The effects of environmental regulation on the efficiency of distribution electricity companies in Spain.

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1. Introduction

The Spanish electricity sector has undergone a profound transformation since 1998. Until then, the activity of the sector was concentrated in companies that were characterised by an important vertical structure and those companies exercised a regional monopoly in Spain. As a consequence of the Electricity Sector Law 54/1997[1], the separation of regulated activities (transport and distribution) and non-regulated activities (production and commercialisation) was established, with electricity companies having to separate accounting and legal activities.

VERTICALLY INTEGRATED COMPANY

DISAGGREGATION AND LIBERALISATION

FIGURE 1

Process of disaggregation and liberalisation. *Source*: Spanish Accounting and Auditing Association.[2]

The value chain of the electricity supply companies may be represented in a simple and systematic way by the following figure:

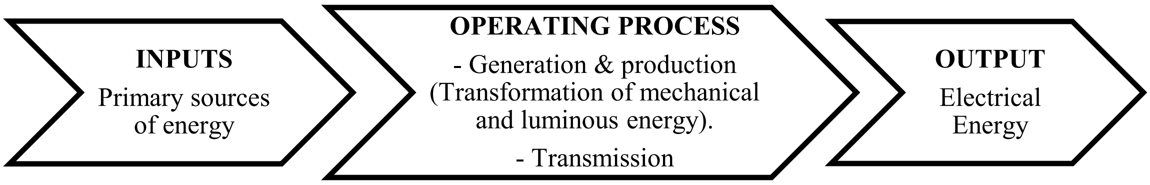

FIGURE 2

Chain of value of electricity supply companies. *Source*: Sánchez-Ortiz et al.[3]

This paper has a strong relationship with the Theory of Economics Regulation which explains the economic basis of regulated activities, such as the distribution of electricity in Spain. State regulatory policy has been around for many years, but the origin of the Theory of Economic Regulation (as theory itself) is found in Stigler's[4] published work, The Theory of Economic Regulation, which is based on the economic analysis of politics, with a focus on political processes while using the principles of neoclassical economics.

The activity of electricity distribution continues to be regulated in the competitive environment in which the electricity sector (generation and sales) operates. The regulation of the activity of distribution of electrical energy is justified by the assurance of an adequate income for the regulated firms. According to Khan[5], the negative consequence is that the widest distribution networks in the regulated electricity sector have a wonderful power over markets and the level of competence is low in regulated sector, due to that fact that there are primary barriers to entry.

However, electricity distribution companies have two possible environmental constraints, which negatively affect the level of efficiency of these companies: the productive overcapacity of the electricity sector and the tariff deficit.

In this paper, in knowing that the distribution is a regulated activity, the efficiency in the electricity distribution companies is studied. To this end, a study was carried out on the efficiency of the main electricity distribution companies in Spain (Endesa, Iberdola, Union Fenosa, EDP and Viesgo) during the period 2006-2015. The technique used was the multi-period efficiency measurement in Data Envelopment Analysis (DEA), an input-oriented model at constant scales (CCR), working with panel data.

2. Analysis of efficiency in the Spanish Electricity Sector

There are important current studies on the Spanish electricity sector and its different activities.[6-8] In the present work, a study of the Spanish electricity sector was undertaken with respect to its different activities (environmental studies, calculation of the price of generation activity, study of demand, regulation, etc.). All of the activities have a common objective, which is to improve the efficiency of the Spanish electricity sector.

The main problems that directly affect the efficiency of the Spanish electricity sector are identified through 1) the report of the Association of Renewable Energy Companies[9] on the productive capacity in the generation and distribution of electricity also and 2) the report of the Commission National Market and Competition[10] on electricity sector debt:

1. Problems with the productive capacity of distribution: Royal Decree 436/2004[11], which explains the activity of production of electricity in a special regime, develops the Law of the Electricity Sector and establishes the legal and economic scheme for the special regime. Once this Royal Decree had been approved, due to the special energy payment (renewables, cogeneration and waste) granted to distributors, an excessive increase was generated in relation to demand (i.e. Government gives grants that are "out of control"). In the following graph, published by the Association of Renewable Energy Companies,[9] in the last ten years installed capacity has grown by 36.3%, from 78,086 MW in 2005 to 105,833 MW in 2015, while the demand for electricity was reduced to a lower value in 2008 (258,117 GWh) than in 2005 (260,704 GWh):

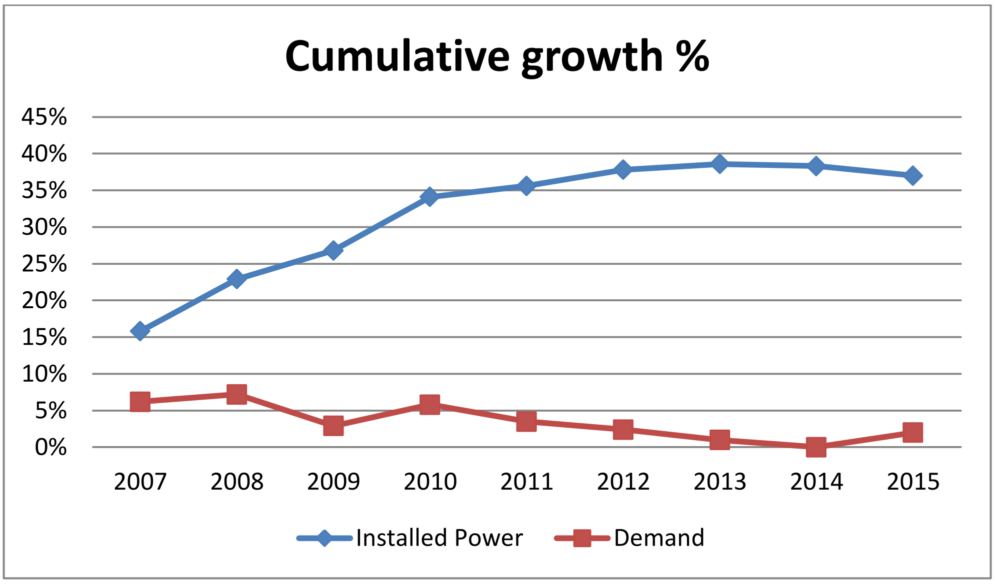

FIGURE 3

Evolution of productive capacity: Installed Power vs. Demand. *Source*: Association of Companies of Renewable Energies.[9]

2. Tariff deficit (Electricity sector debt): The tariff deficit is defined as the difference between the income obtained by electricity companies through the tariff paid by the final consumer (regulated by the State) and the total costs recognised by the Spanish electricity companies. The remuneration is calculated by means of a system of compensation to the electricity companies for costs at are not covered by the system. The differences between the collection of access fees and actual costs are due to two reasons: errors of estimation (revision of annual access tolls) or the government decision on fixing the regulated tariffs. The following chart, published by the Commission National Market and Competition,[10] shows annual deficits between 2000-2016. During the years 2014, 2015 and 2016, there has been a rate surplus after more than a decade of deficit due to the fact that the government approved the Royal Decree 1048/2013[12] in which customers must pay a fixed fee to finance the tariff deficit.

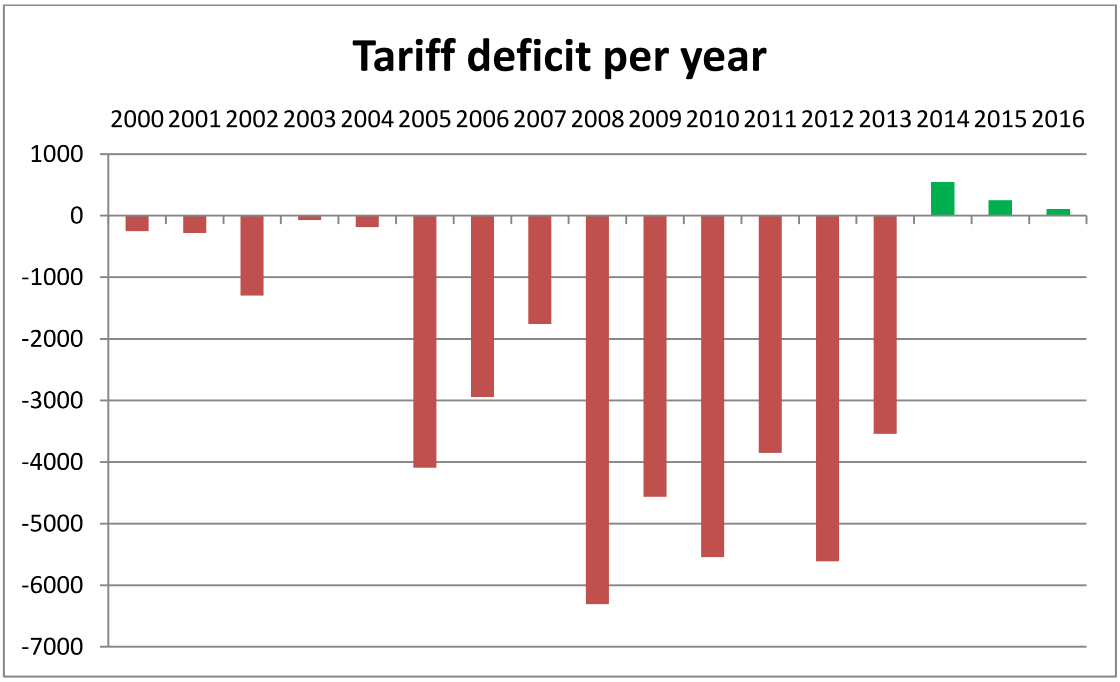

FIGURE 4

Annual evolution of the tariff deficit in Spain during the period 2000-2014. *Source*: Commission National Market and Competition.[10]

According to the Royal Decree 1048/2013[12], tariff deficit has been calculated as follows:

$$R_n^i = R_{n\,base}^i + R_{n\,NI}^i + ROTD_n^i + Q_n^i + P_n^i + F_n^i$$

$R^i_{n\ base}$ = Amount received by distribution companies, based on the completed activities of the two preceding years.

$R^i_{n\ NI}$ = Received amount by building new facilities based on the two preceding years.

$ROTD^i_n$ = Received amount by other regulated activities based on the two preceding years.

Q^i_n= Incentive by quality services. It is calculated via the mean of the quality of service for between four and two preceding years.

P^i_n= Incentive by reducing the "loss of energy". It is calculated via the mean of the "loss of energy" for between four and two preceding years.

F^i_n= Incentive by reducing fraud in the market, based on the two preceding years.

3. Legislative changes: The continuous legislative changes in the electricity sector in Spain have a significant influence on the efficiency of that sector, and more specifically on the distribution activity, as it is a regulated activity. In this paper,

the influence of Law 17/2007[13] on the electricity sector is studied with respect to the efficiency of the distribution companies, through which Law 54/1997[1] has been amended.

3. Analysis of efficiency in the distribution chain in the Spanish electricity sector

3.1. Objectives and research hypotheses

In this section, the objectives of determining the most efficient electricity distribution companies and the proposals on solutions for the improvement of efficiency in Spanish electricity distribution companies are set out:

1. To study the efficiency of each electricity distribution company in Spain.

   H1.1. A wider distribution network positively and significantly influences the efficiency of each electricity distribution company.

   This hypothesis is based on the Theory of Economic Regulation. Khan[5] affirms that there is a strong power market in the regulated sector and, therefore, the wider distribution network must be more efficient because it distributes to more customers.

   H1.2. The approval of Law 17/2007[13], which modifies Law 54/1997[1] of the electricity sector, has had a positive and significant effect on the efficiency of each electricity distribution company.

   Governments usually approve laws to improve the environmental sector. Chang et al.[14] use DEA in order to assess whether the hospital laws have had an influence on the efficiency of these public companies. It has been affirmed in the present study that at the start, any governmental decisions have had a positive influence on the efficiency of each electricity distribution company because the government pursues social welfare by means of the approval of laws.

2. To study the quality of electricity distributed in Spain.

H2.1. A wider distribution network negatively and significantly affects the quality of distributed electric power.

Growitsch et al.[15] and Çelen and Talçin[16] affirm that quality of service should be an integrated part of any efficiency and economic analyses of the regulated distribution sector. In the model of this study, the undesirable output "Interruption time" is used to measure the quality distribution network.

3. To study the influence of regulation on electricity distribution activity in Spain.

H.3.1. Renewable energy subsidies have negatively and significantly influenced the situation of productive overcapacity of electricity distributors.

This hypothesis has been explained in Figure 3 of this paper.

4. To study the incidence of the tariff deficit on the level of efficiency of each distribution company.

H4.1 The tariff deficit impacts negatively and significantly on the level of efficiency of the distribution companies.

This hypothesis has been explained in Figure 4 of this paper.

3.2. Methodology: Multi-period efficiency measurement in data envelopment analysis-oriented input at constant scales (CCR)

The use of this methodology for the study of efficiency in the electricity sector is due in part to the fact that the industry has been regulated for a long period of time by local and central governments. Under such government regulations, it was known that there was a degree of "inefficiency X" that could arise due to a lack of competition discipline in the marketplace[17].

There are many recent studies using DEA analysis to measure efficiency in the electricity distribution sector.[18-22] As the present study is based on panel data and a small sample size, each DMU will be an organisational unit per year and multi-period aggregative analysis is used.[23, 24]

The CCR model that is applied is the dual problem model, where the CCR formulation would be the following[25]:

$$Max\, n_0 - \varepsilon[\sum_{i=1}^{m} S_i^{+} + \sum_{r=1}^{s} S_r^{-}$$

$$s.a.: \sum_{j=1}^{n} \lambda_i X_{ij+} \; S_i^{+} = X_{i0}$$

$$\sum_{j=1}^{n} \lambda_i Y_{rj\,+} \;\; S_r^{-} = n_0 Y_{r0}$$

$$\lambda_i, S_i^{+}, S_r^{-} \geq 0, \quad j = 1, 2, \ldots, n$$

$$i = 1, 2, \ldots, m$$

$$r = 1, 2, \ldots, s$$

For the dual-problem approach to the input-oriented CCR model, Xij and Yij represent the i-th quantity of resources and product corresponding to entity "j"; λj, together with η0, are variables of the model and one of the parameters from which the reference group of the entity under study is constructed. If Si+ and Sr- are the slack variables of each of the constraints of the models, η_0 represents the efficiency rate of the entity being evaluated and η_0 represents an infinitesimal change.

3.2.1. Undesirable Output

It may occur that either the inputs or the undesirable outputs become desirable for the organisation, as in the case of environmental wastes. In this study, the undesirable output is used as an input. To treat undesirable output as an input, Hao Liu et al.[26] propose the following model:

$$\max h_k = \frac{\sum_{r=1}^{t} u_t \;\; y_{rk}}{\sum_{i=1}^{m} v_i\, x_{ik} + \sum_{r=1}^{t} u_t \;\; y_{rk}}$$

Subject to:

$$\frac{\sum_{r=1}^{t} u_t \;\; y_{rj}}{\sum_{i=1}^{m} v_i x_{ij} + \sum_{r=t+1}^{s} u_r\, y_{rj}} \leq 1\, ;\, j = 1, \ldots, n$$

$$u_r, v_i \geq r = 1, \ldots s \;\; i = 1, \ldots, m$$

As can be seen, the previous formulation integrates the undesirable outputs within each DMU, reducing inputs and undesirable outputs in order to increase efficiency.

In the present work, the undesirable output is the time of interruption of the electrical energy in Spain, so that the longer the final interruption in the distribution of electrical energy, the poorer the quality of that electrical energy. A current example using an undesirable output related to quality is in the work of Molino-Senante et al.,[27] where the quality and treatment of water are studied.

3.3. Sample and variables

The empirical study is carried out on a sample made up of the five large electricity distribution companies (Table 1) that operate in Spain, as they carry out 95% of the electricity distribution activity within the country.[10] The period of study of the efficiency of these companies is between 2006 and 2015. There are electric distribution companies that have a wider distribution network (Endesa and Iberdrola). Next, according to the Commission National Market and Competition[10], the supply points to be provided by each distribution company during the fourth quarter of 2014 are shown:

TABLE 1

Sample.

IDENTIFY	DISTRIBUTION COMPANY	NUMBER OF SUPPLIERS	TYPE OF COMPANY
1	ENDESA DISTRIBUCIÓN ELÉCTRICA SL	11,903,759	Large-sized Company
2	IBERDROLA DISTRIBUCIÓN ELÉCTRICA SL	10,830,322	Large-sized Company
3	EDP ENERGÍA (HIDROCANTÁBRICO DISTRIBUCIÓN ELÉCTRICA SA)	658,764	Medium-sized Company
4	UNIÓN FENOSA DISTRIBUCIÓN ELÉCTRICA SA	3,767,759	Medium-sized Company
5	EON ESPAÑA (VIESGO DISTRIBUCIÓN ELÉCTRICA SL)	613,469	Medium-sized Company

To contrast the hypotheses of this work, the following output-oriented efficiency model is proposed (Table 2):

TABLE 2

Efficiency model of Spanish electricity companies.

Efficiency Model	Inputs (units)	Outputs (units)

Indicators of the distribution companies.	Power (MW Megawatts). Number of installations (Nº inst). Operating costs (€ GExp). Number of employees (HR). Capacity of distributors (%).	Operating Revenues (€ Exp). Amount of energy distributed to the marketers (GH/h Gigawatts per hour). Average interruption time (Minutes).

Both the input variables and the output variables have been obtained from the National Commission of Market and Competition, the Ministry of Industry Tourism and Trade and the Iberian Balance Sheets Analysis system.

As for output variables, it is necessary to differentiate between desirable outputs (operating income and quantity of energy sold to marketers) of the undesirable output variable, and average interruption time (since the longer the interruption time, the larger the electrical energy storage that is required).

In this model, the tariff deficit is studied via the relationship between the operating costs (real amount) and operating revenues (90% revenues depends on the remunerations estimated by the Spanish Government). If the variable "operating costs" is inefficient, then operations revenues have been calculated erroneously (because the operating costs are higher than the operations revenues) and, therefore, there is a tariff deficit.

4. Results and discussion

In this model, 50 DMUs are defined since each organisational unit is an electrical energy distribution company in a one-year period, i.e. one DMU would be Viesgo_2006 and another DMU would be Endesa_2007. Charnes et al.[28] explain how to analyse this type of efficiency model, which is distinguished from a normal DEA model in its interpretation, since it allows to obtain conclusions through the temporal efficiency, termed multi-period efficiency (MDEA). This type of analysis is explained by Park and Park[23] and Lan and Wang[29]. It is a type of DEA methodology that is suitable for small samples.

As there is a 10-year time horizon and 5 electricity distribution companies, as previously stated, then there are 50 DMUs. In the following, is a check of whether the requirements that defined in the above are met:

- According to Golany and Roll[30] there are 50 DMUs, 5 inputs and 3 outputs. Therefore, (5 + 3) * 2 = 16. Hence, 50> 16 so that this rule is fulfilled.

As can be seen, 50% (25 DMUs of 50 DMUs) of the analysed units have efficiency levels equal to 1, hence they are efficient. At the same time, in order to analyse the efficiency levels of the electricity distribution companies, the following frequency table has been constructed (Table 3).

TABLE 3

Frequency table of efficiency results of electricity distribution companies 2006-2015 of the DEA CCR model oriented to the input.

Company	Efficiency Frequency	Efficiency Years
ENDESA DISTRIBUCIÓN ELÉCTRICA SL	6	2007 2010 2012 2013 2014 2015
IBERDROLA DISTRIBUCIÓN ELÉCTRICA SL	6	2006 2007 2012 2013 2014 2015
HIDROCANTÁBRICO ENERGIA ELÉCTRICA	4	2007 2008 2010 2011
UNIÓN FENOSA	2	2006 2013
EON ESPAÑA (VIESGO DISTRIBUCIÓN)	7	2006 2007 2009 2012 2013 2014 2015

In Table 3, it can be seen that the company with the highest level of efficiency is Viesgo Distribución (Eon). Therefore, H1.1 is rejected because Viesgo does not have the majority of customers. In the case of Viesgo Distribución (Eon Energía), it is observed that its efficiency level is repeated consistently (7 of the 10 DMUs).

The first inputs (MWI) indicate the phenomenon of productive overcapacity in this model if it affects the inefficiency of this company. For example, the weight of Viesgo_2006 is 0.79473453 and year 2009 is 0.60251842. However, it can be affirmed that its output level achieves the minimising of the impact of this phenomenon of overcapacity, because in 7 of the 10 analysed periods Viesgo has been efficient. Therefore, it can be said that from a strategic perspective, Viesgo Distribución is once again the company that best manages its resources. The same applies for the ratio of operating expenses / operating revenues (rate deficit), that is, operating expenses represent inputs that are relevant to their degree of inefficiency (for example, in 2007 it had a value of 0.7085544) although it affects productive overcapacity to a lesser extent.

Endesa and Iberdrola are efficient for 6 periods of the sample under analysis. This is because it is a regulated sector, where administrative authorisation is required to carry out the electricity distribution activity (high barriers to entry). In addition, one of the reasons why these types of companies are more efficient is the market power (a large market share) that they exert over distribution activity.

It can be observed in Table 6 that, for these types of companies, the inputs that are generating a higher level of inefficiency are again those related to productive overcapacity (for example, Endesa_2009 with a weighting of 0.91626413 or Iberdrola_2010 with a weighting of 0.40101769) and, to a lesser extent, those related to the tariff deficit (the weighting of the operating expenses of Endesa_2006 is 0.49266128). Overcapacity affects practically every year in each of these companies. However, the rate deficit as the temporal evolution in the data (mainly during the period 2008-2012) takes place and the phenomenon of inefficiency caused by this problem is dissipating. This evolution coincides with the tariff deficit graph, where it can be observed that during the year 2014 the compensation for the tariff deficit had been positive.

The companies most affected by their level of efficiency are the companies with an average market share, Unión Fenosa Distribución and Hidrocantábrico Distribución (they are only efficient for 2 and 4 years, respectively). The reasons are similar, as previously explained. The phenomenon of productive overcapacity affects to a greater extent those companies that distribute in several geographical areas and their market share is not so extensive.

In addition, it is important to note that, as with the problem of productive overcapacity, the tariff deficit has a greater impact on these types of companies. Since 2012, this phenomenon is practically affecting the level of Hidrocantábrico's inefficiency (for example, Hidrocantábrico_2014 the weighting is 0.26507219), while in the other DMUs from 2012, this item does not cause a high inefficiency. If the rate deficit is high, it indicates that the operating revenues obtained by the DMUs are not efficient in relation to the expenses derived from their activity. Therefore, both organisations (but mainly Union Fenosa) should rethink an improvement in their level of efficiency.

With respect to hypothesis H1.2, the approval of Law 17/2007, amending the Law 54/1997 of the electricity sector, has had a positive and significant effect on the efficiency of each electrical energy distribution company, hence, it can be said that it has been fulfilled in most of the distribution companies. As can be seen in Table 4, the most inefficient years were 2009, 2010 and 2011, where the economic crisis had an adverse effect on the purchasing power of final consumers, causing a decrease in distributed electric power (consumers were monitoring control over the consumption of electrical energy).

This Law had its positive effect from 2012 (it should be remembered that every Law needs a period of application to see its effects), since what it intended was to establish a new model that improves the levels of efficiency of the sector. To this end, it sought to reduce the market power of the distributors, mainly through a greater control of the sale price of the generators to the distributors, in order to avoid unfair pacts between the large electricity companies.

This objective has been achieved, as it is observed through the weight of the outputs (Table 6) that in most cases a transfer of the efficiency level of the operating income to the amount of energy sold is produced. It can be assumed that the output that is contributing a higher level of efficiency is the amount of energy that is distributed to the final consumer, not the operating revenues they have as distribution companies.

However, in this model it can also be inferred that since the approval of the regulations of Royal Decree Law 14/2010[31] and Royal Decree Law 20/2012[32], the efficiency levels of the distribution companies have been improving in a generic way. Therefore, the phenomenon of tariff deficit has mainly affected the levels of inefficiency of the electricity distribution companies (except Hidrocantábrico, which has an atypical behaviour) during the years 2007 to 2012. With this, they indicate that the Royal Decree, approved since 2010 against the compensation of losses in the sector, is having a positive effect on the level of efficiency.

The results of the inefficient Spanish electricity distribution companies (Table 4) are shown below during the period 2006-2015. In turn, Table 6 shows the frequency in the level of inefficiency by distribution companies and Table 7 shows the weights of both the inputs and the outputs:

TABLE 4

Ranking of inefficient distribution companies for the 2006-2015 period by the input-oriented DEA CCR model.

Rank	DMU	Score
26	Viesgo/2010	0.99528525
27	Fenosa/2007	0.99258528
28	Endesa /2006	0.99134622
29	Iberdrola/2011	0.98839071
30	Hidrocantábrico/2006	0.98542234
31	Fenosa/2008	0.98075543
32	Viesgo/2008	0.97855561
33	Fenosa/2014	0.97347025
34	Endesa/2011	0.97179728
35	Iberdrola2010	0.96904381
36	Hidrocantábrico/2012	0.95036683
37	Viesgo/2011	0.94949001
38	Hidrocantábrico/2013	0.93462756
39	Fenosa/2010	0.9303515
40	Iberdrola2009	0.91107396
41	Fenosa/2012	0.90973532
42	Hidrocantábrico/2014	0.9075846
43	Endesa/2009	0.89564614
44	Fenosa/2011	0.88402526
45	Endesa/2008	0.88279558
46	Hidrocantábrico/2009	0.87811648

47	Hidrocantábrico/2015	0.87717589
48	Fenosa/2015	0.8753307
49	Fenosa/2009	0.86300304
50	Iberdrola2008	0.85287801

TABLE 5

Frequency Table Results of Inefficiencies Electric distribution companies (2006-2015) by the input-oriented CCR model.

Company	Inefficiency frequency	Inefficiency years
ENDESA DISTRIBUCIÓN ELÉCTRICA SL	3	2008 2009 2011
IBERDROLA DISTRIBUCIÓN ELÉCTRICA SL	3	2008 2009 2010
HIDROCANTABRICO ENERGIA ELÉCTRICA	5	2009 2012 2013 2014 2015
UNIÓN FENOSA	7	2007 2009 2010 2011 2012 2014 2015
VIESGO DISTRIBUCIÓN	2	2010 2011

TABLE 6

Frequency Table Results of Inefficiencies Electric distribution companies (2006-2015) by the input-oriented CCR model.

DMU	Score	VX(1) MWI	VX(2) Nº Ins	VX(3) Operating costs	VX(4) HR	VX(5) %Cap	VX(6) Int Time	UY(1) GW/H	UY(2) € Exp
Endesa/2006	1	0.36839097	0	0.49266128	0.13894775	0	0	0.33113815	0.66886185
Iberdrola2006	1	9.15E-02	0	0.45262179	0.44500792	0	1.09E-02	0	1
Hidrocantábrico/2006	1	1	0	0	0	0	0	0.82101877	0.17898123
Fenosa/2006	1	0	0.12567956	0	0.54940739	0.32491305	0	0.70431048	0.29568952
Viesgo/2006	1	0.79473453	0.20526547	0	0	0	0	1	0
Endesa/2007	1	0	0.27327637	0	0.11379323	0.6129304	0	1	0
Iberdrola2007	1	0	0	0	0	1	0	0.52994415	0.47005585
Hidrocantábrico/2007	1	7.62E-02	4.55E-02	0.87830541	0	0	0	0	1
Fenosa/2007	0.99258528	0	3.06E-02	0.54479218	0.30413393	0	0.12050509	0.12524394	0.86734134
Viesgo/2007	1	0	4.75E-02	0.7085544	0.24398106	0	0	4.33E-02	0.95665537
Endesa/2008	0.88279558	0.91865567	0	7.54E-02	0	5.96E-03	0	0.75627297	0.12652261
Iberdrola2008	0.85287801	0.25947737	0	0.12497007	0	0.61555256	0	0.56772553	0.28515248
Hidrocantábrico/2008	1	0.98905027	0	1.09E-02	0	0	0	0.94575468	5.42E-02
Fenosa/2008	1	0	6.17E-02	0.52836795	0.29764988	2.04E-02	9.19E-02	0.1407046	0.8592954
Viesgo/2008	1	0	0.75072611	0	3.10E-02	0	0.21829882	0.85257792	0.14742208
Endesa/2009	0.89564614	0.91626413	0	7.83E-02	0	0.00541289	0	0.78378369	0.11186245
Iberdrola2009	0.91107396	0.40282008	0	7.36E-02	0	0.52355528	0	0.70511483	0.20595913

Hidrocantábrico/2009	0.87811648	0.39782806	0.15832146	0.35017577	9.37E-02	0	0	0.33549256	0.54262392
Fenosa/2009	0.86300304	0.94227166	0	4.56E-02	0	1.21E-02	0	0.77419827	8.88E-02
Viesgo/2009	1	0.60251842	0.38640541	0.01107617	0	0	0	1	0
Endesa/2010	1	0.89440299	0	7.82E-02	0	2.74E-02	0	1	0
Iberdrola2010	0.96904381	0.40101769	0	8.16E-02	0	0.48885994	2.85E-02	0.72464034	0.24440347
Hidrocantábrico/2010	1	0.62255178	0	0.37744822	0	0	0	0.51353045	0.48646955
Fenosa/2010	0.9303515	0.94126862	0	4.58E-02	0	1.30E-02	0	0.8363407	9.40E-02
Viesgo/2010	0.99528525	0.58581612	0.4035185	1.07E-02	0	0	0	0.99528525	0
Endesa/2011	0.97179728	9.61E-02	9.45E-02	0.10536659	0	0.70405284	0	0.67437887	0.29741841
Iberdrola2011	1	8.35E-02	0	0.22189419	0	0.67172142	2.29E-02	0.61441638	0.38558362
Hidrocantábrico/2011	1	0.73976646	0	0.26023354	0	0	0	0.45318231	0.54681769
Fenosa/2011	0.88402526	0	0.51298199	0.20447503	0	0	0.28254298	0.44506965	0.4389556
Viesgo/2011	0.94949001	0	0.26310222	8.86E-03	0	0.56335737	0.16467685	0.94949001	0
Endesa/2012	1	0.57088724	0	0	0	0.34215631	0.08695646	1	0
Iberdrola2012	1	0	0	0.4744016	0.43181643	9.38E-02	0	1	0
Hidrocantábrico/2012	0.95036683	0.64670259	4.52E-02	0.24831122	0	0	0.05975341	0.50020333	0.4501635
Fenosa/2012	0.90973532	0	0.53966638	0.2171032	0	0	0.24323042	0.49874245	0.41099287
Viesgo/2012	1	0	0	0	0.95541854	0	4.46E-02	1	0
Endesa/2013	1	0.98995095	0	0	0	1.00E-02	0	1	0
Iberdrola2013	1	0	0	0.43126074	0.40428679	0.16445247	0	1	0
Hidrocantábrico/2013	0.93462756	0.61339122	4.38E-02	0.25573803	0	0	8.71E-02	0.5112732	0.42335436
Fenosa/2013	1	0.80980022	0.11390234	0	0	0	7.63E-02	1	0
Viesgo/2013	1	1	0	0	0	0	0	1	0

Endesa/2014	1	0	0.13011911	0	0	0.82255059	4.73E-02	0.9953644	4.64E-03
Iberdrola2014	1	0	3.06E-02	0	0	0.96908903	2.97E-04	1	0
Hidrocantábrico/2014	0.9075846	0.62069891	4.43E-02	0.26507219	0	0	6.99E-02	0.48607428	0.42151032
Fenosa/2014	0.97347025	0	0.49823068	0.21540847	8.57E-02	0	0.2006986	0.53688027	0.43658999
Viesgo/2014	1	0	0.34626523	0	0	0.38792641	0.26580836	1	0
Endesa/2015	1	0	0.12246294	0	0	0.87753706	0	0.92687112	7.31E-02
Iberdrola2015	1	0	0	0.13283274	0	0.86716726	0	1	0
Hidrocantábrico/2015	0.87717589	0.62084264	4.53E-02	0.24628663	0	0.01079703	7.68E-02	0.45490856	0.42226733
Fenosa/2015	0.8753307	0.94442909	0	4.46E-02	0	1.09E-02	0	0.79810771	0.07722299
Viesgo/2015	1	0	0.14450361	9.92E-02	0.12658102	0.62969694	0	0.80466279	0.19533721

Once again, it is observed that the problem of productive overcapacity is accentuated during the economic crisis (2009-2011). Although electrical energy is considered a basic necessity, the final consumers have reduced its consumption as a result of the decrease in purchasing power. This is coupled with an increase in subsidies (until 2012) for constructions related to the production of electricity through renewable energy, which has generated the phenomenon of productive overcapacity.

With reference to hypothesis H3.1, renewable energy subsidies have negatively and significantly influenced the situation of productive overcapacity of the electricity distributors and this hypothesis can be affirmed according to this model. These results show that there are political constraints that affect the efficiency levels of the companies.

Regarding the tariff deficit, there is a positive evolution since its greater negative influence on the efficiency indices of energy distribution companies occurs during the period of 2007 to 2011. As can be seen, this time interval coincides with the highest levels of inefficiency of the electricity distribution companies, accepting hypothesis H4.1 that the tariff deficit negatively and significantly affects the level of efficiency of the distribution companies.

Finally, the undesirable output that is termed interruption time (Int time) is examined in more detail, due to its relevance in the efficiency model that has been proposed. Next, the frequency (Table 7) by which the undesirable output has affected the level of inefficiency of the electricity distribution companies is shown.

TABLE 7

Table of interruption time (undesirable output) of electric distribution companies (2006-2015) by the input-oriented CCR model.

Company	Inefficiency Frequency	Interruption Time (Undesirable output)
ENDESA DISTRIBUCIÓN ELÉCTRICA SL	2	2012 2014
IBERDROLA DISTRIBUCIÓN ELÉCTRICA SL	4	2006 2010 2011 2014

HIDRCANTÁBRICO ENERGIA ELÉCTRICA	4	2012 2013 2014 2015
UNIÓN FENOSA	6	2007 2008 2011 2012 2013 2014
EON ESPAÑA (VIESGO DISTRIBUCIÓN)	3	2008 2011 2012

With respect to the undesirable output, "Time of interruption" indicates that it contributes a greater degree of inefficiency regardless of the size of the distribution network, since one of the companies whose efficiency level has been most negatively affected has been Union Fenosa (6 periods). Therefore, hypothesis H2.1 is rejected because a wider distribution network negatively and significantly affects the quality of distributed electric energy, since the distribution companies with a wider network (Endesa and Iberdrola) have not been more inefficient, according to this undesirable output.

This rejection of the hypothesis is explained by the fact that one of the main causes that influences considerably the quality of electrical energy is the location of the distribution centres. In the case of Unión Fenosa, the relevance of the level of inefficiency due to the interruption time is due to the fact that it is distributed in Galicia (and is a part of the Community of Madrid) and the Galician territory is characterised as a rocky terrain with a high level of difficulty for building appropriate infrastructures (as with the railway network, for example).

5. Conclusions

In this work, a study has been carried out on the efficiency of the main electricity distribution companies in Spain (Endesa, Iberdola, Unión Fenosa, EDP and Eon). The technique used was multi-period efficiency measurement in Data Envelopment Analysis (DEA) oriented to input at constant scales (CCR) and working with panel data.

According to the results of this study and the Theory of Economic Regulation, it can be affirmed that state regulation becomes one of the main causes by which electricity distribution companies have overcapacity and tariff deficit, hence, it is an external constraint for the development of efficiency. Therefore, this study shows empirically that government decisions (political constraints) and environmental regulations have a significant influence on the efficiency of regulated companies.

The main cause of this problem of inefficiency in the distribution companies of the sector is the phenomenon of productive overcapacity in most DMUs. Likewise, it can be observed that the phenomenon of the tariff deficit also has a negative impact on the level of efficiency, but to a lesser extent than the phenomenon of productive overcapacity. This analysis indicates that the current remuneration received by electricity distribution companies allows the majority of them to be efficient, although the efficiency level would be higher if the remuneration was adjusted to the real values.

The tariff deficit also has a negative influence on the efficiency of the distribution companies in Spain until 2013. This is due to the fact that Royal Decree 1048/2013[11] was approved to finance the debt of the electricity sector in Spain through the fixed payment by the consumer.

In turn, there is an improvement in the levels of efficiency of companies from 2012, indicating that the regulations approved to alleviate the negative effect on the problem of productive overcapacity and the tariff deficit are having positive effects on the efficiency levels of these companies. As noted in Figure 4, this improvement over the efficiency level is currently observed mainly in the phenomenon of tariff deficit (positive compensation to electricity distributors in 2014). However, statistical data show a reduced impact of the regulations on the problem of productive overcapacity, although there is a slight improvement.

Among the possible solutions that could be proposed in relation to these problems of productive overcapacity and tariff deficit, it is proposed that there should be a greater sale of the market to other countries (thus reducing the power available to the few electricity distribution companies in addition to reducing the problem of productive overcapacity), a fostering of competition in the electricity distribution sector, a reduction of the high barriers of entry to the sector and a series of smart grids to improve the quality of electricity energy.

In conclusion, it is observed that regulation again plays an essential role in regulated activities, requiring a commitment on the part of the State in order to improve efficiency in regulated activities. Therefore, the environment in the regulated sector is very relevant to having a correct operation of the sector. This paper allows to know the main problems faced by the electricity distribution companies which, if properly corrected, will allow stabilisation of the kilowatt price for final consumers.

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