMPORAL ADDITIVE LMDI-I DECOMPOSITION BY ENERGY SOURCES

$$\Delta I = \sum_{i=1}^{n}\sum_{k=1}^{m} w_{i,k} \ln\left(\frac{I_{i,k}^{T}}{I_{i,k}^{0}}\right) \quad \text{A.5}$$

$$\Delta S = \sum_{i=1}^{n}\sum_{k=1}^{m} w_{i,k} \ln\left(\frac{S_{i,k}^{T}}{S_{i,k}^{0}}\right) \quad \text{A.6}$$

$$\Delta Q = \sum_{i=1}^{n}\sum_{k=1}^{m} w_{i,k} \ln\left(\frac{Q_{k}^{T}}{Q_{k}^{0}}\right) \quad \text{A.7}$$

$$w_{i,k} = L(E_{i,k}^{0}, E_{i,k}^{T}) = \frac{E_{i,k}^{T} - E_{i,k}^{0}}{\ln E_{i,k}^{T} - \ln E_{i,k}^{0}} \quad \text{A.8}$$

ANNEX B

EFFECTS OF THE SPATIAL-TEMPORAL IDA DECOMPOSITION

$$\Delta I^{R1,T-R1,0} = \sum_{i=1}^{n} w_i^{R1,T-R\mu} \cdot \ln\frac{I_i^{R1,T}}{I_i^{R\mu}} - \sum_{i=1}^{n} w_i^{R1,0-R\mu} \cdot \ln\frac{I_i^{R1,0}}{I_i^{R\mu}} \quad \text{B.1}$$

$$\Delta S^{R1,T-R1,0} = \sum_{i=1}^{n} w_i^{R1,T-R\mu} \cdot \ln\frac{S_i^{R1,T}}{S_i^{R\mu}} - \sum_{i=1}^{n} w_i^{R1,0-R\mu} \cdot \ln\frac{S_i^{R1,0}}{S_i^{R\mu}} \quad \text{B.2}$$

$$\Delta Q^{R1,T-R1,0} = \sum_{i=1}^{n} w_i^{R1,T-R\mu} \cdot \ln\frac{Q^{R1,T}}{Q^{R\mu}} - \sum_{i=1}^{n} w_i^{R1,0-R\mu} \cdot \ln\frac{Q^{R1,0}}{Q^{R\mu}} \quad \text{B.3}$$

Where

$$w_i^{R1,0-R\mu} = L\left(E^{R1,0}, E^{R\mu}\right) = \frac{E^{R1,0} - E^{R\mu}}{\ln E^{R1,0} - \ln E^{R\mu}} \quad \text{B.4}$$

$$w_i^{R1,T-R\mu} = L\left(E^{R1,T}, E^{R\mu}\right) = \frac{E^{R1,T} - E^{R\mu}}{\ln E^{R1,T} - \ln E^{R\mu}} \qquad \text{B.5}$$

ANNEX C

EFFECTS OF THE IR DECOMPOSITION APPROACH.

$$\Delta I_L = \sum_i w_i \ln\left(\frac{I_{Li}^T}{I_{Li}^0}\right) \qquad \text{C.1}$$

$$\Delta P = \sum_i w_i \ln\left(\frac{P_i^T}{P_i^0}\right) \qquad \text{C.2}$$

$$\Delta S = \sum_i w_i \ln\left(\frac{S_i^T}{S_i^0}\right) \qquad \text{C.3}$$

$$\Delta Q = \sum_i w_i \ln\left(\frac{Q^T}{Q^0}\right) \qquad \text{C.4}$$

$$w_i = L(E_i^0, E_i^T) = \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \qquad \text{C.5}$$

ANNEX D

Table D.1. LMDI-I effects of energy consumption changes in Andalusia by energy sources (ktoe).

Sectors	Effects	2000-2008					2008-2015					2000-2015				
		Coal	**Oil**	**Natural gas**	**Nuclear**	**Renewable**	**Coal**	**Oil**	**Natural gas**	**Nuclear**	**Renewable**	**Coal**	**Oil**	**Natural gas**	**Nuclear**	**Renewable**
Industry	Intensity	-393	-256	1156	-62	-122	93	102	-683	0	-36	-285	-144	434	-59	-149
	Structural	-55	-127	-239	-6	-93	-11	-33	-82	-1	-23	-81	-165	-232	-7	-109
	Activity	90	206	388	9	151	-17	-52	-129	-1	-37	73	149	210	6	98
Construction	Intensity	-3	9	51	-1	7	1	-9	-17	0	-5	-2	-1	21	-1	1
	Structural	1	2	4	0	2	-3	-10	-30	0	-8	-3	-5	-11	0	-4
	Activity	2	5	10	0	4	0	-1	-4	0	-1	1	2	4	0	2
Services	Intensity	-264	-91	631	-58	-37	93	-27	-467	-1	185	-191	-112	216	-59	123
	Structural	13	3	14	2	8	28	4	60	2	29	53	9	29	5	40
	Activity	77	21	85	10	47	-20	-3	-42	-1	-20	67	11	36	7	50
Primary	Intensity	-33	214	164	-8	9	21	-265	-20	0	40	-13	-50	141	-7	48
	Structural	-10	-193	-13	-1	-5	2	43	9	0	2	-10	-124	-9	-1	-6
	Activity	10	204	14	1	5	-3	-56	-12	0	-3	10	121	9	1	6
Transport	Intensity	-13	546	18	-2	51	3	-641	4	0	38	-10	-96	22	-2	90
	Structural	-3	-740	-2	0	-5	1	246	2	0	7	-2	-436	-2	0	-5
	Activity	2	683	2	0	4	0	-189	-2	0	-5	2	436	2	0	5
TOTAL	Intensity	-707	422	2019	-130	-92	210	-838	-1182	0	221	-501	-403	835	-128	113
	Structural	-54	-1055	-236	-5	-92	17	250	-41	1	7	-43	-721	-225	-3	-85
	Activity	182	1118	499	20	211	-40	-301	-188	-2	-66	152	720	261	14	160
	Total	-579	485	2282	-115	26	187	-890	-1412	-1	162	-391	-404	871	-117	189

Table D.2. SP-LMDI-I effects of energy consumption changes in Andalusia by sectors (ktoe).

	2000			2001			2002			2003			2004			2005			2006			2007		
	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect
Primary	45.7	338.1	219.0	42.1	343.4	237.0	75.8	316.6	254.1	117.5	343.7	293.9	239.0	358.9	349.6	321.6	325.1	383.4	294.5	324.9	402.9	238.1	308.8	405.0
Industry	1172.0	-768.3	1209.1	1247.6	-849.9	1310.7	1221.4	-874.0	1384.3	1312.8	-892.1	1537.2	1050.5	-886.0	1548.2	1219.8	-938.0	1696.3	1031.0	-988.9	1726.4	1207.7	-1116.2	1867.4
Construction	-31.6	18.3	23.3	-33.9	19.9	25.1	-36.0	21.4	26.7	-38.6	22.6	28.7	-43.4	22.3	28.3	-42.8	25.1	32.1	-54.3	13.1	17.5	-10.3	42.1	60.1
Transport	52.9	118.8	994.2	77.3	71.8	1072.7	93.7	51.1	1145.9	93.5	22.8	1241.3	217.0	-23.8	1359.9	265.0	-102.5	1435.6	296.5	-143.2	1545.8	349.8	-189.6	1653.9
Services	-66.2	-44.0	388.6	-52.0	-45.3	427.6	-45.3	-44.1	461.0	-13.4	-51.2	514.4	-10.9	-50.0	553.4	19.0	-47.5	604.1	8.5	-43.5	649.9	5.9	-33.8	698.2
Total	1172.9	-337.0	2834.2	1281.0	-460.2	3073.1	1309.6	-529.0	3272.0	1471.8	-554.3	3615.5	1452.2	-578.6	3839.5	1782.6	-737.8	4151.6	1576.3	-837.6	4342.4	1791.2	-988.7	4684.5
	3670			3894			4053			4533			4713			5196			5081			5487		

	2008			2009			2010			2011			2012			2013			2014			2015		
	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect	Intensity effect	Structural effect	Activity effect
Primary	240.9	310.5	409.1	193.8	332.6	379.3	205.0	350.0	380.8	192.6	371.4	382.9	188.8	301.3	348.2	68.9	357.2	340.8	80.2	357.1	317.3	111.2	289.4	318.6
Industry	1529.3	-1240.4	1971.5	1316.5	-1325.8	1722.0	1114.5	-1133.1	1683.1	1003.4	-1075.9	1656.2	976.2	-1064.1	1584.4	1392.8	-1686.8	1550.6	1442.9	-1309.9	1594.6	974.5	-1150.7	1529.1
Construction	-3.2	41.9	63.2	1.4	30.2	56.9	-32.4	11.1	32.5	-29.0	6.3	31.7	-25.5	3.4	30.7	-13.2	-10.6	30.9	-20.4	-2.2	28.7	-16.2	-2.1	32.3
Transport	501.6	-422.8	1628.3	431.9	-409.5	1504.5	353.4	-363.1	1460.0	252.7	-349.5	1418.4	94.3	-296.3	1315.5	-118.9	-184.5	1319.0	83.3	-256.2	1260.5	55.6	-209.0	1323.4
Services	34.2	-18.1	724.2	-48.1	14.4	657.7	-12.2	27.7	666.3	-41.2	38.3	657.1	-72.7	52.2	623.7	-164.3	105.9	630.7	-107.7	64.5	582.5	-113.8	68.2	606.3
Total	2302.8	-1329.0	4796.3	1895.5	-1358.0	4320.3	1628.2	-1107.3	4222.8	1378.5	-1009.4	4146.2	1161.1	-1003.5	3902.6	1165.2	-1418.9	3872.0	1478.3	-1146.6	3783.6	1011.2	-1004.2	3809.7
	5770			4858			4744			4515			4060			3618			4115			3817		

Table D.3. ST-LMDI-I effects of energy consumption changes in Andalusia by sectors (ktoe).

Sectors	2000-2008				2008-2015				2000-2015			
	Intensity effect	Structure effect	Activity effect	Total	Intensity effect	Structure effect	Activity effect	Total	Intensity effect	Structure effect	Activity effect	Total
Primary	195	-28	190	358	-130	-21	-90	-241	65	-49	100	116
Industry	357	-472	762	647	-555	90	-442	-907	-198	-382	320	-260
Construction	28	24	40	92	-13	-44	-31	-88	15	-20	9	4
Transport	449	-542	634	541	-446	214	-305	-537	3	-328	329	4
Services	100	26	336	462	-148	86	-118	-180	-48	112	218	282
Total	1130	-992	1962	2100	-1292	325	-987	-1953	-162	-667	976	147