An analysis of Spain's global and environmental efficiency from a European Union perspective.

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Abstract

Sustainable economic growth from the environmental point of view is one of the commitments of the EU-28. Different measures have been implemented to deal with this issue. This work analyses Spain's natural efficiency and management efficiency, in their static and dynamic sense, for the years 2005-2012, in comparison EU-28. The analysis has been carried out using the Malmquist Index and natural and managerial efficiency. Three variables have been considered as inputs: work, gross fixed capital formation and final energy consumption. Two variables are the outputs: the GDP as a desirable output and greenhouse effect gas emissions as an undesirable output. The result is that Spain's managerial efficiency and natural efficiency are, though their values are lower, evolving in a similar manner to those of the countries which have been at the heart of the EU longer. These levels of efficiency are higher than those of the block of countries which have joined the EU-28 more recently. The natural Malmquist Index results indicate that these are the countries which have had a greater growth in productivity, above Spain's and the average of the more "veteran" countries.

Keywords: Managerial efficiency, Natural efficiency, GHG emissions, Data Envelopment Analysis, Malmquist Index

1.- Introduction

Anthropogenic emissions of greenhouse gases (GHG) have increased considerably from the pre-industrial era to nowadays, boosted to a great extent by economic and population growth (Stern, 2013; Cook *et al.*, 2013; Huamán and Jun, 2014; Revesz *et al.*, 2014; Rafaj *et al.*, 2015; Wedmann *et al.*, 2015). The continuing and uninterrupted emission of GHG causes a greater warming and significant changes in specific elements of the climate system, increasing the likelihood of giving rise to generalised and irreversible damage in both people and ecosystems. This is why limiting the warming and its negative effects by significantly reducing GHG emissions is a task which cannot be put off any longer (IPCC, 2014). This need was broadly dealt with in the climate conference in Paris (COP21) held in December 2015, in which 195 countries adopted a legally-binding global agreement for the first time.

Nowadays, most countries have sustainable development as one of their main objectives. This means the reconciling of economic growth with reducing GHG emissions, or what is known as the decoupling of growth and emissions. Specifically, the European Union (EU) is a major protagonist in the global fight against climate change in general, and in the reduction of GHG emissions in particular. The EU and other developed countries manifested in the aforementioned Paris Climate Summit their intention to continue supporting the implementation of measures aimed at the reduction of emissions and the mitigating of the impact of climate change on developing countries (United Nations, 2015).

Concern for environmental protection has been present in the EU since 1972 (Knill and Liefferink, 2013) and is covered in articles 11 and 191 to 193 of the Treaty of Functioning of the European Union (2012). Yet the Strategy in favour of sustainable development had already been adopted in 2001 (European Commission, 2001). This was updated in 2005.

The set of measures related to climate and energy adopted by the EU in March 2007 and passed by the European Parliament in December 2008 are centred on the reduction of emissions, on the growing use of renewable energy and on fostering energy efficiency. This initiative established a series of ambitious measures to reduce GHG by 20% below the levels of 1990 by 2020. The EU offered to extend this reduction to 30% if other developed countries agreed to do their part in a global effort. In the long term the EU has focused on reducing emissions to 80-95 % of the 1990 levels by 2050 (European Council, 2007)

EUROPA 2020 was adopted later: a strategy for smart, sustainable and inclusive growth, energy sustainability and the fight against climate change being among its five basic aims (European Commission, 2010).

In this context, environmental assessment is an analysis technique which is used a great deal in the scientific area related with the study and prevention of the consequences of climate change in general and contamination in particular. This work applies a methodology of environmental evaluation based on the well-known Data Envelopment Analysis (DEA) to the EU countries during the period 2005-2012. The analysis differentiates between the countries which joined the European Union before 2004 (B-2004) and those that did so afterwards (A-2004). The results obtained suggest that the time belonging to the EU differentiates the behaviour of these two blocks of countries regarding their environmental and energy efficiency achievements.

DEA is considered to be one of the most successful approaches in the research field dealing with the economic evaluation of the environment (Glover and Sueyoshi, 2009). In fact, Zhou *et al.* (2008) compiled more than 100 articles which apply DEA to the environment and energy. Within these studies, since Färe *et al.*'s (1989) there have been many works of this nature which divide the outputs into two categories - the desirable and the undesirable – among which are those of Dyckhoff and Allen (2001), Ramanathan (2002), Lansink and Bezlepkin (2003), Korhonen and Luptacik (2004), Liang *et al.*, (2004), Triantis and Otis (2004), Zaim (2004), Picazo-Tadeo *et al.*, (2005), Kumar (2006) and Pasurka (2006). There have also been numerous works in recent years which have followed this plan - Fare and Groskopf (2010), Liu *et al.*, (2010), Zhou *et al.,* (2010), Sahoo *et al.*, (2011), Wang *et al.,* (2014), Kounetas (2015), Sueyoshi and Goto (2015), and Zhang *et al.*, (2015).

Our work continues in this line, according to the model proposed by Sueyoshi and Goto (2013, 2015), but instead of taking firms as the analysis units, we use the EU-28 countries. To the best of the author´s knowledge, DEA and Malmquist has not been used commonly to make a comparative analysis of the environmental efficiency in the EU, differentiating between the countries that belonged to it before 2004 (basically located in western Europe) and those which entered from this date (for the most part from eastern Europe). There are other papers which used countries in their analyses, such as Hoang and Alauddin, 2012; Krautzberger and Wetzel, 2012; Bampatsou et al., 2013; Menegaki, 2013; Chang, 2014; Woo et al., 2015). Finally, Kounetas (2015) has done a similar study but he separates the North-South clusters and he only analyzes two years (2002 and 2008).

This exposition will allow every country to have the chance of analyzing its situation from a double comparative reference, the first with countries of the same geographical environment and which have an equal permanence in the EU and the second with the countries with a different time of permanence in the European Union and a different geographical location. Besides, the authors in this paper are interested in technology innovation as a way of decreasing the bad output (i.e., GHG emissions) in the countries of the EU and in paying special attention on Spain.

The evaluation that we propose in this work could be good for a country to decide on a strategy regarding its natural and managerial disposability for energy and its environment's efficiency and future, accelerating their development. It must know where it stands in comparison to other countries with similar and different geographical, regulatory or other contextual environments. In our model, and following Woo *et al.*

(2015), we use employment, energy consumption and gross fixed capital formation (GFCF) as inputs, and the GDP as a desirable output and GHG emissions as an undesirable output. Via the Malmquist Index natural efficiency and managerial efficiency were calculated from a static and dynamic point of view, considering the possibility of a frontier crossover taking place between one period and another due to technological progress.

This work is organised as follows. Section 2 presents the data used, as well as explaining the DEA methodology employed, based on the measuring of natural and managerial efficiency and the Malmquist Index associated with these two efficiencies which have an efficiency frontier crossover. Section 3 analyses the results obtained, comparing the situation of Spain with that of the EU-28. Lastly, the conclusions and possible political implications are in Section 4.

2. – Methodology and Data

In this section, we start by mentioning two strategic concepts for environmental protection that use the DEA approach proposed by Sueyoshi and Goto (2012a; 2012b; 2012c; 2012d; 2012e; 2013 and 2014) to measure Natural and Managerial Efficiency.

The first concept is referred to as natural disposability. This indicates that a DMU (Decision Making Unit) mainly considers a decrease in the vector of inputs to decrease the vector of bad outputs as well as to increase the vector of good outputs as much as possible (Sueyoshi and Goto, 2012b; 2012c). Managerial disposability indicates an opposite case to natural disposability. In disposability, a firm increases a directional vector of inputs to decrease a directional vector of undesirable outputs by utilising technology innovation in undesirable outputs as well as to increase the vector of good outputs as much as possible.

To describe the concept of natural and managerial disposability by an axiomatic expression, let us consider $X \in R_m^+$ as an input vector, G $\in$ R_s^+ as a desirable output vector and B $\in$ R_h^+ as an undesirable output vector. All of them are column vectors whose components are all positive.

The concept of natural and managerial disposability is specified by the following vectors of production factors under constant RTS (Returns to Scale) and constant DTS (Damage to Scales: corresponding to RTS in undesirable outputs), respectively

$$P^n(X) = \left\{ (G,B)\,; G \leq \sum_{j=1}^{n} G_j\,\lambda_j;\ B \geq \sum_{j=1}^{n} B_j\,\lambda_j;\ X \geq \sum_{j=1}^{n} X_j\,\lambda_j;\ \lambda_j \geq 0, j = 1, \dots n \right\} \tag{1}$$

$$P^m(X) = \left\{ (G,B)\,; G \leq \sum_{j=1}^{n} G_j\,\lambda_j;\ B \geq \sum_{j=1}^{n} B_j\,\lambda_j;\ X \leq \sum_{j=1}^{n} X_j\,\lambda_j;\ \lambda_j \geq 0, j = 1, \dots n \right\} \tag{2}$$

The concept of natural and managerial disposability is extended into a time horizon by the measurement of the Malmquist Index (Sueyoshi 2013, 2014).

Natural Disposability: The Malmquist Index with a frontier crossover between the two periods can be reorganised as follows:

$$INC_{t-1}^{t} = \sqrt{\frac{\mathrm{UENt-1}}{\mathrm{IUENt-1 \rightarrow t-1\&t}}\,\frac{\mathrm{UENt}}{\mathrm{IUENt \rightarrow t-1\&t}}} \tag{3}$$

The degree of $\mathrm{UEN_t}$ of the k th DMU in the t th period is measured by the following model under natural disposability:

$$\text{(P1)}\ Max\ \xi + \varepsilon\left[\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \tag{4}$$

$$\begin{aligned}
s.t. \sum_{j\epsilon J_t} x_{ijt}\,\lambda_{jt} + d_i^x \quad &= x_{ikt}\,;\ \ \forall\ k\epsilon J_t\,;\ \ i = 1, \dots, m \\
\sum_{j\epsilon J_t} g_{rjt}\,\lambda_{jt} - d_r^g\ -\ \xi\ g_{rkt} \quad &= g_{rkt};\ \ \forall\ k\epsilon J_t\,;\ \ r = 1, \dots, s \\
\sum_{j\epsilon J_t} b_{fjt}\,\lambda_{jt} + d_f^b\ +\ \xi\ b_{fkt} \quad &= b_{fkt};\ \ \forall\ k\epsilon J_t\,;\ \ f = 1, \dots, h \\
\lambda_{jt} \geq 0;\ \ j = 1, \dots, n; t = 2, \dots, T;\ \ &\xi \text{unrestricted}; d_i^x \geq 0; i = 1, \dots, m \\
d_r^g \geq 0; r = 1, \dots, s;\ \ &d_f^b \geq 0;\ \ f = 1, \dots, h
\end{aligned}$$

Where $R_i^x = (m+s+h)^{-1}\left(max\{x_{ij}; j\epsilon J_{t-1} \cup J_t\} - min\{x_{ij}; j\epsilon J_{t-1} \cup J_t\}\right)^{-1}$

$$R_r^g = (m+s+h)^{-1}\left(max\{g_{rj}; j\epsilon J_{t-1} \cup J_t\} - min\{g_{rj}; j\epsilon J_{t-1} \cup J_t\}\right)^{-1}$$

$$R_f^b = (m+s+h)^{-1}\left(max\{b_{fj}; j\epsilon J_{t-1} \cup J_t\} - min\{b_{fj}; j\epsilon J_{t-1} \cup J_t\}\right)^{-1}$$

The degree of UEN_{kt} of the k-th DMU in the t th period is determined by:

$$UEN_{kt} = 1 - \left[\xi + \varepsilon\left(\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right)\right] \quad (5)$$

The degree of UENt−1 regarding the k-th DMU in the t−1 th period is measured by replacing t by t−1 in Model (P1).

The degree of $IUIN_{t-1 \rightarrow t}$ regarding the k th DMU from the t−1 th period to the t th period is determined by the following model:

$$(P2)\ Max\ \xi + \varepsilon\left[\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \quad (6)$$

$$\begin{aligned} s.t. \sum_{j\epsilon J_{t-1\&t}} x_{ijt-1}\,\lambda_{jt-1\&t} + d_i^x &= x_{ik(t-1)};\ \forall\, k\epsilon J_{t-1};\ i = 1,\dots,m \\ \sum_{j\epsilon J_{t-1\&t}} g_{rjt-1}\,\lambda_{jt-1\&t} - d_r^g - \xi\ g_{rkt} &= g_{rk(t-1)};\ \forall\, k\epsilon J_{t-1};\ r = 1,\dots,s \\ \sum_{j\epsilon J_{t-1\&t}} b_{fjt-1}\,\lambda_{jt-1\&t} + d_f^b + \xi\ b_{fkt} &= b_{fk(t-1};\ \forall\, k\epsilon J_{t-1};\ f = 1,\dots,h \end{aligned}$$

$$\lambda_{jt-1\&t} \geq 0;\ j = 1,\dots,n; t = 2,\dots,T;\ \xi \text{ unrestricted}; d_i^x \geq 0; i = 1,\dots,m$$

$$d_r^g \geq 0; r = 1,\dots,s;\ d_f^b \geq 0;\ f = 1,\dots,h$$

The degree of $IUEN_{t \rightarrow t-1\ \&t}$ of the k th DMU between the two periods is determined by the following model:

$$(P3)\ Max\ \xi + \varepsilon\left[\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \quad (7)$$

$$\begin{aligned} s.t. \sum_{j\epsilon J_{t-1\&t}} x_{ijt}\,\lambda_{jt} + d_i^x &= x_{ikt};\ \forall\, k\epsilon J_t;\ i = 1,\dots,m \\ \sum_{j\epsilon J_{t-1\&t}} g_{rjt}\,\lambda_{jt} - d_r^g - \xi\ g_{rkt} &= g_{rkt};\ \forall\, k\epsilon J_t;\ r = 1,\dots,s \\ \sum_{j\epsilon J_{t-1\&t}} b_{fjt}\,\lambda_{jt} + d_f^b + \xi\ b_{fkt} &= b_{fkt};\ \forall\, k\epsilon J_t;\ f = 1,\dots,h \end{aligned}$$

$$\lambda_{jt} \geq 0;\ j = 1,\dots,n; t = 2,\dots,T;\ \xi \text{ unrestricted}; d_i^x \geq 0; i = 1,\dots,m$$

$$d_r^g \geq 0; r = 1,\dots,s;\ d_f^b \geq 0;\ f = 1,\dots,h$$

This index can be equal to or higher than the unit, as in Sueyoshi and Goto (2013). In the first case it would imply a frontier crossover in two consecutive periods. This means that the DMU in question would not progress technically between these two periods. Contrariwise, if it were higher than the unit, it would imply that a technical or operational progress had taken place.

Managerial Disposability: The Malmquist index with a frontier crossover between the two periods can be reorganised as follows:

$$IMNC_{t-1}^{t} = \sqrt{\frac{\text{UEM}_{t-1}}{\text{IUEM}_{t-1 \to t-1\&t}} \frac{\text{UEM}_{t}}{\text{IUEM}_{t \to t-1\&t}}} \tag{8}$$

The degree of UEM_t of the k th DMU in the t th period is measured by the following model:

$$(P4)\ Max\ \xi + \varepsilon \left[\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \tag{9}$$

$$\begin{aligned} s.t. \sum_{j \epsilon J_t} x_{ijt}\, \lambda_{jt} - d_i^x \quad\quad\quad\quad & = x_{ikt};\ \ \forall\, k\epsilon J_t;\ \ i = 1, \dots, m \\ \sum_{j \epsilon J_t} g_{rjt}\, \lambda_{jt} - d_r^g\ -\ \xi\ g_{rkt} & = g_{rkt};\ \ \forall\, k\epsilon J_t;\ \ r = 1, \dots, s \\ \sum_{j \epsilon J_t} b_{fjt}\, \lambda_{jt} + d_f^b\ +\ \xi\ b_{fkt} & = b_{fkt};\ \ \forall\, k\epsilon J_t;\ \ f = 1, \dots, h \end{aligned}$$

$$\lambda_{jt} \geq 0;\ \ j = 1, \dots, n;\ t = 2, \dots, T;\ \xi \text{ unrestricted};\ d_i^x \geq 0;\ i = 1, \dots, m$$

$$d_r^g \geq 0;\ r = 1, \dots, s;\ \ d_f^b \geq 0;\ \ f = 1, \dots, h$$

The degree of UEM_{kt} regarding the k-th DMU in the t th period determined by

$$UEM_{kt} = 1 - \left[\xi + \varepsilon\left(\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right)\right] \tag{10}$$

The degree of UEM_{t-1} regarding the k th DMU at the t−1 th period is measured by replacing t by t−1 in Model (P4).

The degree of IUEMt−1 → t−1 &t of k th DMU in the t−1 th period is determined by the following model:

$$(P5)\ Max\ \xi + \varepsilon \left[\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \tag{11}$$

$$s.t. \sum_{j\epsilon J_{t-1\&t}} x_{ijt-1\&t}\,\lambda_{jt-1\&t} - d_i^x = x_{ikt-1}\,;\ \ \forall\, k\epsilon J_{t-1}\,;\ \ i = 1,\dots,m$$

$$\sum_{j\epsilon J_{t-1\&t}} g_{rjt-1\&t}\,\lambda_{jt-1\&t} - d_r^g \ - \ \xi\ g_{rkt} = g_{rkt-1};\ \ \forall\, k\epsilon J_{t-1}\,;\ \ r = 1,\dots,s$$

$$\sum_{j\epsilon J_{t-1\&t}} b_{fjt-1\&t}\,\lambda_{jt-1\&t} + d_f^b \ + \ \xi\ b_{fkt} = b_{fkt-1};\ \ \forall\, k\epsilon J_{t-1}\,;\ \ f = 1,\dots,h$$

$$\lambda_{jt-1\&t} \geq 0;\ \ j = 1,\dots,n;\ t = 2,\dots,T;\ \xi \text{ unrestricted};\ d_i^x \geq 0;\ i = 1,\dots,m$$

$$d_r^g \geq 0;\ r = 1,\dots,s;\ \ d_f^b \geq 0;\ \ f = 1,\dots,h$$

The degree of $\text{IUEM}_{t \to t-1\ \&t}$ of the k th DMU in the t th period is determined by the following model:

$$\text{(P6)}\ Max\ \xi + \varepsilon\left[\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right] \qquad (12)$$

$$s.t. \sum_{j\epsilon J_{t-1\&t}} x_{ijt-1\&t}\,\lambda_{jt-1\&t} + d_i^x = x_{ikt}\,;\ \ \forall\, k\epsilon J_t\,;\ \ i = 1,\dots,m$$

$$\sum_{j\epsilon J_{t-1\&t}} g_{rjt-1\&t}\,\lambda_{jt-1\&t} - d_r^g \ - \ \xi\ g_{rkt} = g_{rkt};\ \ \forall\, k\epsilon J_t\,;\ \ r = 1,\dots,s$$

$$\sum_{j\epsilon J_{t-1\&t}} b_{fjt-1\&t}\,\lambda_{jt-1\&t} + d_f^b \ + \ \xi\ b_{fkt} = b_{fkt};\ \ \forall\, k\epsilon J_t\,;\ \ f = 1,\dots,h$$

$$\lambda_{jt-1\&t} \geq 0;\ \ j = 1,\dots,n;\ t = 2,\dots,T;\ \xi \text{ unrestricted};\ d_i^x \geq 0;\ i = 1,\dots,m$$

$$d_r^g \geq 0;\ r = 1,\dots,s;\ \ d_f^b \geq 0;\ \ f = 1,\dots,h$$

In a similar way to the natural Malmquist Index, in this case the value can be the same or higher than the unit. If it takes the value unit, this implies that a frontier crossing takes place in two consecutive periods, so the DMU considered would not attain environmental progress between these two periods. Contrariwise, if it were higher than the unit, this would imply that technical or operational progress had taken place which affects the environmental approach.

2.2. Data

Five variables have been chosen for the study: three inputs and two outputs, for the years 2005 to 2012. The inputs are employment, energy consumption and the GFCF. One desirable (GDP) and one undesirable (GHG emissions) output are considered.

The first input is total employment, which is people who worked at least one hour for pay or profit during the reference week or were temporarily absent from such work (in thousands of people, Eurostat) (this input is used in Menegaki, 2013; Woo et al., 2015; Kounetas, 2015; Makridou et al., 2016). The second input is the energy consumption, which is gross inland consumption (in thousands of Toe, Eurostat) (this input is used in (Menegaki, 2013; Kounetas, 2015; Makridou et al., 2016). The real GFCF, the third input, consists of resident producers' acquisitions, minus disposals, fixed assets during a given period plus certain additions to the value of non-produced assets made by the productive activity of the producer or institutional units (in millions of euros, Eurostat) (this input has also been used by Menegaki, 2013; Woo et al., 2015; Kounetas, 2015; Makridou et al, 2016). The outputs employed have been one desirable, the real GDP (expressed in millions of euros, the same output is used by Woo et al., 2015; Kounetas, 2015) and one undesirable, this is the GHG emissions (these emissions are an aggregate of 6 greenhouse gases: CO2, N2O, CH4, HFC, PFC, SF6, in thousands of equivalent tonnes of CO2), as in Menegaki (2013) and Makridou et al. (2016)).

As stated by Cooper et al., (2001) the number of DMUs must be at least three times the sum of the number of inputs and outputs. In this analysis, the number of DMUs is above this ratio by 28/15.

On the other hand, DEA methodology enables the existence of a relation between the input and output variables. As can be seen in the correlation analysis in Table 1, the coefficients are high (at a 5%significance level), which indicates there is a strong relation between the input and output variables.

Table 1. Correlation coefficients between inputs and outputs.

	EMPLOYMENT	ENERGY CONSUMPTION	GFCF
GDP	0.804053	0.630199	0.829257
EMISSIONS	0.922527	0.610454	0.871506

Source: Own elaboration

We chose 2005 to 2012 as our time period. The choice of 2005 was in order to include one year before the world economic crisis and that in which there were most of the countries of the second block which joined in May 2004. Choosing 2012 was due to it being the last year available in the database used (Eurostat).

Table 2 shows the arithmetic mean of the variables considered for the study period. In this table the difference of the size of the countries analysed is noted both in terms of employment and of GDP or energy consumption. Though these are absolute differences, relativising them contributes different results as we will see with the DEA analysis. For example, Germany is the country with the greatest energy consumption, followed by France (whose energy consumption is 80% of Germany's), but the emissions of France are relatively lower (54%).

Table 2. Arithmetic mean of the variables by country for the 2005-2012 period.

	INPUTS			OUTPUTS	
	EMPLOYMENT	ENERGY CONSUMPTION	GFCF	GDP	EMISSIONS
Austria	4038	33950	60614	267273	85490
Belgium	4506	58019	74563	324553	130020
Bulgaria	3620	19089	7065	26896	63746
Croatia	1655	8764	9455	38937	29955
Cyprus	386	2699	3688	16433	10015
Czech Republic	4980	44508	36326	131236	140048
Denmark	2770	19541	45375	218324	62244
Estonia	622	5874	3703	12521	19064
Finland	2497	35866	39460	171926	70641
France	27268	266903	412380	1834183	522785
Germany	40652	331337	470291	2374449	960006
Greece	4621	30123	40030	197523	125034
Hungary	3831	26019	18131	81523	70934
Ireland	1978	15036	37212	167353	64463
Italy	24599	177348	300966	1471877	521542
Latvia	956	4624	4385	15368	11376
Lithuania	1356	8150	5180	23483	22867
Luxembourg	213	4602	6688	33898	12317
Malta	161	939	1133	5640	3032
Netherlands	8617	82094	120402	579254	202041
Poland	15281	97229	60697	295906	404336
Portugal	4964	25087	33543	160215	76633
Romania	9444	37970	28569	96825	130612
Slovakia	2330	17852	13140	53997	47149
Slovenia	961	7289	7793	31383	20007
Spain	20029	136679	252496	958391	384909
Sweden	4504	49399	76516	333853	63064
United Kingdom	29142	215721	303748	1760479	629334

Source: Eurostat data

To facilitate the presentation of the analysis and, due to the degree of affinity regarding the financing and evolution of the European policies applied, especially those concerning energy and the environment, the EU-28 has been divided into two clusters. One is the block whose date of joining the EU is prior to 2004 and therefore its members have had more time to implement policies oriented at defending the environment and energy efficiency (Cluster B). The other comprises those countries which joined the EU-28 after 2004 (Cluster A). These blocks have two more coincidences: as is noted in Fig. 2, they could be called West and East blocks. Furthermore Table 3 and Fig. 3 show that the impact of the world economic crisis, which covers most of the period, has been different in the two blocks. Block B-2004 has had an average GDP growth close to zero during the period while this variable has been somewhat better in the other block, with an average of 0.13%.

Fig. 1.

Fig. 2.

3.- Results and discussion

This study analyses natural and managerial efficiency following the model of Sueyoshi and Gotto (2013), as well as analysing the evolution of the Malmquist Index for the period 2005-2012 and for all the EU-28 countries.

3.1. Natural and managerial efficiency

As has been explained in the Methodology section, natural and managerial efficiency, associated with there being desirable and undesirable outputs, indicate the degree to which countries try to fulfil the strategies Sueyoshi and Goto (2013) called "natural disposability" and "managerial disposability".

Both strategies seek to increase the desirable output and reduce the undesirable output. While "natural disposability" is based on reducing the inputs, "managerial disposability" is centred on the improvement of technology to achieve its aims, even increasing the inputs.

Fig. 3.

As can be noted in Fig. 3, Sweden is the only country which is efficient in both. It must be taken into account that Sweden has certain peculiarities. Firstly, more than 80% of the energy consumed comes from non-GHG contaminating sources, as 33.2% of its energy consumption is derived from nuclear energy and 51.1% from renewable energies, 60% of which is from biomass and 37% from hydroelectric sources (Eurostat, 2012). The aim of renewable energy consumption fixed for Sweden by 2020 is 49% (Eurostat). In 2013 it had already surpassed this by 3%. This explains the strong commitment of the Swedish State to a sustainable economy (Aström *et al.*, 2013). In fact, it is one of the countries which have succeeded in decoupling economic growth, GHG emissions and energy consumption. Specifically, it is the sixth country in percentage growth of GDP in this period and fifth in reducing emissions (see Table 3). This undertaking comes from years ago, as it is one of the countries which have most supported tax incentives for green energies (Cansino *et al.*, 2011). It has also established an instrument which seems to have contributed to this – the carbon tax implemented in 1991 (Jagers and Hammar, 2009; Hammar and Sjöströmb, 2011; Lin and Li, 2011; Brännlund et al., 2014). Likewise, it is the second country (after Luxembourg) which has contributed most per capita to the Green Fund for Climate of the United Nations for the period 2015-2018 (United Nations, 2015).

Table 3. Variation rate of GHG emissions, energy consumption and GDP during the period 2005-2012.

Countries	Rate of GHG emissions Variation	Rate of energy consumption Variation	Rate of GDP variation
Austria	-0.14	-0.02	0.08
Belgium	-0.18	-0.07	0.06
Bulgaria	-0.04	-0.08	0.20
Croatia	-0.14	-0.09	-0.02
Cyprus	-0.06	-0.01	0.09
Czech Republic	-0.10	-0.05	0.22
Denmark	-0.19	-0.08	0.01
Estonia	0.04	0.09	0.13
Finland	-0.11	0.01	0.03
France	-0.12	-0.07	0.04
Germany	-0.06	-0.07	0.05
Greece	-0.18	-0.12	-0.20
Hungary	-0.21	-0.15	-0.23
Ireland	-0.16	-0.10	-0.06
Italy	-0.20	-0.11	-0.08
Latvia	-0.01	-0.01	0.10
Lithuania	-0.07	-0.19	0.15
Luxembourg	-0.10	-0.07	0.21
Malta	0.05	0.00	0.18
Netherlands	-0.08	0.00	0.04
Poland	0.00	0.06	0.27
Portugal	-0.22	-0.18	-0.08
Romania	-0.16	-0.10	0.13
Slovakia	-0.15	-0.12	0.51
Slovenia	-0.07	-0.04	0.01
Spain	-0.21	-0.11	-0.05
Sweden	-0.14	-0.02	0.19
United Kingdom	-0.15	-0.13	-0.14

Source: Own elaboration.

From the natural point of view, Denmark and Luxembourg are efficient every year in the period under consideration[1]. In this period they have both managed to decouple GDP growth from emissions and energy consumption. Denmark has also opted for

1 Ireland is not efficient in 2008.

taxing carbon emissions and for renewable energies. It implemented the carbon tax in the same year as Sweden - 1991 (Hammar and Sjöströmb, 2011). By 2012 it had almost attained its aim of 30% renewable energy consumption for 2020. This has meant that it is the EU-28 country which has the highest percentage of emissions reduction during the study period.

Luxembourg is a different case (Suzuki and Nijkamp, 2016). Its economy is very peculiar and its efficiency is due in part to its reduction of energy consumption and emissions during the period despite the GDP having grown. Its economy also has a particular specialisation: 26.3% (Eurostat, average for the period) of it is in the Financial and Insurance sector.

From the managerial point of view, the other efficient country in almost all the periods is Lithuania. As can be noted in Table 3, this country is one of those which have managed to decouple emissions, energy and GDP growth. Its commitment to renewable energies is one of its main assets, as the aim for 2020 is 40%, 92.75% of which had been met by 2013. It is moreover a country which is specialising in sustainable tourism (Navickas and Malakauskaite, 2015).

Concentrating on Spain, and comparing it with the measures of the two aforementioned blocks, we can see that in the case of natural efficiency (Fig. 4), despite starting out from a lower position, the trend is similar to that of the countries of the oldest block. In general, there is an upwards trend but the impact of the economic crisis from 2009 to 2011 is clearly seen, with efficiency picking up again from 2012. This could be an effect of this country's reduction in public spending, GFCF, salaries and employment. The annual growth rate of public spending had been reducing until 2011, when it was -1.1% with respect to 2010 (Eurostat). The GFCF decreased its variation rate from 2007, being at its most negative in 2009 - 19%. The growth of the salaries variable slowed in Spain from 2008, reaching -0.5% in 2012, with respect to 2011 (Eurostat). On the other hand, employment has reduced throughout all the period. The highest unemployment growth rates were in 2008 and 2009 (40% and 60%, with respect to the previous year). This could in part explain the growth of efficiency in this period. This occurred again in 2012, coinciding with an upturn in the growth of unemployment – in this case of 16%, with respect to 2011 (INE).

These results are supported by a Wilcoxon-Mann-Whitney test, which shows the two-tailed hypothesis H0: A = B; HA: A ≠ B between UEN A-2004 and UEN B-2004. The results show that Mc= 194 and taking a level of significance α=0.05, the interval (M(α/2,n1,n2),M(1-α/2,n1,n2)) =(55,140) is obtained. Because Mc does not belong to the interval, H0 is rejected. An Upper-Tailed Test H0: B ≤ A; HA: B > A is also carried out. The results show that Mc= 194 >M (1-α,n1,n2)=133, hence H0 is rejected and HA is accepted.

Fig. 4.

The evolution of both efficiencies in the block of those countries which joined later can be due to various factors. Specifically, the uptrend which is noted from 2007-2008 coincides with the start of a new distribution of community funding. This allocation means a shift in the distribution policy. The countries which joined after 2004 and that had a lower per capita income were given greater prominence (Boboc and Alecu, 2013).

As in the case of natural efficiency, a Wilcoxon-Mann-Whitney test is performed to show the two tailed hypothesis H0: A = B; HA: A ≠ B between UEM A-2004 and UEM B-2004. The results show that Mc= 116 and taking a level of significance α=0.05, the interval $(M(\alpha/2,n1,n2),M(1-\alpha/2,n1,n2))=(55,140)$ is obtained. Because Mc belongs to this interval, H0 is accepted.

However an Upper-Tailed Test H0: $B \leq A$; HA: $B > A$ is carried out from 2005 up to 2009. The results show that $Mc= 144 > M(1-\alpha,n1,n2)=133$, hence H0 is rejected and HA is accepted.

The result of the Upper-Tailed Test for the period 2005-2009, supports the results of the work given that H0 is rejected. However, when the Upper-Tailed Test has been done for the complete period - 2005-2012- H0 is accepted. Hence, we conclude that there is a turning point in 2009 which coincides with the downward trend of managerial efficiency in the previously cited countries of the cluster B-2004.

Fig. 5.

The evolution of both efficiencies in Spain therefore follows a different trend, especially in the aftermath of the world economic crisis. The evolution of the values of these efficiencies indicates that the reduction in the number of jobs, investments, public spending and energy consumption has meant a gain in productivity, maintaining a growing trend of natural efficiency. However, managerial efficiency - which depends on investments in cleaner technology - has been affected by the halt in introducing renewable energies and the fall of the GDP and investments.

The managerial efficiency results are more uneven between the two blocks and Spain. An explanation could be due to the evolution of the renewable energies share over the period evaluated. An important question deals with the relation between our proposed indices of managerial efficiency and certain available measures of renewable energy development by country. On the one hand, we can disregard the growth of renewable energy output by itself as a potential factor of increasing managerial efficiency, since no significant correlation can be identified through bivariate (linear and non-linear) regressions by countries between efficiency and renewable energy growth. However, this fact does not necessarily mean that the energy that iscollected from resources which are naturally replenished on a human timescale does not decisively contribute to an efficiency gain in the allocation of national energy resources. To the contrary, it is possible to show numerically that managerial efficiency in the sense discussed in this paper is greatly improved when the renewable energy share in total energy output is considered as an explanatory variable.

For the sake of simplicity, the proposed numerical exercise refers to a linear pooled regression of our index of managerial efficiency (ME) against the aforementioned explanatory variable (SHARE) in the context of first-order autoregressive error terms, or $AR(1)$ process. The model relates 224 observations from the available panel data (8 annual observations from 28 countries). This data set is measured across two dimensions. One dimension is time (subscript t), and the other is usually called the cross-section dimension (subscript i), given here by countries. Therefore, there are two ways of identifying the pool statement of the data set. In this case, cross-section identifiers have been used to sort all the observations in the pooled sample, since the sample organized by time-identifiers does not support any significant autoregressive process. In general, the error terms for a model using panel data are likely to display certain types of dependence. These should be taken into account when we estimate such a model.

Since this type of autoregressive model is widely used and probably well-known to the reader, we show directly the main statistical result from the Nonlinear Least Squares (NLS) estimation of the proposed model (Davidson and MacKinnon, 2004):

$$ME_{it} = \underset{(0.037)}{0.595} + \underset{(0.002)}{0.007}\ SHARE_{it} + \hat{u}_{it} \quad where \quad \hat{u}_{it} = \underset{(0.049)}{0.838}\ \hat{u}_{it-1} + \hat{\varepsilon}_{it}$$

$$R^2 = 0.79 \qquad Inverted\ AR\ root = 0.84 \qquad Durbin - Watson\ statistic = 1.83$$

Although innovations are supposed to be i.i.d. (independent and identically distributed) random variables, we have encountered strong evidence of heteroskedasticity of an unknown form, and the numbers in parenthesis are consequently heteroskedasticity-robust standard errors (white correction). No evidence of further auto-correlation has been detected. Asymmetry and excess kurtosis have been detected in the residual analysis, but the high value of R-squared and the clear fulfillment of the stationary condition are unaffected by this circumstance. Seen as a whole, these results can be interpreted in the sense that the renewable energy share in the total energy output has a relevant, positive and statistically significant influence on managerial efficiency.

3.2. Malmquist Index

As was explained in the Methodology section, the Malmquist Index (MI) has been calculated for the natural and managerial efficiencies, assuming that there is a frontier crossover between periods.

Fig. 6.

The evolution of this index in Spain differs from that of the rest of the countries of the block that it belongs to, mainly because of the drop caused by the impact of the world economic crisis. This very pronounced decrease of the index also occurs in Ireland, which has an average GDP fall similar to that of Spain. Only two of the countries of the cluster A-2004, specifically Croatia and Hungary, have negative average GDP variation rates in the period (see Table 3). On the other hand, in block B-2004 there are various countries which have values below zero. To the bailed out Ireland, Portugal and Greece we have to add the United Kingdom and Italy, all of them having a very similar evolution of the natural MI.

The behavior of this trend, in which Spain is included, coincides with that described in Woo et al. (2015), who attribute it directly to the world economic crisis. This result is tempered in our work by differentiating between the changes which took place in productivity due to the natural approach and the managerial approach. It is noteworthy that Ireland came out more swiftly from this very pronounced decrease while, in Spain, it finished in stagnation in the 2007-2009 period. This can be due to the beginning of the economic slowdown in 2007, which is confirmed in 2008 (the GDP growth rate is -0.008%, with respect to 2007 (Eurostat, 2008)), and, as Bellod (2015) remarks, fiscal stimulus measures not having been enforced.

As can be seen in Table 3, the average of the GDP growth rates for the two blocks differs. The greater growth of the East European countries implies that the MI based on the natural approach - that is to say, the increase of productivity due to the mere fact of producing more without valuing the environmental aspect more - grows more than in the other block. Contrariwise, in the West block, the impact of the economic and financial crisis was greater and therefore the average of the growth rates was close to zero, causing the natural MI to be much less.

In the case of managerial-based MI, the behaviour of the two blocks is the opposite, as can be seen in Fig. 7. Although there continues to be improvements in efficiency, in general the values are lower than for the natural approach. In this case, the highest values, at the beginning and the end of the period, are those of the block of countries which have been longer at the heart of the EU-28 and, therefore, as has been seen in the

Introduction, have had policies oriented towards slowing down climate change and improving energy efficiency for longer (Cansino *et al.*, 2010, 2011; Capros *et al.*, 2011; Carvalho, 2012).

Fig. 7 clearly shows the impact that these latter strategies based on seeking cleaner technologies have had in the different countries of the EU-28 on the improvement of productivity, as a greater growth in the managerial MI has taken place since 2008.

Fig. 7.

Fig. 8 indicates the measures and typical deviations of the MI in the EU-28 for all the period. This shows the changes accumulated during the period considered (Woo, 2015: 372) in the case of natural efficiency. Although an improvement has taken place in all the countries, those of cluster A-2004 are the ones which have achieved better results, albeit with a higher dispersion. In Fig. 4 it is noted how they have had higher values since 2007; that is to say, from when the distribution of European funds began to benefit them to a greater extent. In the case of managerial efficiency, the countries which have been longest in the EU-28 are the ones which get better results, the dispersion being (measured on the axis on the right) much lower than that of the natural approach in all the cases.

Fig. 8.

Fig. 9.

Spain is to be found in the middle in both cases. The case of Sweden is noteworthy. It is in the last position in both approaches, in spite of being an efficient country in both senses, as was mentioned before. This position is due to the MI analysing the evolution of the changes implemented in the countries. Sweden's commitment to sustainable growth began before and therefore their current gains are lower.

4.- Conclusions

Environmental assessment is an important research area for DEA because all countries and also all private and public sectors have been paying attention to global warming and climate change. As an assessment tool, DEA has a considerably large research capability (Sueyoshi and Goto, 2010).

This article has analysed environmental efficiency for Spain from the natural and managerial perspectives over the 2005 to 2012 period compared with the other countries which make up the EU-28. To do so, we have used three input variables (final consumption of energy, employment and GFCF) and two outputs - one desirable (GDP) and the other undesirable (GHG emissions). This analysis of efficiency has used the methodology employed by Sueyoshi and Goto (2012b; 2012c), carrying out a static and dynamic analysis in which the strategies of "natural disposability" and "managerial disposability" are estimated via DEA analysis, and it has measured gains in productivity by applying the Malmquist Index.

For a clearer analysis, the EU-28 countries have been divided into two clusters – those which joined the EU before 2004 (Spain is in this group) and those which joined later. This division is not random as it basically coincides with the East and West blocks of the EU-28 and the analysis shows that in the case of environmental efficiency these groups have two different speeds.

The period analysed has been marked by the world economic crisis as shown in this study's results and data. This crisis has affected some countries more sharply. This is the case of Spain, which in some of the aspects analysed is far from following the trend of the countries of the cluster that it belongs to. In the analysis of efficiency, the higher levels of the EU's West block countries stand out, Spain being in the last place within this block in the case of natural efficiency, though it has a better result in managerial efficiency - the fruit of its environmental policies.

These differences between Spain and the EU's West block are especially seen in the analysis of the evolution of the natural Malmquist Index, which is similar to that of Greece and Portugal. In the case of managerial efficiency, the similarities are greater, though a time-lag exists. This analysis indicates that there could be a relation between the evolution of managerial efficiency and the implementing of clean energies, specifically renewable energies. This is why their use is crucial to gain in environmental efficiency. Given the importance of this topic in the implementation and development of renewable energies, as an extension to this research line it could be interesting to introduce renewable energies into the analysis, even differentiating between their different categories.

The results obtained could justify two matters. On the one hand, the contribution of the EU's regional policy to the convergence of its member states, by reducing some of its economic differences such as is the case of natural efficiency. On the other hand, it is being seen that the monitoring and fulfilment over time of the environmental policy is effective in achieving the technological progress which is necessary to improve the levels of managerial efficiency. This implies that governments have to stick to the line of implementing policies which boost the production of clean energies, as was agreed in the Paris Climate Summit in December 2015.

It would be suitable to extend this study when we have some information from some years after the economic crisis which began in 2007. This is because the results of our analysis might change in a context of stability or economic growth, in which economic funds destined to improving the negative effects of the economic crisis on certain vulnerable groups in these conditions, such as the unemployed population, could be used in environmental campaign policies to raise public awareness, following specific strategies of electrical vehicle promotion (Kempton et al., 2015) or of the generalization of the environmental label use. Therefore, the consumers would be involved as active agents in the environmental efficiency progress,being allowed to choose less pollutant products (Zhao and Zhong, 2015).

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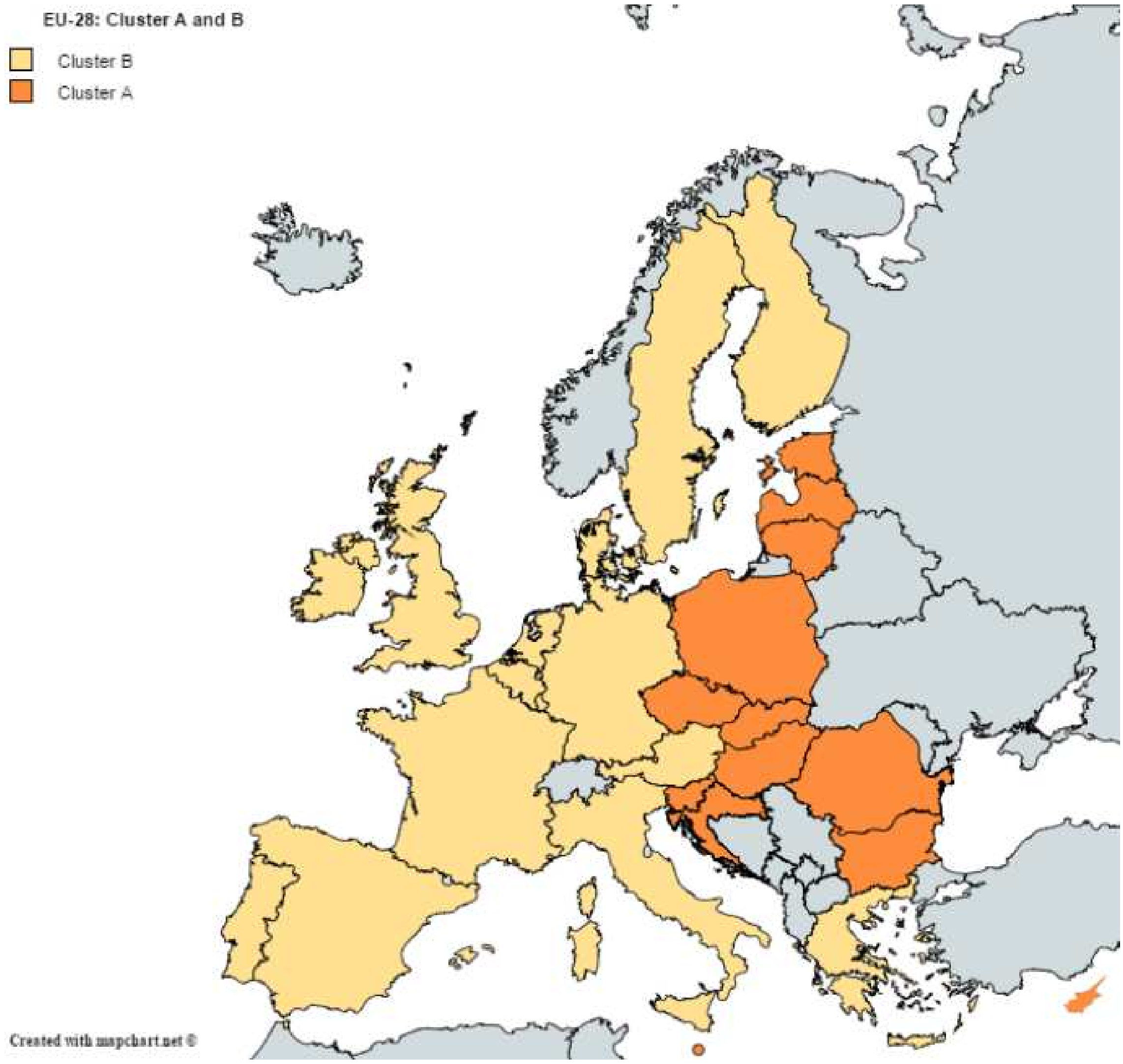
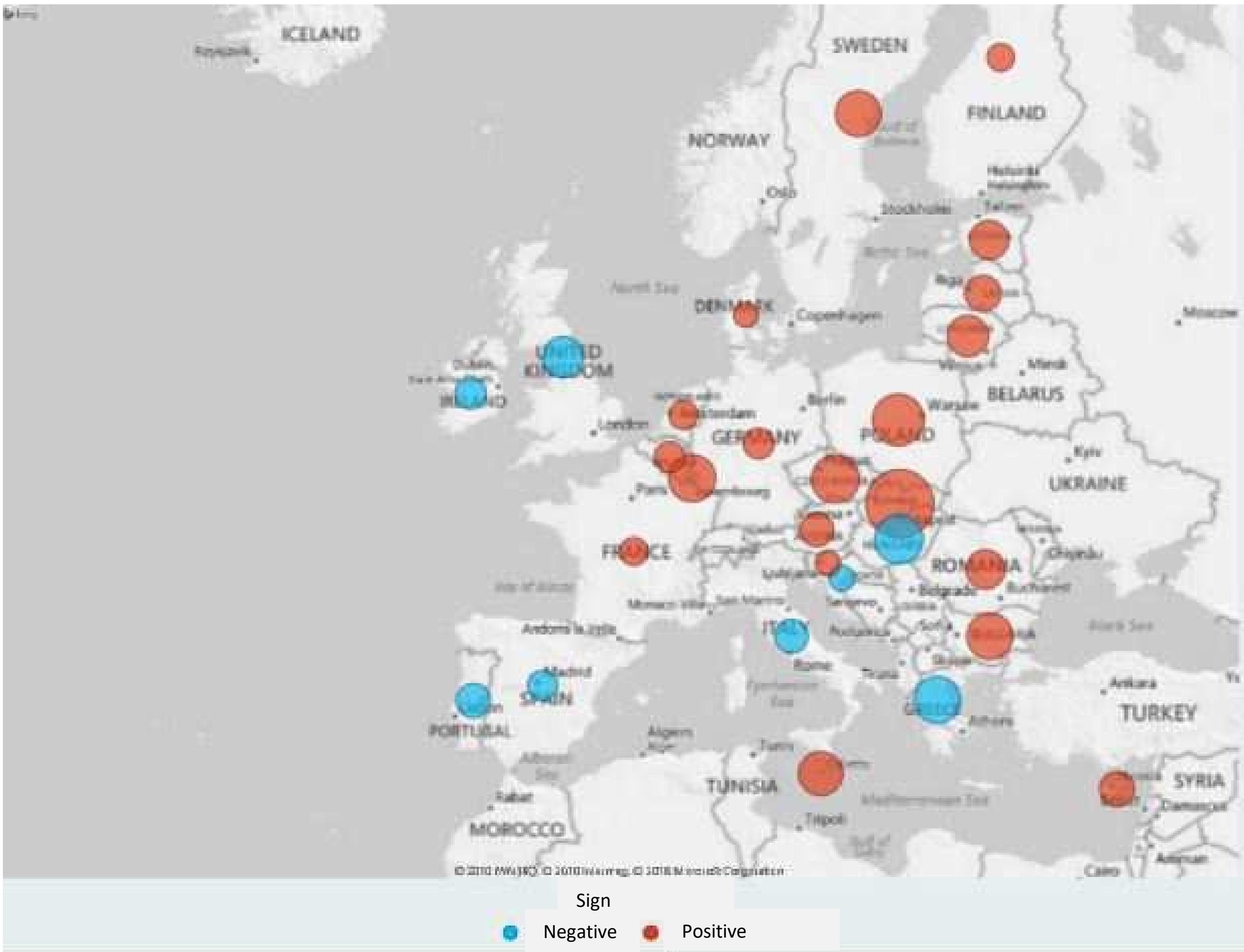
An analysis of Spain's global and environmental efficiency from a European Union perspective.

Fig. 1. Blocks into which the study was divided.



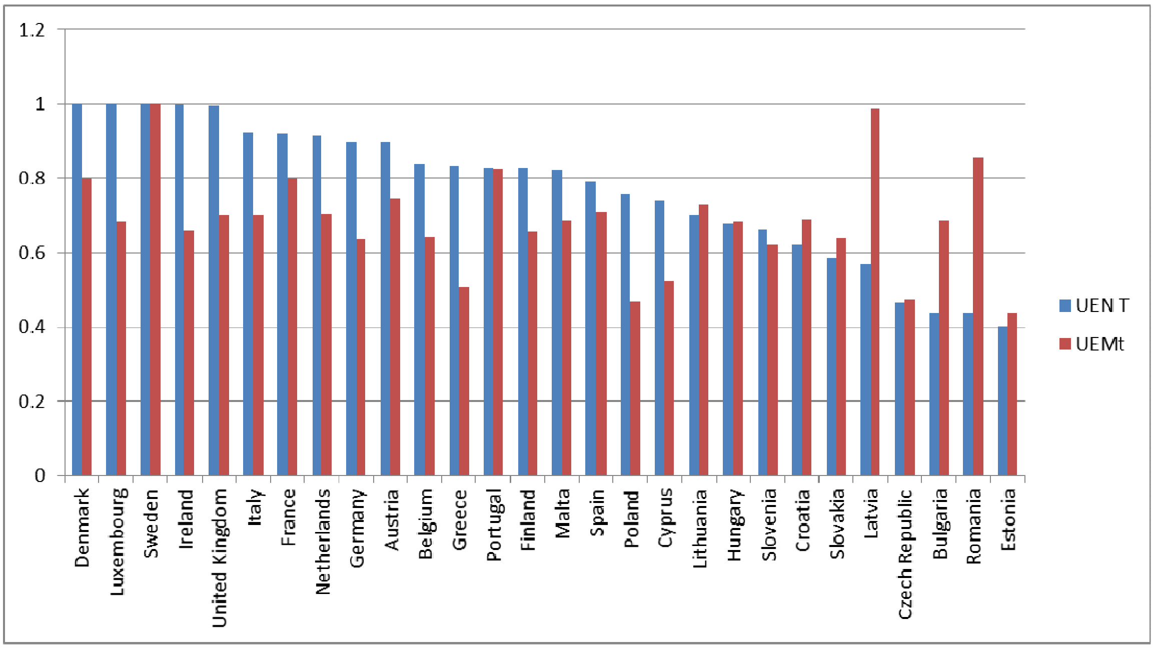
Source: Own elaboration with the programme map.chart

Fig. 2. Measure of the GDP growth rate in the EU-28 for the 2005-2012 period.



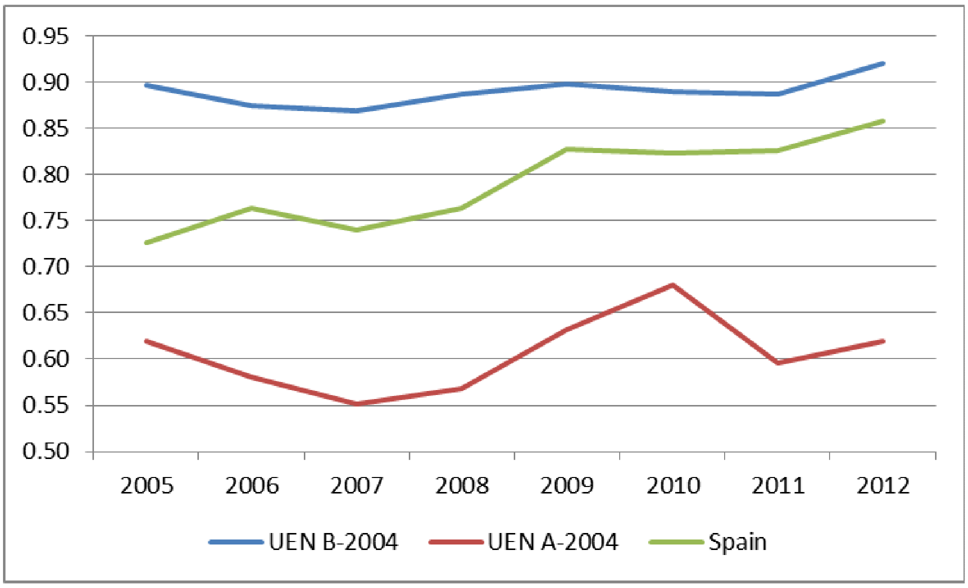
Source: Own elaboration with the programme Power view.

Fig. 3. Average of natural and managerial efficiency for the EU-28. 2005-2012 Period.



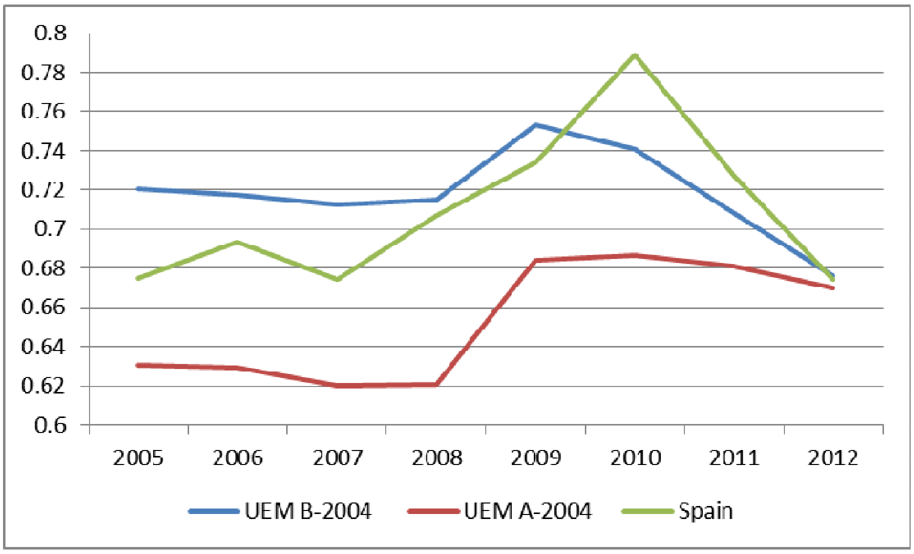
Source: Own elaboration.

Fig. 4. Comparison of the average natural efficiency in Spain with that of the EU-28 countries (2005-2012).



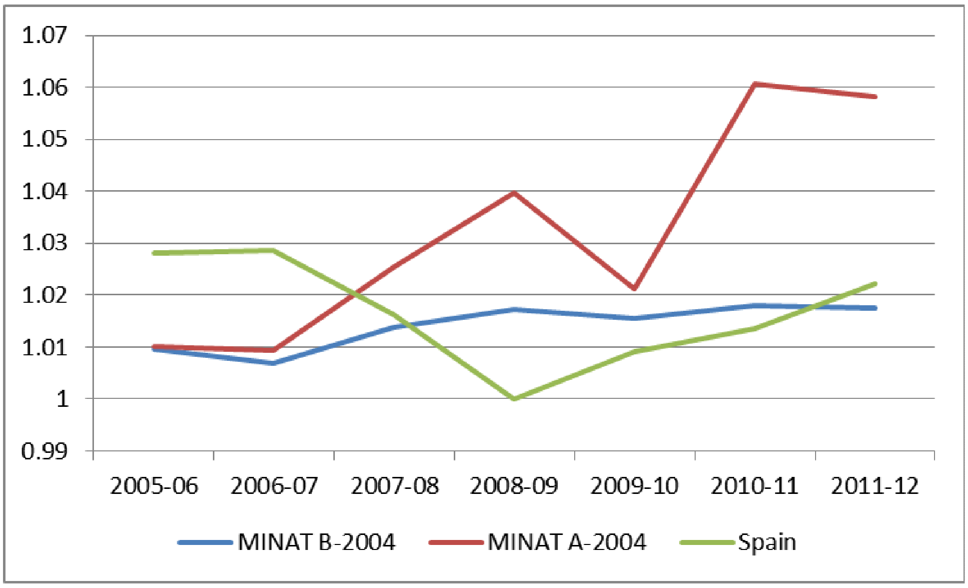
Source: Own elaboration.

Fig. 5. Comparison between the average managerial efficiency of Spain and the EU-28 countries (2005-2012).



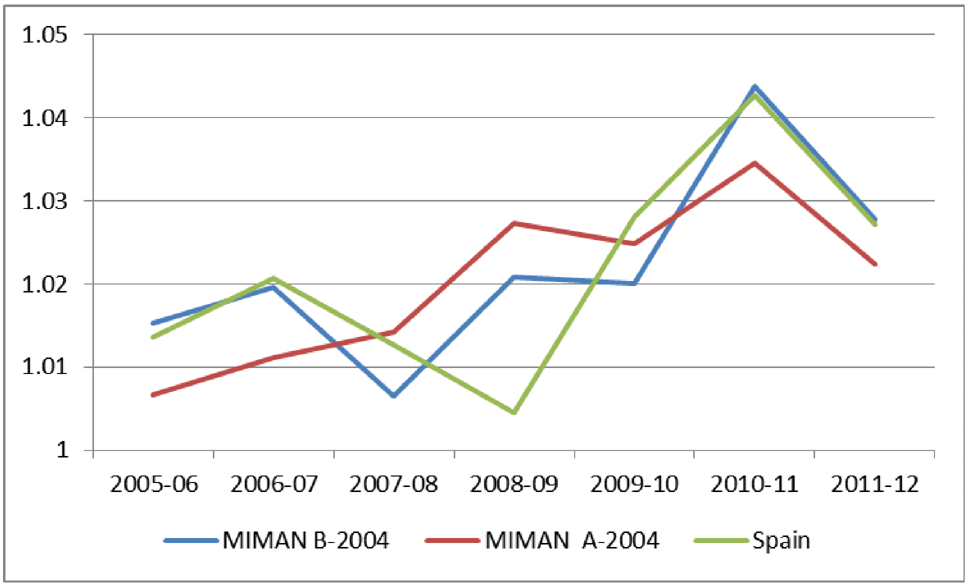
Source: Own elaboration.

Fig. 6. Evolution of the Malmquist Index based on natural efficiency. Period 2005-2012.



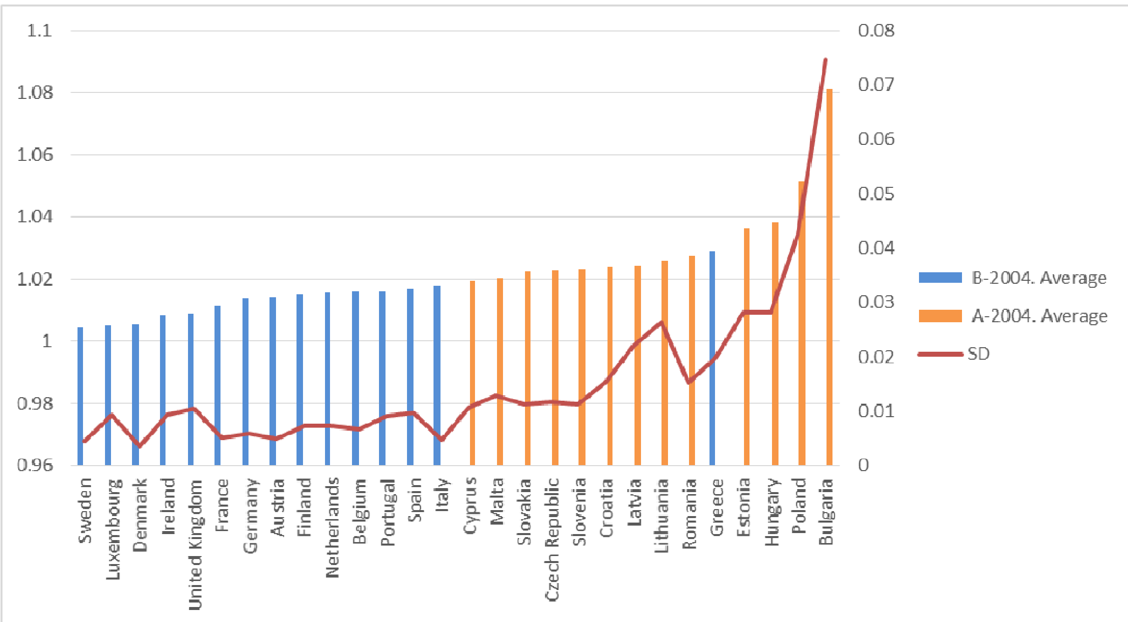
Source: Own elaboration.

Fig. 7. Evolution of the Malmquist Index based on managerial efficiency. Period 2005-2012.



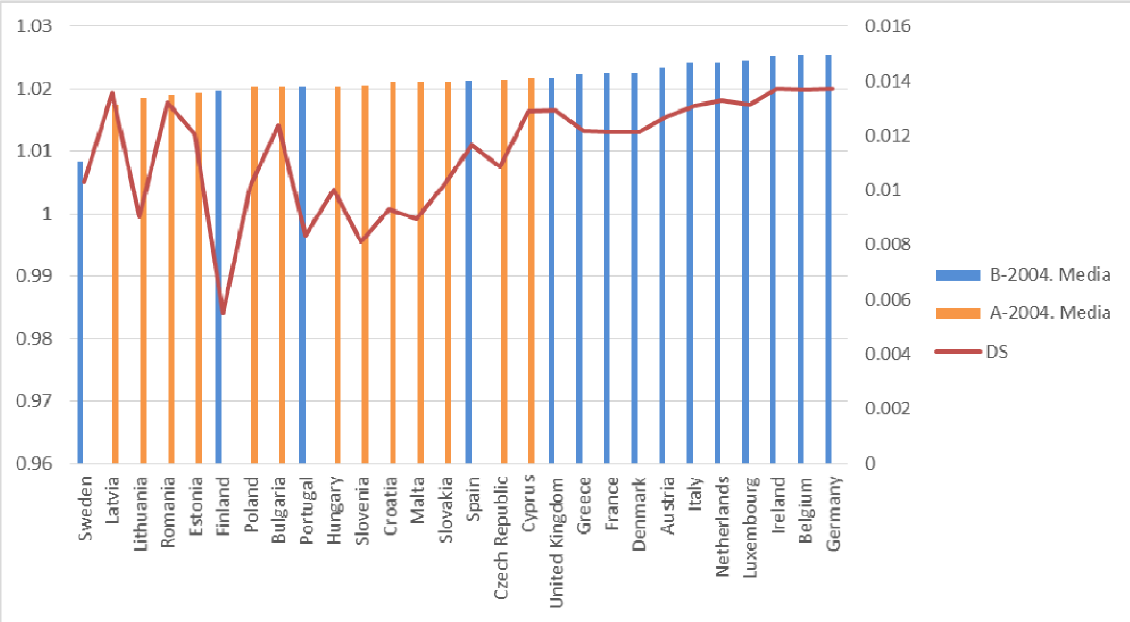
Source: Own elaboration.

Fig. 8. Average and typical deviation of the Malmquist Index based on natural efficiency.



Source: Own elaboration.

Fig. 9. Average and typical deviation of the Malmquist Index based on managerial efficiency.



Source: Own elaboration.