What position does Spain occupy in the EU-28 (2008-2017) from the standpoint of natural and managerial efficiency?

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What position does Spain occupy in the EU-28 (2008-2017) from the standpoint of natural and managerial efficiency?

Abstract: The European Union (EU) has become the group of countries most interested in the fight against climate change and is therefore committed to reducing greenhouse gas emissions. This research analyses the Natural and Managerial efficiency of the EU-28 countries for the period 2008-2017. The Data Envelopment Analysis methodology is used and Natural and Managerial Malmquist indices are obtained by assuming that a shift in the efficiency frontier exists and by considering that frontier crossings are possible across the different periods considered. The input variables used are those of Gross Fixed Capital Formation (GFCF), non-emitting energy consumption, and employment. Gross domestic product (GDP) and greenhouse gas (GHG) emissions are taken as the desirable and undesirable output variables, respectively.

The results of the analysis indicate that both Natural and Managerial efficiency have worsened in Spain during the period considered, whereby Spain has dropped in the relevant ranking. With regard to the Malmquist Index (MI), during this entire period, the position of the evolution of Spain in relation to all EU countries was better within the sphere of Managerial efficiency, than in that of Natural efficiency.

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1. - Introduction

Currently, a large number of countries have prioritised the objective of sustainable development in order to maximise economic growth whilst minimising greenhouse gas emissions. In the specific case of European Union (EU) countries, this objective has been reinforced both from internal and external points of view by following the Paris Climate Agreement and continuing to support the implementation of emission reduction policies, thereby reducing the impact of climate change, not only within the borders of the EU, but also in developing countries (United Nations, 2015).

Air pollution has grown significantly since the early industrial era to the present day, driven largely by economic and population growth (Stern, 2013; Cook et al., 2013; Huaman and Jun 2014; Revesz et al. 2014; Rafaj et al. 2015; Wiedmann et al. 2015). This pollution from greenhouse gas (GHG) emission will produce greater warming and significant alterations in certain elements of the climate model, thereby enlarging the probability of considerable widespread harm to people and ecosystems.

The EU has long been working to reduce this pollution. From 1997 with the Kyoto protocol, a climate and energy framework focused on the reduction of GHG emissions, the progressive increase in the use of renewable energy, and a commitment to increased energy efficiency has been adopted. Specifically, Directive 2009/28 established mandatory national objectives: a reduction of GHG emissions by 20%, renewable energy consumption at 20% of the total energy consumed in the EU, and renewable energy consumption at a minimum of 10% of the energy consumed for transportation by the year 2020.

The 2030 climate policy aims to achieve reductions in greenhouse gas emissions of approximately 45% by 2030, exceeding the commitment under the Paris Agreement to decrease emissions by at least 40% by 2030, compared to 1990 (European Commission, 2018a) . The goal of the EU's long-term strategy is to achieve net zero greenhouse gas emissions by 2050, across a socially just transition in a cost-effective way (European Commission, 2018b).

In 2018, from among the EU-28 Member States, 12 of them had already achieved a rate equal to or above their national 2020 mandatory objectives: Bulgaria (20.5%), Czech Republic (15.2%), Denmark (36.1%), Estonia (30%), Greece (18%), Croatia (28%), Cyprus (13.9%), Italy (17.8%), Latvia (40.3%), Lithuania (24.4%), Finland (41.2%), and Sweden (54.6%) (Eurostat, 2019).

The objective of this paper is to carry out a comparative analysis of Spain's position within the EU-28, in terms of environmental efficiency. To this end, the natural efficiency approach and the managerial efficiency approach are employed, as is the evolution of progress measured by the Malmquist Index, whereby the production level is maintained, and time windows of different amplitudes are used in order to obtain more information on this dynamic analysis.

In this situation, environmental evaluation is an analytical method that is widely used in the scientific research field, and is connected with the study and prevention of the negative effects of climate change in general, and of pollution, in particular. This article applies an environmental assessment methodology, based on data envelope analysis (DEA), regarding EU countries during the 2008-2017 period.

The DEA, as shown in the review by Zhou et al. (2008), has become one of the most successful methods in the fields of environmental research and analysis on energy efficiency (Mardani et al. 2017). In the field of environmental assessment, Färe et al. (1989) introduced the division of output into two categories, desirable and undesirable, which has been widely used ever since. Liu et al. (2010), Zhou et al. (2010), Sahoo et al. (2011), Wang et al. (2014), Kounetas (2015), Zhang et al. (2015), Zografidou et al. (2016), and Wang et al. (2019). Accordingly, this current work follows the Sueyoshi and Goto model (Sueyoshi and Goto 2013; Sueyoshi and Goto 2015; Sueyoshi, Goto and Wang 2017), whereby EU countries have been used as reference units, in line with Sanz-Díaz et al. (2017).

Through this approach, the intention is to shed light on the importance of the policy followed by EU countries to achieve the global objective of sustainable growth, which focuses on strategies based on the promotion of clean energy (Commission, 2010).

In our model and in line with Woo et al. (2015), employment and gross fixed capital formation (GFCF) are used as non-energy inputs, and the novelty of this paper involves the use of non-emitting energy consumption as an input. The gross domestic product (GDP) is used as a desirable output, and CO_2 emissions are used as an undesirable output. Non-emitting energy consumption includes renewable and nuclear energy; this is one of the bets of the European Commission in 2022, based on the JCR report (Abousahl et al. 2021), which has raised some controversy in the different European governments.

On the basis of these variables, the Natural and Managerial efficiency have been calculated. The first concept indicates that DMUs consider that the input vector must be reduced in order to reduce undesirable outputs, whilst increasing the desirable output vector, if possible (Sueyoshi and Goto,2012a). The second concept describes that the DMU increases the input vector in order to reduce the undesirable output vector, for which it needs to employ innovative technology to produce such an effect, whilst increasing the desirable output vector, if possible.

The Malmquist Index (MI) is also incorporated to examine Natural and Managerial efficiency, from a dynamic point of view, while contemplating the possibility of a frontier shift between two periods caused by technological progress (Rodríguez, Regueiro and Doldán 2020).

This paper is organised as follows: Section 2 describes the data employed and provides an explanation of the methodology used for the DEA, based on the measurement of Natural and Managerial efficiency and the MI, with the corresponding shift in the efficiency frontier, while using several time windows. In Section 3, the results are analysed by comparing the position of Spain with that of the remaining EU countries. Lastly, the conclusions are shown in Section 4

2. - Methodology and Data

2.1. Methodology

The DEA is a non-parametric mathematical programming technique that calculates the efficiency frontier and indicates which Decision-Making Units (DMUs) are on the frontier, and which are not. In this analysis, a radial model with windows of two or more periods is used.

The DEA technique identifies a frontier that envelopes the data and that is used to evaluate the performance of all of the entities under analysis. The term Decision-Making Unit (DMU) represents any entity that is to be evaluated as part of a homogeneous collection, that is, all DMUs utilises and produce similar inputs and outputs. The result of this process is a set of performance scores that ranges between zero and unity, with the unity value representing the maximum efficiency. Moreover, the DEA identifies the reasons for inefficiency in each input and output for all DMUs. The set of efficient DMUs serves as a benchmark to improve future performance on inefficient DMUs.

This section begins by presenting two concepts associated with the environmental protection assessment that derive from the application of the DEA methodology to the environment, and which have been proposed by Sueyoshi and Goto (2012a, 2012b, 2012c, 2012d, 2012e, 2014, 2015) to measure Natural and Managerial efficiency of various DMUs.

The first concept refers to "Natural disposability", which indicates that DMUs consider that the input vector must be reduced in order to reduce undesirable outputs, whilst increasing the desirable output vector, if possible (Sueyoshi and Goto, 2012a, 2012b, 2012c). The second concept, 'Managerial disposability', describes the opposite situation, in which the DMU increases the input vector in order to reduce the undesirable output vector, for which it needs to employ innovative technology to produce such an effect, while increasing the desirable output vector, if possible.

In the DEA literature, the concept of "managerial disposability" or "managerial efficiency" exposes the capacity of a DMU to optimize several outputs on a simultaneous basis (eg, increasing or at least maintaining desirable outputs while minimizing undesirable outputs), while inputs are at least maintained or increased (Exposito and Velasco, 2018). The multiple optimization problem applied in DEA (with desirable and undesirable outputs) is usually achieved through the introduction of "innovation" into the way that inputs are used to obtain outputs, thereby allowing undesirable outputs to be reduced while still augmenting (or at least maintaining) desirable outputs (Sueyoshi and Goto 2011).

To describe the concepts of Natural and Managerial disposability using an axiomatic expression, $X \in R_m^+$ must be considered as the input vector, $G \in R_s^+$ as the desirable output vector, and $B \in R_h^+$ as the undesirable output vector. All three are column vectors, whose components are all positive.

The concepts of Natural and Managerial disposability are specified by the following production factor vectors, under constant returns to scale (RTS) and constant damages to scale (DTS), respectively, (where DTS is the parallel economic concept to RTS for the case of undesirable outputs):

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

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

Note that the subscript (j) stands for the j-th DMU and λ_j represents the j-th structural or intensity variable, for j=1,…,n. The superscript (N) specifies the natural disposability concept, and the superscript (M) denotes the managerial disposability concept. There is a difference between the two concepts of disposability: the production technology under natural disposability, $P^N(X)$, has the inequality on inputs, $X \geq \sum_{j=1}^{n} X_j \, \lambda_j$; while the managerial disposability, $P^M(X)$, has the inequality $X \leq \sum_{j=1}^{n} X_j \, \lambda_j$.

It is important to note that in the radial approach it is possible to incorporate unified inefficiency scores in the computational framework.

In production economics, there are several formulations of indices (such as the Laspeyres and Paasche price indices) as Törmquist and Fisher indices that analyse which is more appropriate when calculating indices of input and output quantities. Total Factor Productivity (TFP) (Coelli 2005) and the Malmquist Caves, Christensen and Diewert 1982) index link efficiency and productivity using a distance function based on productivity measures. The Malmquist Index examines an occurrence of a frontier shift across multiple periods.The Malmquist-Luenberger (M-L) index, introduced by Chung, Färe,, andGrosskopf (Chung, Färe and Grosskopf 1997) , is particularly useful when measuring productivity and environmental performance associated with undesirable outputs. The distance function of the M-L index is characterised by the directional distance function (DDF) (Chambers, Chung and Färe 1996).

In this paper, the desirable and undesirable outputs are incorporated in order to address the environment assessment. It is therefore important to unify desirable and undesirable outputs in measurement indices, such as ecotechnology innovation for pollution reduction.

The concept of Natural and Managerial disposability is analysed on a time horizon through the MI values (Sueyoshi, Goto, Wang 2017).

2.1.1. Malmquist Index: Natural Disposability

The Malmquist indexes (MI) allow obtain interperiod changes in relative efficiency to be evaluated. (Sueyoshi et al. 2017). These indexes are estimated for alternative time periods or temporal 'windows', which help us to evaluate changes and trends in the medium and long term. This methodology allows for the dynamic assessment of the capacity of each country to achieve specified objectives, compared to the remaining countries

Positive change in the index (MI) under natural disposability signifies potential economic growth.

Firstly, no occurrence of frontier crossover is considered across different periods; that is to say, an efficiency frontier shifts without a frontier crossing occurring between the two periods. The MI between two periods (z-th: base and t–th: specific) can be specified using the following expression [24]:

$$IN_z^t = \sqrt{\frac{\mathrm{UEN}_z^R}{\mathrm{IUIN}_{\mathrm{z\to t}}^R}\,\frac{\mathrm{IUIN}_{\mathrm{t\to z}}^R}{\mathrm{UEN}_t^R}} \tag{1}$$

where UEN_z^R is the Unified Efficiency in the z-th base period, and UEN_t^R is the Unified Efficiency in the t-th base period. $\mathrm{IUIN}_{\mathrm{t\to z}}^R$ is the Inter-temporal Unified Index from the t-th period to the z-th period and $\mathrm{IUIN}_{\mathrm{z\to t}}^R$ is the Inter-temporal Unified Index from the z-th period to the t-th period. $\mathrm{IUIN}_{\mathrm{z\to t}}^R$ and $\mathrm{IUIN}_{\mathrm{t\to z}}^R$ may become more or less than unity, since they depend on a frontier structure (including a crossover) between the two periods. They are therefore intertemporal unified indicators. They are measured under Natural (N) disposability under constant RTS. Here, no occurrence of the frontier crossover between the two (z-th and t-th) periods is assumed.

Secondly, the possible occurrence of frontier crossover is considered and the MI may be specified, using the following expression (Sueyoshi, Goto, Wang 2017):

$$INC_z^{t-1\&t} = \sqrt{\frac{\mathrm{UEN}_z^R}{\mathrm{IUIN}_{\mathrm{z}\to t-1\&t}^R}\,\frac{\mathrm{IUIN}_{\mathrm{t\to z}}^R}{\mathrm{UEN}_{t\to t-1\&t}^R}} \tag{2}$$

where $\mathrm{IUIN}_{\mathrm{z}\to t-1\&t}^R$ is the Inter-temporal Unified Index from the z-th period to the $t-1\&t$-th period, and $\mathrm{UEN}_{\mathrm{t}\to t-1\&t}^R$ is the Unified Efficiency from the t-th period to the $t-1\&t$-th period.

Frontiers encountered in consecutive periods may intersect for various reasons. These intersections may be due either to low production in subsequent periods or to the implementation of new technologies that elevate environmental efficiency due to time lags in obtaining results.

In order to avoid infeasible solutions on index measurement, it is necessary to assume constant RTS. All efficiency and index measures are obtained by radial measurement under Natural disposability.

Each of the values applied in (1) and (2) are reached by linear programming problems, which are explained below.

No occurrence of frontier crossover

These measures are formulated by the following radial models:

The degree of unified efficiency UEN_t^R of the *k-th* DMU in the *t* period $(t = z + 1, \dots, T)$ is measured by the following model under Natural disposability:

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

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

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

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

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

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

where $d_i^{x-}, 1 \leq i \leq m$, $d_r^g, 1 \leq r \leq s$ and $d_f^b, 1 \leq f \leq h$ are the corresponding slack variables related to inputs, desirable outputs, and undesirable outputs, and these constitute decision variables in (P1). The column vector of unknown variables $\lambda = (\lambda_1, \dots, \lambda_n)$, called the structural or intensity variables, are considered as decision variables in (P1). The scalar value, ξ, unrestricted, represents a unified inefficiency measure. The degree of inefficiency is measured as the distance between an efficiency frontier and an observed vector of desirable and undesirable outputs. The scalar value ϵ_s is an Archimedean number and indicates the relative importance between the inefficiency measure and the sum of all slack variables, and it is taken as a sufficiently small number. The superscript ϑ has the value 0 for the Natural disposability, and J_t stands for all DMUs in the t-th period.

Adjustments to the data range, R, in model (P1) are determined by the upper and lower bounds of the production factors as follows:

$$R_i^x = (m+s+h)^{-1}\left(max\{x_{ij}; j\epsilon J_z \cup J_{z+1} \cup \dots J_T\} - min\{x_{ij}; j\epsilon J_z \cup J_{z+1} \cup \dots J_T\}\right)^{-1}$$

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

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

The degree of UEN_t^R of the *k-th* DMU in the *t* period is measured by:

$$\mathrm{UEN}_t^R = 1 - \left[\xi^* + \varepsilon\left(\sum_{i=1}^m R_i^x d_i^{x-*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*}\right)\right] \tag{3}$$

The level of unified inefficiency under natural disposability is calculated in Equation (3) between brackets in UEN_t^R and the unified efficiency is attained by subtracting the level of inefficiency from unity. This can either be less than unity, which shows inefficiency, or be unity, thereby indicating full efficiency.

The degree of UEN_z^R, with respect to the k-th DMU in the period z, is measured by replacing t with z in the Model (P1), where the superscript $(*)$ indicates that it is the optimum of (P1).

The degree of $\mathrm{IUIN}_{t\to z}^R$ with respect to the k-th DMU in the t-th period, projecting from the t-th period to the z period, is determined by the following model:

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

$$s.t. \sum_{j\epsilon J_z} x_{ijz}\lambda_{jz} + (-1)^{\vartheta} d_i^{x-} = x_{ikt};\ \forall\ k\epsilon J_t;\ i = 1,\dots,m$$

$$\sum_{j\epsilon J_z} g_{rjz}\lambda_{jz} - d_r^g - \xi\ g_{rkt} = g_{rkt};\ \forall\ k\epsilon J_t;\ r = 1,\dots,s$$

$$\sum_{j\epsilon J_z} b_{fjz}\lambda_{jz} + d_f^b + \xi\ b_{fkt} = b_{fkt};\ \forall\ k\epsilon J_t;\ f = 1,\dots,h$$

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

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

The degree of the $\mathrm{IUIN}_{\mathrm{t \to z}}^R$ index is measured by:

$$\mathrm{IUIN}_{\mathrm{t \to z}}^R = 1 - \left[\xi^* + \varepsilon\left(\sum_{i=1}^m R_i^x d_i^{x-*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*}\right)\right] \qquad (4)$$

The degree of $\mathrm{IUIN}_{\mathrm{z \to t}}^R$, with respect to the k-th DMU in the z-th period, projected from the z-th period to the t-th period, is determined by the following model:

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

$$s.t. \sum_{j \epsilon J_t} x_{ijt} \lambda_{jt} + (-1)^\vartheta d_i^{x-} = x_{ikz};\ \forall\ k \epsilon J_z;\ i = 1, \dots, m$$

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

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

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

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

The degree of the $\mathrm{IUIN}_{\mathrm{z \to t}}^R$ index is measured by:

$$\mathrm{IUIN}_{\mathrm{z \to t}}^R = 1 - \left[\xi^* + \varepsilon\left(\sum_{i=1}^m R_i^x d_i^{x-*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*}\right)\right] \qquad (5)$$

Possible occurrence of frontier crossover

The possible occurrence of frontier crossover can now be considered, and for the MI to obtain it, it is necessary to solve the following two models (P4) and (P5):

The degree of $\mathrm{UEN}_{t \to t-1\&t}^R$ on the k-th DMU in the t-th period is measured by the following model:

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

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

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

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

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

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

The degree of $\mathrm{UEN}^R_{t\to t-1\&t}$, with respect to the k-th DMU in the t-th period, is determined as follows:

$$\mathrm{UEN}^R_{t\to t-1\&t} = 1 - \left[\xi^* + \varepsilon\left(\sum_{i=1}^m R_i^x d_i^{x-*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*}\right)\right] \tag{6}$$

The degree of $\mathrm{IUIN}^R_{z\to t-1\&t}$ on the k-th DMU in the t-th period is measured by the following model:

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

$$s.t. \sum_{j\epsilon J_{t-1\&t}} x_{ijt-1\&t}\,\lambda_{jt-1\&t} + (-1)^{\vartheta} d_i^{x-} \qquad = x_{ikz};\;\; \forall\; k\epsilon J_z\,;\;\; i = 1, \dots, m$$

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

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

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

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

The degree of $\mathrm{IUIN}^R_{z\to t-1\&t}$, with respect to the k-th DMU in the z-th period, is determined as follows:

$$\mathrm{IUIN}^R_{z\to t-1\&t} = 1 - \left[\xi^* + \varepsilon\left(\sum_{i=1}^m R_i^x d_i^{x-*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*}\right)\right] \tag{7}$$

2.1.2. Malmquist Index: Managerial disposability

If there is a shift in the frontier, then potential progress occurs due to technological development and improved management in the periods used. The alteration of the index (MI) under managerial disposability also implies the potential prevention of industrial pollution.

The MI with a frontier shift between two periods may be represented as follows:

$$IM_z^t = \sqrt{\frac{\mathrm{UEM}_z^R}{\mathrm{IUIM}_{\mathrm{z \to t}}^R} \frac{\mathrm{IUIM}_{\mathrm{t \to z}}^R}{\mathrm{UEM}_t^R}}$$

$$IMC_z^{t-1\&t} = \sqrt{\frac{\mathrm{UEM}_z^R}{\mathrm{IUIM}_{\mathrm{z} \to t-1\&t}^R} \frac{\mathrm{IUIM}_{\mathrm{t \to z}}^R}{\mathrm{UEM}_{t \to t-1\&t}^R}}$$

It should be noted that, in order to obtain this index (Managerial), it is only necessary to replace the superscript ϑ, giving the value 1 instead of zero (Natural), and to replace all d_i^{x-} with d_i^{x+} in the (P1), (P2), (P3), (P4), and (P5).

These models can easily be generalised for windows of three or more periods (Sueyoshi, Goto, Wang 2017). This paper presents data collected with windows of several periods.

For instance, the following models indicate the levels of potential performance, due to the frontier shift. All data is also pooled into a single balanced panel data, for the purpose of measuring the level of unified inefficiency under Natural disposability, and each k DMU in the period t.

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

$$s.t. \sum_{t=z}^{T} \sum_{j \epsilon J_t} x_{ijt}\, \lambda_{jt} + (-1)^{\vartheta} d_i^{x+} \qquad = x_{ikt}\,;\ \ \forall\ k \epsilon J_t\,;\ \ i = 1, \dots, m$$

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

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

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

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

where $R_i^x = (m+s+h)^{-1}\left(max\{x_{ij}; j \epsilon J_z \cup J_{z+1} \cup \dots J_T\} - min\{x_{ij}; j \epsilon J_z \cup J_{z+1} \cup \dots J_T\}\right)^{-1}$

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

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

where the superscript ϑ has the value 1 for the Managerial disposability and J_t stands for all DMUs in the t-th period.

The degree of UENT_t^R of the *k-th* DMU in the *t* period is measured by the following:

$$\text{UENT}_t^R = 1 - \left[\xi^* + \varepsilon\left(\sum_{i=1}^{m} R_i^x d_i^{x+*} + \sum_{r=1}^{s} R_r^g d_r^{g*} + \sum_{f=1}^{h} R_f^b d_f^{b*}\right)\right] \quad (8)$$

And similarly, the level of unified inefficiency under Managerial disposability and each k DMU in the t-th period.

$$\text{(P7) } Max\ \xi + \varepsilon\left[\sum_{i=1}^{m} R_i^x d_i^{x+} + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right]$$

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

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

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

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

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

where $R_i^x = (m+s+h)^{-1}\left(max\{x_{ij}; j\epsilon J_z \cup J_{z+1} \cup \dots J_T\} - min\{x_{ij}; j\epsilon J_z \cup J_{z+1} \cup \dots J_T\}\right)^{-1}$

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

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

where the superscript ϑ has the value 1 for the Managerial disposability, and J_t stands for all DMUs in the t-th period.

The degree of UEMT_t^R of the *k-th* DMU in the *t-th* period is measured by:

$$\text{UEMT}_t^R = 1 - \left[\xi^* + \varepsilon\left(\sum_{i=1}^{m} R_i^x d_i^{x+*} + \sum_{r=1}^{s} R_r^g d_r^{g*} + \sum_{f=1}^{h} R_f^b d_f^{b*}\right)\right] \quad (9)$$

It is interesting to note that the combination of Malmquist indices under natural and managerial disposability provides a total potential on how to achieve the optimal level of sustainability under these two different concepts of disposability.

2.2. Data

In this paper, five variables are included in the analysis: three inputs and two outputs. The two non-energy inputs are total employment (in thousands of people) and GFCF deflated by the Harmonised Index of Consumer Prices for each country and year (in millions of euros). In addition, the analysis includes an energy input: non-emitting energy consumption, that is, consumption of renewable and nuclear energy (in thousands of tonnes of oil equivalent). As highlighted in the Introduction, this input provides an innovative contribution to this work. Two outputs are considered, one desirable and the other undesirable. The first is GDP in constant terms, for which the same price index is employed to deflate the GFCF (expressed in millions of euros). The undesirable output is GHG emissions (in thousands of tonnes of CO_2 equivalent). The database used is that of Eurostat (2008-2017) to the period under study..

As indicated in the previous section, the variables selected are in agreement with those used in previous studies. Specifically, Woo et al. (2015) include many of the articles published with a similar methodology, and in which countries are used as DMUs. Likewise, Menegaki (2013), Chang (2014), Kounetas (2015), Makridou et al. (2016), Zhang et al. (2019), Wei et al. (2019), and Gökgöz and Güvercin (2018), who are not included in the review by Woo et al. (2015), also use similar variables for the analysis of environmental efficiency in Europe.

Table 1 shows the arithmetic mean of the variables considered for the period under study, plus a column in which the percentage of non-emitting energy has been calculated over the total energy consumption of the country in question. This table shows how Spain occupies the middle of the table, position 13, in the percentage of non-emitting energy (24.31%). The country with the most prominent position therein is Sweden, which exceeds 70%.

Table 1. Arithmetic mean of the variables per country for the period 2008-2017.

COUNTRIES	EMPLOYMENT (thousands of people)	NON-EMITTING ENERGY CONSUMPTION (thousands of TOE)	GFCF (millions of €)	GDP (millions of €)	EMISSIONS (thousands of tonnes of CO2 eq.)	% OF NON-EMITTING ENERGY
Sweden	4568	33915	97416	417987	54783	71,50
France	25629	133648	480361	2160899	345478	54,21
Finland	2413	15518	46217	210222	59130	47,24
Slovenia	922	2480	8157	38980	15795	34,73
Latvia	873	1577	5351	23118	10842	33,77
Slovakia	2375	5386	16920	75913	37266	32,49
Bulgaria	3019	5615	9638	43119	50684	31,63
Austria	4024	9415	76834	337353	59449	28,21
Denmark	2687	4485	52838	265979	84646	27,74
Romania	8355	8592	41667	157741	108053	26,66
Hungary	3954	6771	23759	111521	48821	26,27
Czech Republic	4898	11015	44296	169254	105996	26,16
Spain	18236	30822	241005	1107783	278534	24,31
Croatia	1596	1892	10110	47151	20122	22,07
Portugal	4432	5031	32392	182916	59337	20,15
Lithuania	1286	1792	6775	35074	21529	19,25
Germany	38678	60355	581935	2919249	778977	19,25
Belgium	4481	14094	92036	402222	91138	18,56
United Kingdom	29222	25945	363159	2226102	458038	16,73
Italy	22176	24150	313207	1690416	352603	16,47
Estonia	597	855	4914	19311	19353	15,70
Greece	3869	2369	31447	200880	85490	11,46
Poland	15577	7973	80925	406751	345703	8,58
Ireland	1968	874	50481	209583	52487	7,32
Netherlands	8178	4484	138732	692132	176753	5,96
Cyprus	367	128	3588	19161	7149	5,70
Luxembourg	236	171	9049	47479	8076	4,85
Malta	179	14	1670	8296	3529	2,46

Source: Authors' own based on Eurostat database (Eurostat, 2020a, 2020b, 2020c,2020d)

3. - Results and Discussion

Natural and Managerial efficiency are analysing in this paper following the model of Sueyoshi and Gotto (2013, 2017). The evolution of the MI is analysed for the period 2008 to 2017 for EU-28 countries.

3.1. Natural and Managerial Efficiency

These efficiencys, indicate the degree to which countries attempt to follow the strategies of "Natural disposability" and "Managerial disposability", as denominated by Sueyoshi and Goto (2013).

Both strategies aim to increase the desirable output while reducing the undesirable output. While *Natural disposability* is based on the reduction of inputs, *Managerial disposability* focuses on improving technology to achieve its objectives, and may even increase inputs.

Natural Efficiency

Countries have been ranked in quartiles, according to the average of the period studied. The average Natural efficiency of the period in the countries situated in the first quartile lies between 0.995 for Luxembourg and 0.898 for Austria, as shown in Table 2. In this group of countries, Luxembourg presents maximum Natural efficiency in 7 of the 10 years of study, and its position appears consolidated by being at the frontier of Natural efficiency, in the last four years analysed. The other two countries of the group that reach maximum Natural efficiency are Sweden (2013, 2015, and 2016) and Malta (2008 and 2009). In these four countries, a decoupling between economic growth and GHG emissions has been produced because the rate of GDP growth has not been accompanied by a growth in contamination, as shown in Table 3.

Of the remaining countries, only Greece (2014 and 2015) and Cyprus (2014) are located on the Natural efficiency frontier. In these two countries, both the average GDP rate and the average emissions rate have been negative, as shown in Table 3.

The range of average Natural efficiency of the countries classified in the fourth quartile is between 0.590 for Latvia and 0.359 for Estonia. In the case of Latvia, the average rate of GDP and of emissions is negative, whilst in the case of Estonia there is a coupling between economic growth and contamination, with both increasing in the middle of the period. These two Baltic countries are joined in the fourth quartile by five Eastern European countries, which have registered a decoupling between GDP growth and emissions (see Table 3).

In this period, the behaviour of the Natural efficiency divides the European Union into two: the western countries plus Greece and Cyprus, with levels close to maximum efficiency, and the eastern countries, with values below 50% of the maximum value of the same.

Table 2. Natural efficiency of the countries considered between 2008 and 2017 and the average of this period.

Position			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
Q1	1	Luxembourg	*1.000*	0.969	*1.000*	*1.000*	0.987	0.996	*1.000*	*1.000*	*1.000*	*1.000*	0.995
	2	United Kin.	0.941	0.979	0.986	0.985	0.991	0.979	0.982	*1.000*	0.997	0.980	0.982
	3	Sweden	0.877	0.889	0.910	0.949	0.977	*1.000*	0.995	*1.000*	*1.000*	0.999	0.960
	4	Malta	*1.000*	*1.000*	0.908	0.970	0.945	0.988	0.984	0.915	0.909	0.828	0.945
	5	France	0.853	0.888	0.887	0.898	0.901	0.910	0.935	0.948	0.954	0.947	0.912
	6	Italy	0.792	0.841	0.836	0.847	0.888	0.943	0.970	0.963	0.961	0.947	0.899
	7	Austria	0.835	0.869	0.858	0.861	0.905	0.906	0.940	0.911	0.949	0.945	0.898
Q2	8	Greece	0.626	0.719	0.791	0.839	0.947	0.970	*1.000*	*1.000*	0.976	0.933	0.880
	9	Ireland	0.831	0.819	0.936	0.958	0.836	0.880	0.821	0.865	0.858	0.878	0.868
	10	Netherlands	0.778	0.796	0.844	0.835	0.879	0.893	0.918	0.771	0.842	0.844	0.840
	11	Portugal	0.636	0.705	0.745	0.810	0.887	0.935	0.929	0.903	0.919	0.865	0.834
	12	Cyprus	0.564	0.645	0.689	0.799	0.920	0.950	*1.000*	0.972	0.830	0.720	0.809
	13	Denmark	0.662	0.763	0.863	0.861	0.841	0.838	0.847	0.825	0.781	0.777	0.806
	14	Germany	0.770	0.817	0.811	0.785	0.789	0.804	0.803	0.815	0.812	0.809	0.801
Q3	15	Belgium	0.721	0.774	0.771	0.788	0.794	0.804	0.812	0.814	0.818	0.824	0.792
	16	Spain	0.699	0.744	0.764	0.756	0.794	0.847	0.827	0.802	0.817	0.803	0.785
	17	Finland	0.676	0.686	0.705	0.709	0.722	0.756	0.791	0.813	0.768	0.782	0.741
	18	Slovenia	0.486	0.551	0.646	0.679	0.707	0.694	0.738	0.762	0.806	0.786	0.686
	19	Croatia	0.502	0.522	0.643	0.668	0.694	0.696	0.718	0.713	0.709	0.716	0.658
	20	Hungary	0.590	0.591	0.666	0.683	0.693	0.654	0.617	0.607	0.707	0.625	0.643
	21	Lithuania	0.424	0.647	0.669	0.628	0.668	0.656	0.641	0.629	0.630	0.639	0.623
Q4	22	Latvia	0.475	0.564	0.615	0.576	0.499	0.573	0.601	0.614	0.705	0.674	0.590
	23	Slovakia	0.452	0.575	0.575	0.519	0.616	0.636	0.652	0.548	0.649	0.649	0.587
	24	Poland	0.454	0.453	0.496	0.487	0.512	0.540	0.536	0.538	0.581	0.608	0.520
	25	Romania	0.331	0.400	0.392	0.353	0.351	0.443	0.462	0.460	0.537	0.565	0.429
	26	Czech Rep.	0.371	0.387	0.395	0.416	0.428	0.453	0.450	0.427	0.475	0.492	0.429
	27	Bulgaria	0.191	0.269	0.368	0.381	0.394	0.422	0.422	0.426	0.513	0.519	0.391
	28	Estonia	0.264	0.423	0.399	0.319	0.279	0.287	0.348	0.435	0.437	0.403	0.359
		Average	0.636	0.689	0.720	0.727	0.744	0.766	0.776	0.767	0.784	0.770	0.738

Source: The authors' own.

In the case of Natural efficiency, as shown in Table 2, it is located in the third quartile if the average of Natural efficiency of the period studied is considered, although according to the value of Natural efficiency, in the first and last year of the period, Spain moved from position 12 in 2008, to 14 in 2017 and has only been overtaken by Greece and Portugal. The European Union intervened in both of these countries, which had low rates of GDP at the beginning of the period analysed.

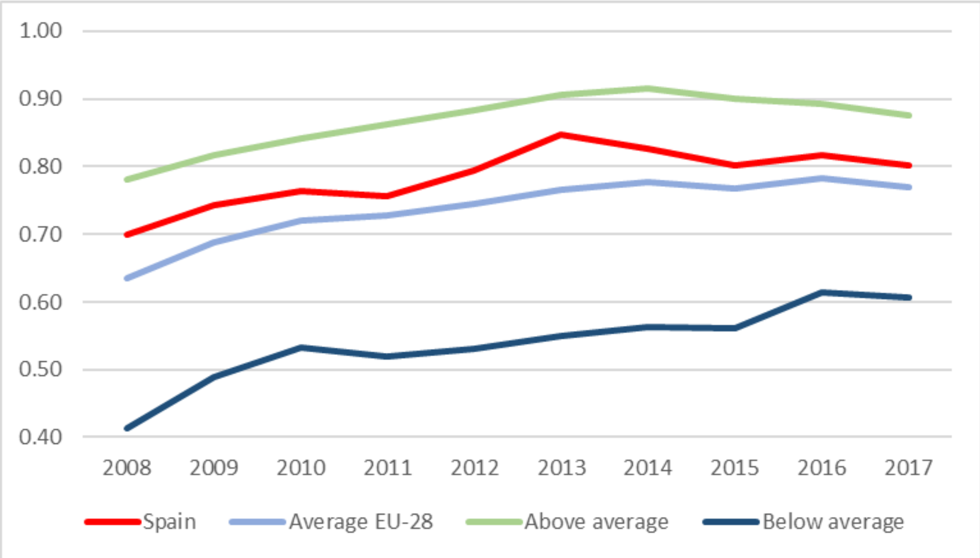
Table 3. Variation rate of GHG emissions, non-emitting energy consumption, and GDP during the 2008-2017 period (%)

COUNTRIES	NON-EMITTING ENERGY CONSUMPTION	GDP	GHG EMISSIONS
Austria	0.20	0.08	-0.16
Belgium	0.10	0.07	-0.18
Bulgaria	0.13	0.27	-0.13
Croatia	0.16	*-0.09*	*-0.24*
Cyprus	0.75	*-0.04*	*-0.20*
Czech Republic	0.22	0.05	-0.15
Denmark	0.78	0.09	-0.19
Estonia	0.64	0.17	0.02
Finland	0.14	0.00	-0.20
France	***-0.02***	0.05	-0.15
Germany	0.01	0.15	-0.09
Greece	0.71	*-0.31*	*-0.31*
Hungary	0.20	*-0.08*	*-0.11*
Ireland	1.30	0.57	0.14
Italy	0.46	*-0.06*	*-0.28*
Latvia	0.40	*-0.02*	*-0.11*
Lithuania	***-0.58***	0.08	-0.02
Luxembourg	1.05	0.26	0.00
Malta	43.36	0.59	-0.14
Netherlands	0.26	0.02	-0.04
Poland	0.60	0.09	-0.01
Portugal	0.12	*-0.01*	*-0.07*
Romania	0.09	0.00	-0.25
Slovakia	0.03	0.15	-0.19
Slovenia	0.04	0.02	-0.19
Spain	0.25	*-0.05*	*-0.18*
Sweden	0.16	0.21	-0.13
United Kingdom	0.72	-0.04	-0.03

Source: Authors' own based on the Eurostat Database (Eurostat, 2020a, 2020b, 2020c, 2020d).

With the objective of facilitating the analysis, the 28 countries were grouped into two clusters. The first cluster, "Above Average", groups those countries whose average was above the European average for the entire period. The second group, "Below Average", is composed of the countries whose average was below the European average for the period considered.

Figure 1. Comparison of Natural Efficiency in Spain against the average of the EU-28 Countries (2008-2017).



Source: The authors' own.

The evolution of the Natural efficiency of Spain follows the same growth trend as the average of all of the EU-28 countries, for both the above-average and below-average clusters, as shown in Figure 1.

Managerial Efficiency

On the other hand, as shown in Table 4, the average Managerial efficiency, for the period in the countries in the first quartile, lies between 0.934 for Sweden and 0.813 for Portugal. In this group of countries, Sweden presents the maximum Managerial efficiency in the last two years of the period analysed, which is why its position appears consolidated since it is at the frontier of Managerial efficiency. No other country of the group reaches maximum Managerial efficiency during the period analysed.

In the remaining countries, not one is on the frontier, or the average, of Managerial efficiency, in any year of the period considered. The range of the average Managerial efficiency of the countries, classified in the fourth quartile, is between 0.564 for Cyprus and 0.338 for Estonia. This Baltic country is the EU-28 country that is furthest from both the Natural and Managerial efficiency frontier.

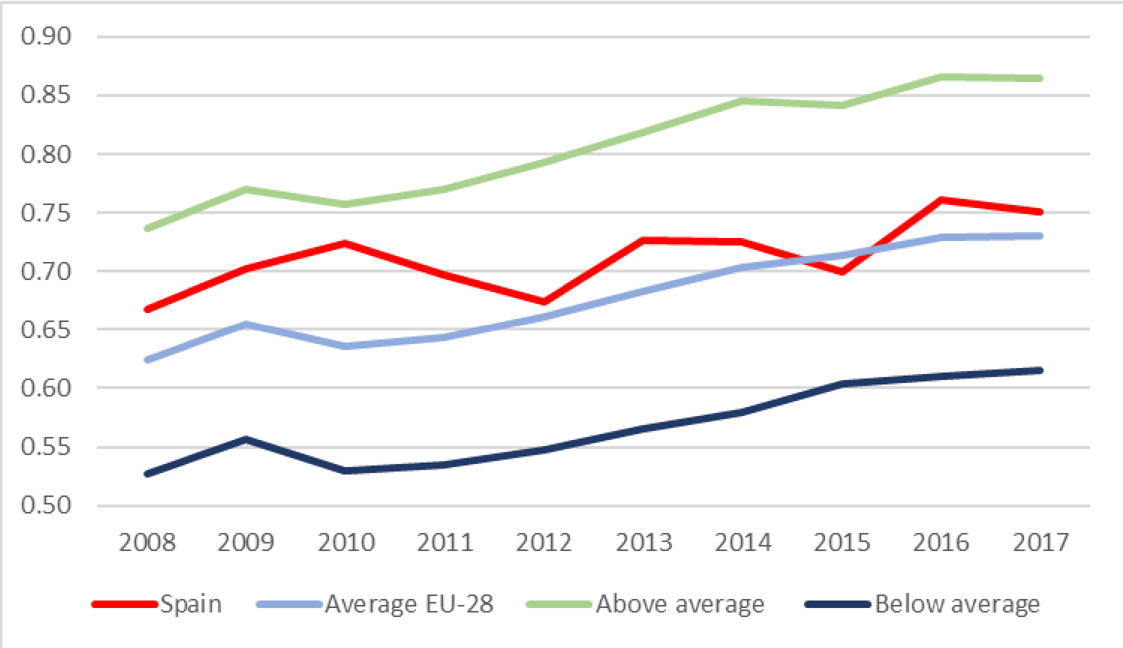
Table 4. Managerial efficiency of the countries considered between 2008 and 2017 and the average of this period.

Position			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
Q1	1	**Sweden**	0.835	0.862	0.832	0.903	0.948	0.977	0.982	0.997	*1.000*	*1.000*	0.934
	2	**Hungary**	0.745	0.810	0.798	0.810	0.879	0.930	0.967	0.954	0.988	0.958	0.884
	3	**Latvia**	0.926	0.910	0.755	0.838	0.868	0.898	0.899	0.881	0.892	0.889	0.876
	4	**Croatia**	0.779	0.840	0.828	0.801	0.834	0.855	0.922	0.926	0.932	0.949	0.867
	5	**Romania**	0.724	0.857	0.831	0.776	0.814	0.879	0.885	0.874	0.903	0.909	0.845
	6	**France**	0.776	0.794	0.793	0.818	0.823	0.825	0.857	0.868	0.883	0.880	0.832
	7	**Portugal**	0.768	0.798	0.853	0.836	0.814	0.822	0.839	0.791	0.826	0.782	0.813
Q2	8	**Luxembourg**	0.738	0.723	0.743	0.809	0.807	0.824	0.850	0.816	0.840	0.849	0.800
	9	**Austria**	0.719	0.752	0.730	0.741	0.796	0.800	0.835	0.802	0.842	0.837	0.785
	10	**United King.**	0.652	0.629	0.640	0.654	0.679	0.683	0.747	0.832	0.850	0.883	0.725
	11	**Spain**	0.668	0.702	0.725	0.697	0.674	0.727	0.725	0.699	0.761	0.751	0.713
	12	**Italy**	0.641	0.684	0.678	0.684	0.686	0.723	0.749	0.742	0.763	0.775	0.712
	13	**Slovakia**	0.605	0.654	0.638	0.638	0.690	0.700	0.742	0.757	0.771	0.772	0.697
	14	**Belgium**	0.600	0.644	0.627	0.661	0.671	0.675	0.694	0.694	0.709	0.716	0.669
Q3	15	**Lithuania**	0.635	0.736	0.666	0.629	0.637	0.670	0.648	0.655	0.626	0.605	0.651
	16	**Bulgaria**	0.625	0.714	0.645	0.565	0.613	0.688	0.663	0.639	0.672	0.670	0.649
	17	**Slovenia**	0.579	0.623	0.618	0.594	0.611	0.621	0.687	0.684	0.660	0.695	0.637
	18	**Ireland**	0.589	0.601	0.542	0.565	0.554	0.577	0.600	0.712	0.776	0.734	0.625
	19	**Netherlands**	0.615	0.610	0.598	0.614	0.615	0.612	0.616	0.611	0.624	0.641	0.616
	20	**Germany**	0.554	0.573	0.572	0.588	0.584	0.583	0.609	0.621	0.637	0.652	0.597
	21	**Finland**	0.552	0.538	0.498	0.545	0.577	0.568	0.600	0.638	0.620	0.648	0.578
Q4	22	**Cyprus**	0.467	0.483	0.521	0.568	0.603	0.634	0.597	0.604	0.575	0.586	0.564
	23	**Malta**	0.477	0.479	0.446	0.465	0.480	0.550	0.562	0.652	0.735	0.764	0.561
	24	**Denmark**	0.466	0.472	0.489	0.494	0.524	0.538	0.571	0.580	0.567	0.583	0.528
	25	**Czech Rep.**	0.450	0.479	0.465	0.475	0.495	0.521	0.528	0.539	0.538	0.548	0.504
	26	**Greece**	0.465	0.496	0.500	0.479	0.439	0.459	0.481	0.522	0.560	0.547	0.495
	27	**Poland**	0.472	0.502	0.471	0.469	0.482	0.486	0.509	0.511	0.501	0.495	0.490
	28	**Estonia**	0.352	0.389	0.289	0.315	0.330	0.306	0.319	0.385	0.349	0.341	0.338
		Average	0.624	0.655	0.635	0.644	0.662	0.683	0.703	0.714	0.729	0.731	0.678

Source: The authors' own.

Furthermore, Spain has dropped from 10th (2008) to 14th (2017) position for Managerial efficiency. Italy, Slovakia, and Malta lagged behind Spain in 2008 and, 10 years later, they were ahead. Unlike in Spain, in these three countries, the rate of variation of Research and Development expenditure in percentage of GDP for the period studied was positive (Eurostat, 2020e) . Nevertheless, if the Managerial efficiency is considered at both the beginning and final years of the period, as well as its average, then Spain remains in the second quartile.

Figure 2. Comparison of Managerial efficiency in Spain against the average of EU-28 countries (2008-2017).



Source: The authors' own.

As shown in 2, the behaviour of Managerial efficiency in Spain is different from that of Natural efficiency. The European average presents a growing trend throughout the period, while in Spain, the trend oscillates, with periods of growth alternating with periods of downturn, with Managerial efficiency in Spain (0.699) also falling below the European average (0.714) in 2015. This could be explained by the behaviour of R&D&I (research, development, and innovation) spending in relation to GDP during the period 2008-2017, in which it increased steadily within the EU from 1.83% in 2008 to 2.08% in 2017, while in Spain this spending oscillated throughout the period, with 1.24% in 2008 and 1.21% in 2017 (Eurostat, 2020e).

In summary, the average of the Natural and Managerial efficiency lies between the average of the above-average cluster and that of the below-average cluster, as shown in Figures 1 and 2. In order to verify whether the data obtained show statistical evidence of this circumstance, we must solve the null hypothesis H_0: Spain = EU above average, versus alternative hypothesis H_1: Spain < EU above average, and H_0: Spain = EU below average, versus alternative hypothesis H_1: Spain > EU below average. Since the sample size is not large, and the data are matched per year, the Wilcoxon non-parametric test was used for paired samples (Eurostat, 2020c). For calculation of the statistics and p-value of the test, R software was used. In comparison with above average, the statistic value is W=0, and in the comparison to below average, W=55 (for both Natural and Managerial efficiency). In all the comparisons the obtained p-value is equal to 0.001. Therefore, there is strong evidence (significance level less than 1%) that the efficiency of Spain is less than the EU above-average countries, and is higher than the EU below-average countries.

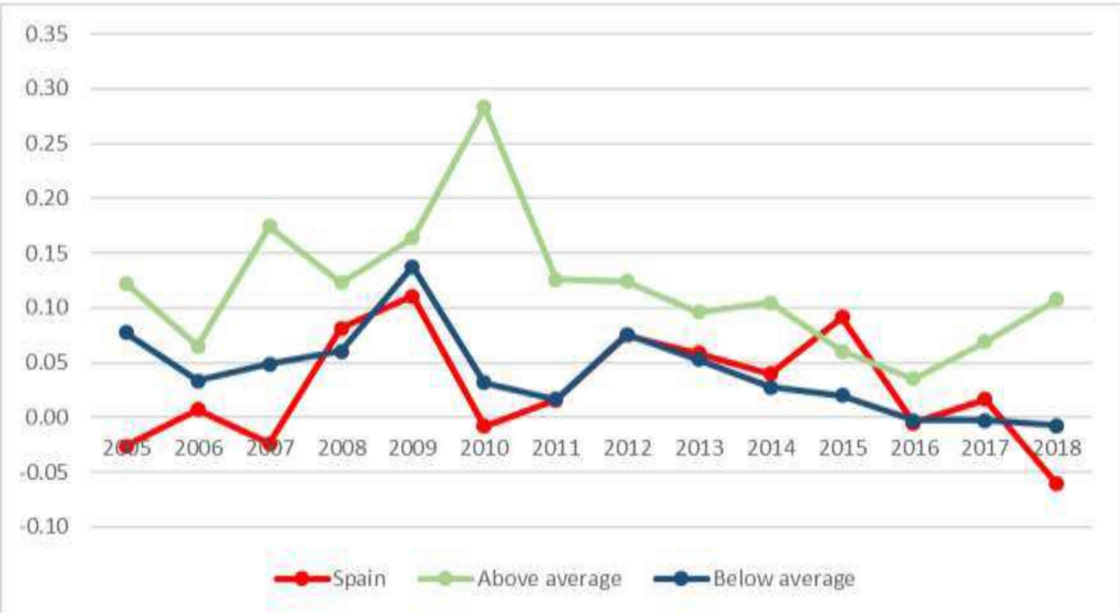
3.2. Malmquist Index

This section reflects the results of the calculation of the MI for the Natural and Managerial efficiencies considered for the 28 countries studied and, as explained in the methodology section, it was assumed that a frontier shift may occur between periods.

For this analysis, the division of the countries into the two aforementioned clusters has been maintained.

As shown in Figure 3, the renewable energy growth rate of the group of above-average countries reaches its maximum in 2010, due to the increase in electricity demand in those countries in that same year. This same variable reaches very low levels, both in the case of Spain, and in the group of below-average countries. This differential fact could explain the different situation of the Natural Malmquist Indixes for these two groups of countries.

Figure 3. Renewable energy growth rate in the period 2005-2018.



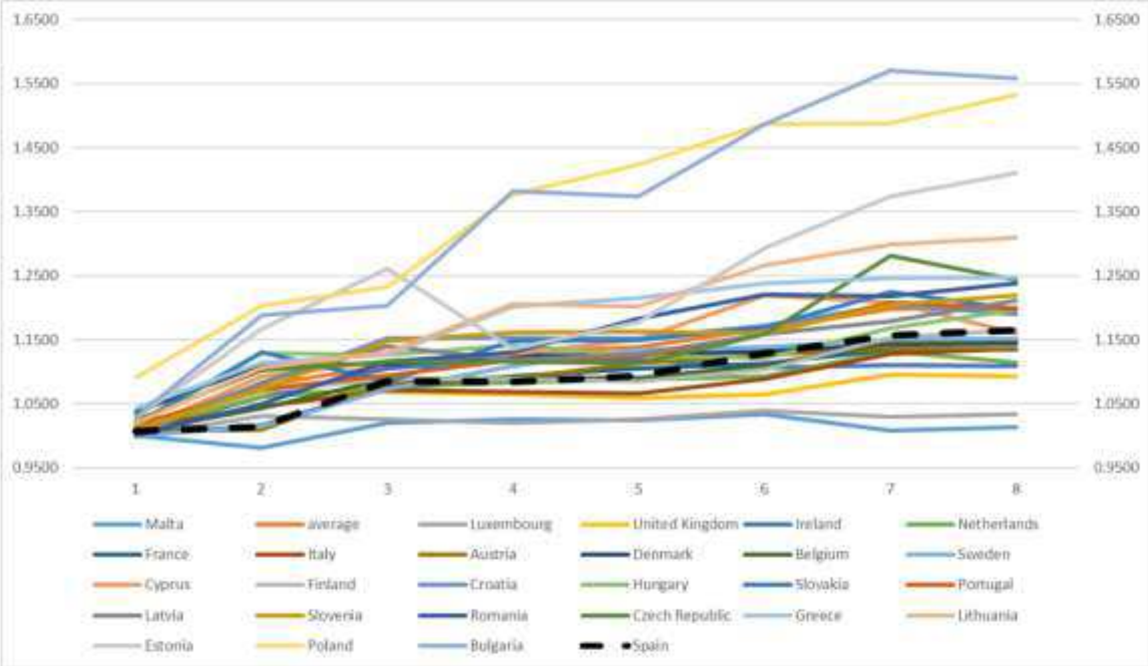
Source: The authors' own based on Eurostat data [10].

Figure 3 also shows that, except for one year, the renewable energy growth rate in Spain is less than the above average. Compared to the alternative hypothesis H_1: Spain < EU above average, a statistic value W = 1 is obtained, with a p-value equal to 0.0001, so there is strong evidence that the renewable energy growth rate in Spain is less than that of the above-average cluster. Regarding the below-average cluster, there is no statistical evidence that shows that the renewable energy growth rate in Spain is greater or lesser, compared to the alternative hypothesis H_1: Spain < EU below average, we obtain W = 24 with a p-value equal to 0.1277, while for H_1: Spain > EU below average, we obtain W = 24 with a p-value equal to 0.888.

Natural Malmquist Index

The evolution of the Natural MI by considering windows of increasing time intervals for the above-average countries (Figure 4), indicates that the behaviour of these countries is very similar. The exceptions are in Bulgaria and Poland, which experienced the most significant growth in the period 2008-2017. This growth is concentrated in the time window 2008-2012, and coincides with a huge growth in the consumption of renewable energy in both countries during that period. Specifically, the rate of variation in renewable energy consumption in 2012, compared to 2008, was 53.6% and 55.4% in Bulgaria and Poland, respectively. In the rest of the group, there was an improvement at two points during the period considered, in the intervals 2010-2011 and 2015-2017, which were years of growth of renewable energy consumption in this group of countries.

Figure 4. Natural Malmquist Index growth for the windows T = 2 to T = 9 (2008-2017)

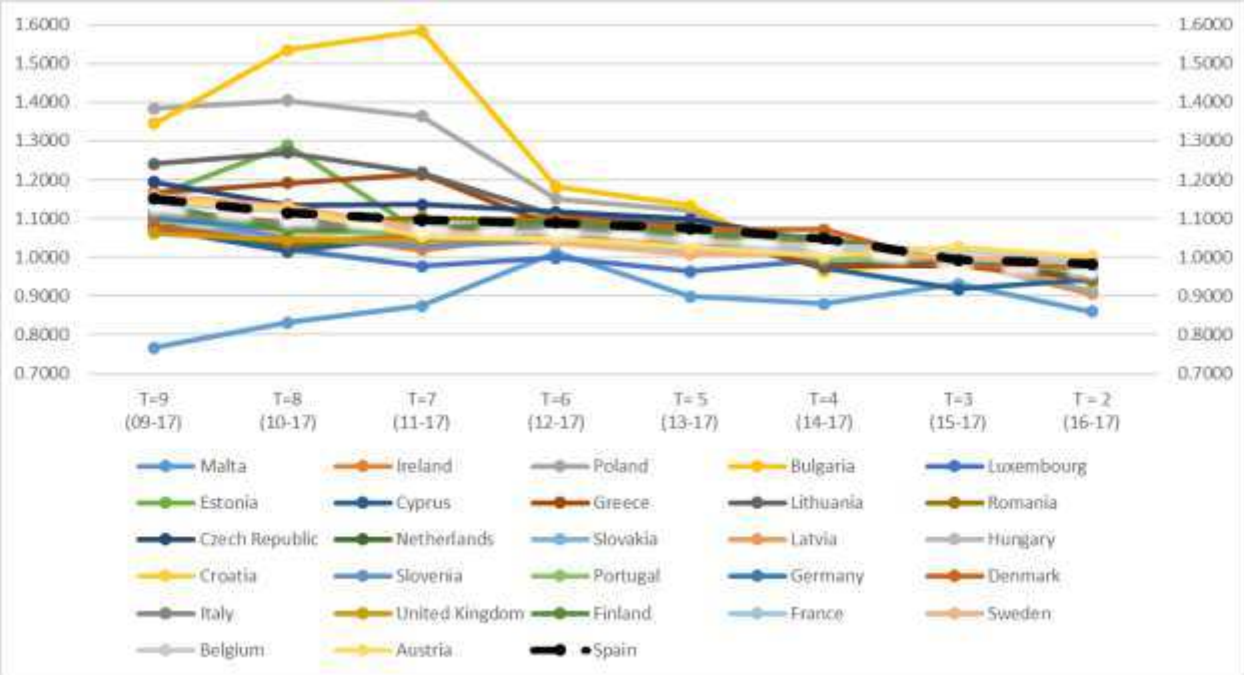


Source: The authors' own.

Specifically, in the case of Spain, there was a jump in the transition from T = 2 (2008-2009) to T = 4 (2008-2011), with a growth rate of renewable energy consumption in 2011, compared to 2008 of 76.5%. There was also a considerable jump in the transition from T = 5 (2008-2012) to T = 7 (2008-2014), in which the growth rate of renewable energy consumption in 2014, compared to 2008, was 71.5%.

The same conclusion is reached if the evolution of the Natural MI is analysed when taking into consideration decreasing time intervals. It confirms that 2011 and 2014 are the years in which the most significant changes occur in the behaviour of the Natural Malmquist Index (see Fig. 5).

Figure 5. Decreasing Natural Malmquist Index for windows from T = 9 to T = 2 (2008-2017).



Source: The authors' own.

Figure 5 shows that again Bulgaria and Poland display a different behaviour from that of the remaining countries in their group, during the period between 2009 and 2012. Most countries of this group present a similar behavior with a significant fall, on passing from T =8 to T =6, that is to say, when omitting the year 2011.

The MI values on Natural efficiency for the entire study period are shown in Table 5 and reflect that Spain was one of the countries with the lowest index values in every year. In fact, if the countries were classified by the average for the period, Spain would be located in the fourth quartile and above the Czech Republic, Denmark, Poland, and Bulgaria only. Performing the Wilcoxon non-parametric test of the null hypothesis against the alternative hypothesis H_1: Spain < EU average, yields W=29 and a p-value of 0.248. Therefore, there is no statistical evidence that the increase in productivity in Spain is lower than the EU average.

Table 5. Malmquist Index for Natural efficiency for the period 2008-2017, in order of the average of each year.

Position			2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	Average
	1	**Malta**	1.0000	1.0411	1.0000	1.0103	1.0000	1.0000	0.9403	0.9478	0.8603	0.9778
	2	**Cyprus**	1.0082	1.0370	1.0077	1.0006	1.0072	1.0213	0.9424	0.8892	0.9435	0.9841
	3	**Luxembourg**	1.0000	1.0111	1.0000	1.0016	1.0000	1.0000	1.0118	0.9970	0.9385	0.9956
Q1	4	**Ireland**	1.0034	1.0143	1.0114	1.0315	1.0116	1.0259	0.9978	0.9798	0.9063	0.9980
	5	**United King.**	1.0099	1.0000	1.0000	1.0000	1.0013	1.0010	1.0333	0.9927	0.9807	1.0021
	6	**Portugal**	1.0177	1.0171	1.0015	1.0075	1.0079	1.0217	0.9914	0.9966	0.9687	1.0034
	7	**Slovenia**	1.0106	1.0246	1.0035	1.0024	1.0100	1.0129	1.0060	0.9962	0.9664	1.0036
	8	**Croatia**	1.0095	1.0228	1.0071	1.0057	1.0091	1.0139	1.0034	0.9959	0.9652	1.0036
	9	**Estonia**	1.0281	1.0015	1.0143	1.0167	1.0071	1.0247	1.0098	0.9935	0.9400	1.0040
	10	**Romania**	1.0000	1.0211	1.0076	1.0136	1.0069	1.0124	1.0252	0.9944	0.9554	1.0041
Q2	11	**Greece**	1.0437	1.0212	1.0079	1.0383	1.0005	1.0133	0.9887	0.9782	0.9463	1.0042
	12	**Netherlands**	1.0081	1.0123	1.0089	1.0135	1.0117	1.0120	1.0356	0.9831	0.9598	1.0050
	13	**Italy**	1.0102	1.0109	1.0107	1.0071	1.0055	1.0146	1.0177	0.9931	0.9765	1.0051
	14	**Latvia**	1.0000	1.0134	1.0068	1.0162	1.0070	1.0223	1.0230	0.9956	0.9633	1.0053
	15	**Germany**	1.0139	1.0130	1.0047	1.0087	1.0054	1.0072	1.0413	0.9816	0.9733	1.0055
	16	**Sweden**	1.0000	1.0105	1.0191	1.0120	1.0103	1.0000	1.0079	1.0027	0.9906	1.0059
	17	**Hungary**	1.0167	1.0165	1.0039	1.0136	1.0119	1.0083	1.0237	0.9956	0.9634	1.0060
Q3	18	**France**	1.0010	1.0058	1.0232	1.0118	1.0102	1.0096	1.0246	0.9936	0.9847	1.0072
	19	**Slovakia**	1.0194	1.0074	1.0076	1.0108	1.0082	1.0137	1.0424	0.9954	0.9629	1.0075
	20	**Austria**	1.0065	1.0086	1.0307	1.0058	1.0117	1.0100	0.9775	1.0213	1.0034	1.0084
	21	**Belgium**	1.0070	1.0117	1.0114	1.0107	1.0109	1.0099	1.0108	1.0141	0.9906	1.0086
	22	**Lithuania**	1.0200	1.0008	1.0076	1.0653	1.0180	1.0352	0.9870	0.9949	0.9519	1.0090
	23	**Finland**	1.0104	1.0177	1.0038	1.0120	1.0093	1.0061	1.0545	0.9884	0.9832	1.0095
	24	**Spain**	1.0080	1.0106	1.0326	1.0052	1.0039	1.0169	1.0387	0.9937	0.9822	1.0102
Q4	25	**Czech Rep.**	1.0238	1.0292	1.0055	1.0110	1.0058	1.0221	1.0681	0.9918	0.9562	1.0126
	26	**Denmark**	1.0368	1.0205	1.0169	1.0194	1.0134	1.0106	1.0680	0.9779	0.9758	1.0155
	27	**Poland**	1.0919	1.0013	1.0121	1.0841	1.0196	1.0553	0.9766	0.9940	0.9121	1.0163
	28	**Bulgaria**	1.0296	1.0225	1.0158	1.1741	1.0260	1.0561	0.9680	0.9932	0.9345	1.0244
		Average	1.0155	1.0152	1.0101	1.0218	1.0089	1.0163	1.0113	0.9883	0.9584	1.0051

Source: The authors' own.

The evolution of this index for Spain is related to the evolution of the Spanish economy, and differentiates three periods. The first (2008-2011), marked by GDP growth, reflects the stability of the index, which indicates a very slight improvement in productivity. The second period (2011-2014), with a decrease in the GDP variable, is reflected by a slight drop in the index, although it does not stagnate. The last period (2014-2017), marked by severe adjustment policies carried out in Spain with the largest drop in GDP, represents an upswing in productivity, making it the fourth-greatest country in the EU-28 in terms of growth for the period 2010-2011. This behaviour coincides with the trend described in Woo et al. (2015), which attributes it to the global economic crisis.

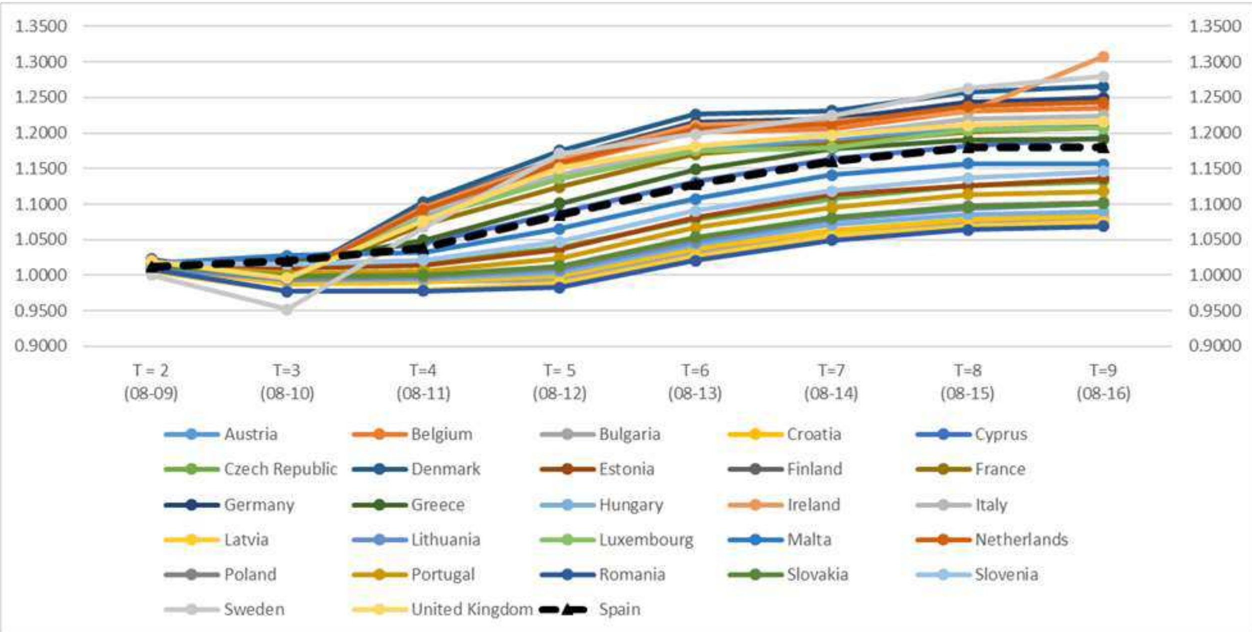
Managerial Malmquist Index

The behaviour is different in the case of the MI based on the Managerial approach, as shown in Fig. 6. Although there were still improvements in efficiency, the values, in general and for the EU-28 average, were lower than those for the Natural approach. As shown in this figure, Spain began the period with productivity gains higher than the EU-28 average, although the sharp loss of Managerial efficiency resulted in ending the period below the average, and in remaining at almost the same rate over the last four years. Throughout the period analysed, Spain's average of Spain was higher than that of the EU, although, in this case, there is no statistical evidence, as the test are W = 20 with a p-value of 0.1875.

If the evolution of Managerial productivity is analysed through the behaviour of the MI by dividing the study period into increasing time windows, and by focusing on the comparative study of the countries that were below the average of the index for nine periods in which Spain is included, then it can be concluded that the countries of this group followed a uniform trend (see Fig. 6). In the first two time windows, the Managerial MI was stable, thereby initiating a path of very moderate sustained growth, until T = 7, in which it stabilised again.

Spain followed the same trend as other countries, with three clearly differentiated periods, from T = 2 to T = 4; from T = 5 to T = 7; and, from T = 8 to T = 9. The jump in Managerial productivity in this period occurred in 2012 and 2014. Throughout the period, the MI = 1 in 2008 and did not reach 1.1 in 2016, which implies an average annual growth of just over 1% in the period considered.

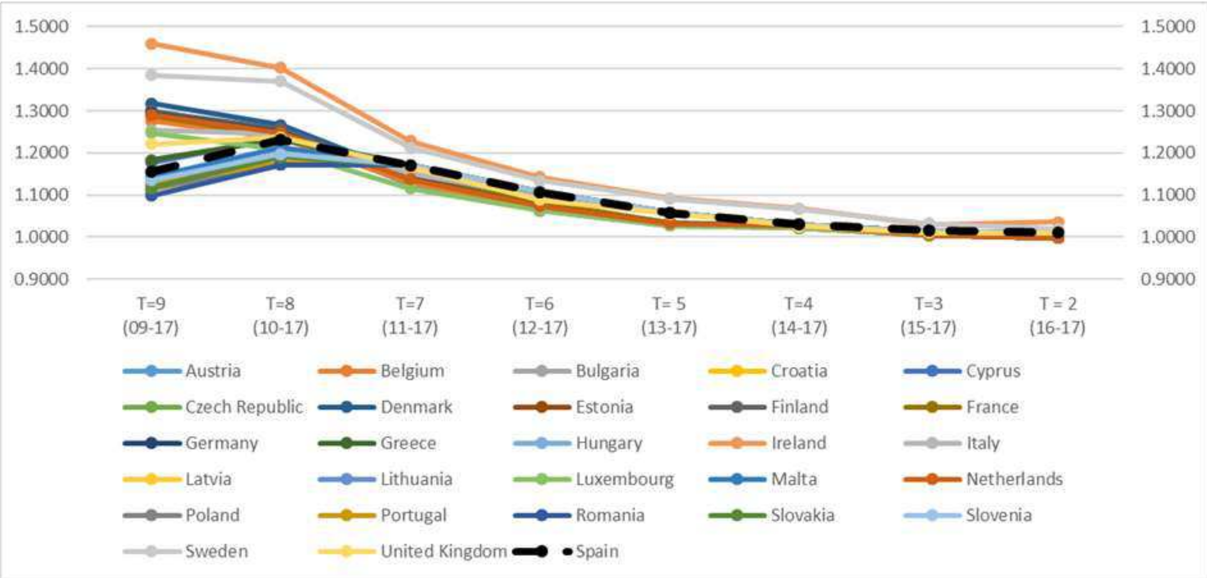
Figure 6. Increasing Managerial Malmquist Index from T = 2 to T = 9 (2008-2017).



Source: The authors' own.

The behaviour of the Managerial MI is shown in Fig. 7, in this case with decreasing time windows, which corroborates previous results. The evolution of Managerial productivity had a very similar behaviour in all the countries within the group of Spain: it begins to grow when year 2014 is introduced, and an increased growth of Managerial productivity is also observed when the year 2012 is introduced.

Figure 7. Decreasing Managerial Malmquist Index for time windows from T = 9 to T = 2 (2008-2017).



Source: Authors' own.

Table 6 shows the results for the MI for Managerial efficiency of all countries analysed for the entire period, ordered in terms of the average of the period, broken down into time windows of two years. The table reveals Spain in Q2 and shows where it fits within the top 10. Ireland occupies the first position in this ranking, whilst Sweden holds the last. This can be explained by the difference in the margin of improvement within those countries, since Sweden starts from much higher levels of productivity than Ireland.

Table 6. Malmquist Index for Managerial efficiency for the period 2008-2017, ordered in terms of the average for the whole time period (last column).

Position			2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	Average
Q1	1	Ireland	1.0201	1.0181	1.0500	1.0308	1.0213	1.0031	1.0200	1.0135	1.0365	1.0237
	2	Greece	1.0150	1.0415	1.0308	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0202
	3	Cyprus	1.0161	1.0400	1.0298	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0200
	4	Denmark	1.0225	1.0203	1.0522	1.0326	1.0218	1.0032	1.0212	1.0054	0.9983	1.0197
	5	United King.	1.0196	1.0155	1.0459	1.0285	1.0193	1.0137	1.0179	1.0045	1.0109	1.0195
	6	Italy	1.0186	1.0168	1.0443	1.0280	1.0227	1.0137	1.0140	1.0045	1.0109	1.0193
	7	Finland	1.0213	1.0192	1.0518	1.0313	1.0209	1.0031	1.0205	1.0052	0.9984	1.0191
Q2	8	Malta	1.0173	1.0321	1.0235	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0186
	9	Germany	1.0206	1.0186	1.0487	1.0303	1.0208	1.0031	1.0206	1.0052	0.9984	1.0185
	10	Spain	1.0112	1.0325	1.0265	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0183
	11	Netherlands	1.0199	1.0180	1.0476	1.0297	1.0203	1.0030	1.0206	1.0053	0.9984	1.0181
	12	Belgium	1.0193	1.0174	1.0464	1.0285	1.0195	1.0029	1.0194	1.0049	0.9985	1.0174
	13	France	1.0167	1.0148	1.0430	1.0285	1.0227	1.0052	1.0154	1.0043	0.9987	1.0166
	14	Slovenia	1.0166	1.0270	1.0112	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0166
Q3	15	Slovakia	1.0134	1.0309	1.0085	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0163
	16	Hungary	1.0145	1.0320	1.0053	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0162
	17	Czech Rep	1.0165	1.0258	1.0093	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0162
	18	Estonia	1.0157	1.0259	1.0089	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0161
	19	Bulgaria	1.0080	1.0374	1.0049	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0161
	20	Austria	1.0174	1.0157	1.0422	1.0266	1.0175	1.0026	1.0175	1.0045	0.9986	1.0159
	21	Luxembourg	1.0179	1.0161	1.0417	1.0250	1.0174	1.0025	1.0173	1.0044	0.9986	1.0157
Q4	22	Latvia	1.0053	1.0348	1.0047	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0154
	23	Croatia	1.0137	1.0283	1.0011	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0153
	24	Romania	1.0084	1.0330	1.0006	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0151
	25	Poland	1.0147	1.0246	1.0006	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0149
	26	Lithuania	1.0102	1.0282	1.0006	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0148
	27	Portugal	1.0138	1.0213	1.0006	1.0285	1.0227	1.0137	1.0140	1.0045	1.0109	1.0144
	28	Sweden	1.0000	1.0000	1.0382	1.0229	1.0006	1.0022	1.0322	0.9983	1.0192	1.0126
		Average	1.0151	1.0245	1.0257	1.0285	1.0210	1.0099	1.0164	1.0047	1.0085	1.0172

Source: The authors' own.

4. - Conclusions

This paper analyses the environmental efficiency of Spain from two different aspects: the natural approach and the managerial approach, in the context of the EU-28.

The variables used in the analysis are divided into three inputs (non-emitting final energy consumption, employment, and GFCF), and two outputs, of which one is desirable (GDP) and the other undesirable (GHG emissions). In order to analyse the environmental efficiency of these two approaches, the methodology used by Sueyoshi and Goto (2012a, 2012b, 2012c, 2012d, 2012e, 2014, 2015) was taken as a reference. Additionally, static and dynamic analyses were carried out in which "Natural disposability" and "Managerial disposability" strategies were estimated, using DEA, as well as the MI to measure productivity gains across multiple periods. As mentioned above, the combination of Malmquist indices under natural and managerial disposability points out how to obtain the highest level of sustainability under two different disposability concepts.

The main characteristic of the period from an economic standpoint is the global economic recession. This fact was reflected in the results obtained, as well as the different impacts it has had on the countries considered, and the effect of the measures implemented in the most highly affected countries. Within the EU, Spain stands as one of the countries most affected by the recession, which is reflected in the evolution of the efficiency results. The two approaches follow different behaviours. The evolution of these efficiency values indicates that the reduction in the number of jobs, investment, public spending, and in energy consumption, have led to productivity gains, thereby maintaining a growth trend for Natural efficiency. During the studied period, Spain remains consistently closer to the above-average countries than to the below-average countries, in the case of Natural efficiency. However, the distance between Spain and the above-average countries has been maintained throughout the entire period, and hence there has been no convergence of Spain with this group of countries. This difficulty for Spain to converge with the EU countries in the highest positions of any ranking of an economic nature is one of the pending subjects of the Spanish economy.

Equally, in the case of Managerial efficiency, in the period under study, Spain remains closer to the above-average countries than to the below-average countries. However, in this case, if the beginning and end of the period are compared, Spain has suffered a loss of convergence with the above-average countries. This is a circumstance that is accompanied by the loss of convergence between investment in R&D&I in Spain and the group of countries that are above average in terms of Managerial efficiency. Similarly, the evolution in Spain has been greatly affected by the lack of investment in renewable energy, as well as by the drop in GDP and investment in R&D&I.

The results for MI substantiate the results of both efficiency approaches, and, despite the economic recession and the drop in investment in renewable energy, productivity gains have not stagnated (having not dropped to value 1). Although gains since the global crisis have remained very slight, Spain ended the studied period with an upswing in the case of the Managerial approach. In fact, the changes in the frontier of Natural efficiency place Spain in Q4 of the average of the period for all EU countries, while it occupies Q2 of the average of the period for all EU countries, in the case of advances in the frontier of Managerial efficiency.

Spanish energy policy should prioritise the development of solar renewable energy over other renewable energy sources, given the high number of hours of full sunlight per year, following the Irish model (located in the first quartile of the evolution of natural and managerial efficiency, according to the Malmquist index in the period analysed), and given that Ireland has firmly opted for wind energy thanks to its privileged location for the development of this type of energy (Irish Wind Energy Association, 2020) .

In times of economic difficulties, such as those experienced in much of the period analysed, the behaviour of Spain in matters of efficiency, both Natural and Managerial, has not been employed to improve convergence with those countries positioned above Spain in most of the rankings of an economic nature. With the start of a serious economic recession, triggered by COVID-19, the Spanish authorities should bear this fact in mind by the Spanish authorities, so that appropriate measures can be taken, such as the maintenance of investment in R&D&I and/or in renewable energy. An attempt should be made to redirect the Spanish economy along a path whereby the gap in convergence with the economically stronger countries of the European Union does not increase. This would, in turn, break the trend of Spain suffering from economic crises more intensely than the remaining EU countries, from which, consequently, more effort is required in order to break free.

The political and economic uncertainty generated in the EU by the pandemic and by Brexit may have affected the results of this paper, which makes it necessary to continue this line of research in the coming years, by expanding both the time series and the territorial scope of study

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Statements & Declarations

- **Ethical Approval.** Not Applicable
-**Consent to Participate.** All authors consent to participate
-**Consent to Publish.**All authors consent to publish
-**Authors Contributions.** All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Rocío Yñiguez], [Maria Teresa Sanz-Díaz], [Francisco Velasco-Morente] and [Francisco Javier Ortega-Irizo]. The first draft of the manuscript was written by [all authors] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.
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-**Competing Interests.** The authors have no relevant financial or non-financial interests to disclose
-**Availability of data and materials.** Not Applicable

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List of Abbreviations
DDF: Directional Distance Function
DEA: Data Envelopment Analysis
DMU: Decision-Making Unit
DTS: constant damages to scale
EU: European Union
GDP: Gross Domestic Product
GFCF: Gross Fixed Capital Formation
GHG: Greenhouse Gases
MI: Malmquist Index
ML: The Malmquist-Luenberger index
R&D&I: Research Development, and Innovation
RTS: constant returns to scale
TFP: Total Factor Productivity