An Analysis of the Effect of Renewable Energies on Spanish Electricity Market Efficiency

Blanca Moreno[1] and María Teresa García-Álvarez[2]
[1]University of Oviedo/Department of Applied Economics
[2]University of La Coruna/Department of Economic Analysis and Business Administration
Spain

1. Introduction

The deployment of renewable energy is a key concept in European Union by environmental and economic reasons. This energy contributes to the securing of the objectives established by Kyoto Protocol of the United Nations Framework Convention on Climate Change (Kyoto, 11 December 1997) which entails that European Union has made the commitment to reduce their emissions by 8% during the period 2008-2012 and by at least 20% below 1990 levels by 2020.

In order to reduce emissions of carbon dioxide and others greenhouse gases, special strategies have been implemented to promote electricity generation from renewable within the regulatory framework of the European Union. The 2009/28/EC directive of the European Parliament on the promotion of the use of energy from renewable sources requires each member state to increase its share of renewable energies in energy mix to raise the overall share to 20% by 2020. In Spain, the target means that renewable sources must account for at least 20% of final energy consumption by 2020 - the same as the EU average.

In Spain, the Renewable Energy Development Plan 2005-2010 -and the Renewable Energy Plan 2011-2020 which is concurrently being drafted, processed by the Industry and Energy Council of the Spanish government and the Spanish Institute for Energy Diversification and Saving-IDEA, set the policies and strategies to its deployment of renewable energies (RES). According to the first plan is expected a contribution from RES of 12.1% of primary energy consumption in 2010 and electricity generation from RES of 30.3% of gross electricity consumption. As a result of the design of policies to promote renewable energies, Spain has registered an increase in the share of electricity from RES from 17.8% in 1990 to 29.4% in 2009 as we can see in Figure 1.

The development of renewable energy industries became a way to achieve environmental objectives. Besides, provides several positive effects, mainly referred to the expected increasing in energy self-sufficiency, employment, investment and production, the improvement of opportunities of regional and local development and the creation of a domestic industry (Moreno and López, 2008). Some of those positive effects which have been quantified by Deloitte-Appa (2009) are:

- *A positive contribution of renewable energies to GDP in Spain.* The increase of the industry of renewable energies in the period 2005-2008 gets a value of 55% in terms of GDP. The renewable technologies with greater impact on GDP have been wind energy, photovoltaic solar, biomass and mini-hydraulic.
- The development of the *research, development and innovation activities*. The high increase of some renewable production technology has entailed the creation of an important industry related to equipment and components fabrication with an innovative profile.
- The development of a fundamental concept in the *environmental protection* of Spain. The emissions of carbon dioxide (CO_2) are reduced in around 23,6 ton millions in the period 2005-2010.
- The *increasing of employment* in the renewable energy industry. The creation of employment has a value of 120.722 jobs until 2008. The 62% of them is direct jobs and the remaining 37% is indirect employment.

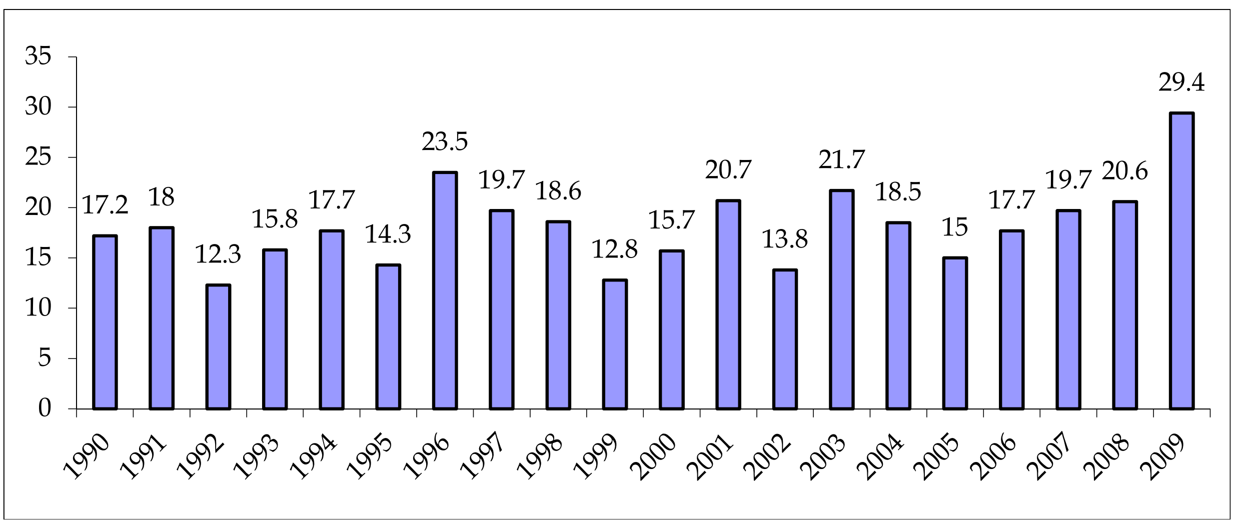


Fig. 1. Electricity generated from renewable sources, % of gross electricity consumption. Source of data: Eurostat.

In contrast to the investment-induced positive production and employment effects, some disadvantages are associated to renewable technologies as those associated to their predictability and manageability, transportation systems, costs related to adjustments in production and their prices.

Regarding the RES-E effects on electricity prices a controversial debate has arisen. This chapter attempts to contribute to this debate.

The inclusion of electricity generation from renewable energy (RES-E) has been produced in a more liberalized electricity market. The energy market liberalization has been implemented across the European Union since 1996 (Directive 96/92/EC of the European commission concerning common rules for the internal market in electricity).

The electricity industry is progressively restructuring in order to reduce the amount of economic- productive and pricing- inefficiencies that existed in the former vertically-integrated, state-owned monopoly regime.

The creation on the wholesale electricity market is one of the key concepts in the Spanish electricity industry restructured process (Law 54/1997 and Law 17/2007).

Theoretically, competitive markets should lead to efficiency gains in the economy. However, the real benefits from increasing the competition are object of debate because the market´s opening–up does not necessary imply market efficiency and competitive prices. It depends on the characteristics of the electricity supply and the electricity demand.

Regarding the electricity supply, the electricity generated from renewable energies is physically integrated into the wholesale electricity market and can influence electricity market efficiency and competitiveness.

These production technologies are characterized by having lower short-term marginal cost than fossil conventional Technologies (Jensen & Skytte, 2003; Weigt, 2009). Therefore, their entrance in the electricity markets can allow the reduction of the wholesale electricity prices because they displace the marginal technology based on fossil fuel.

However, there is not clear evidence about the effect of the development of renewable energies on the final electricity prices as the development of renewable energy technologies is mainly driven by different public renewable support schemes. Most RES-E support systems are financed via the electricity market, which could increase the electricity prices.

Then, the overall effect of the RES-E on electricity prices is not clear.

Significant econometric evidence about the effect of renewables is not easy to find at country level. Traditional parametric methods require an elevated sample size for the efficient estimation of the coefficients in the models. However, the sample data regarding the introduction of renewables in the liberalized market is limited as legal opening electricity market in Spain finish in 2003. Therefore, when trying to estimate models through regression procedures a dimensionality problem arises.

As an alternative to explain the impact of RES-E on electricity prices we propose a model by using a Maximum Entropy Econometric approach.

This approach has been defined by Golan (2002) as "a sub-discipline of processing information from limited and noisy data with minimal a priori information on the data-generating process". It has its roots in Information Theory and builds on the entropy-information measure (Shannon 1948), the classical maximum entropy principle (Jaynes 1957a, 1957b), which was developed to recover information from underdetermined models, and the Generalized Maximum Entropy Theory (Golan et al., 1996).

We investigate its possibilities in the estimation of Spanish electricity market efficiency.

The chapter is structured in the following way: firstly, the effects of renewable energies on wholesale electricity market are studied; secondly, the main characteristics of the different mechanisms of renewable support used in the European Union are briefly described. Later, we analyze the promotion policies of this type of production technology in Spain and the consequent effects on the economy. After that, the Maximum Entropy Econometric procedure is described and finally the estimated effect of RES-E on Spanish electricity prices is presented.

Some concluding remarks complete the paper.

2. The effect of renewable energy on wholesale electricity market

The electricity generated from renewable energies (RES-E) is physically integrated into the wholesale electricity market.

In wholesale electricity daily market (which sets the 89% of final electricity price in Spain), electricity generation selling companies determine, for every generation unit, the offered amount and price according to their short-term marginal cost, which is the variable cost of producing one extra unit of electricity (including the fuel, the emissions, and the operation and maintenance costs).

The supply curve is constructed according to the "merit order" of plants of different technologies in generation markets, ranking capacity from the cheapest to the most expensive (in terms of marginal costs). Plants with low marginal cost are used to cover base demand; plants with intermediate marginal cost operate in the middle of the merit generation and finally plants with high marginal cost are used to cover demand peaks. In parallel, electricity consumers establish the demanded amount.

Finally, supply and demand settle at the same marginal kWh cost of electricity. Thus, in the wholesale market all of the electricity producers get the same price according to the marginal kWh cost of electricity.

Suppose a wholesale market without RES-electricity plants (this is illustrated in Figure 2 below). The figure shows how the different types of production units typically offer electricity at different costs corresponding to their short-term marginal cost.

The production units with the lowest short-term marginal cost are nuclear plants followed by technologies based on coal and gas as combined heat and power or condensing power plants. The resulting price is the price level at which the supply and demand curves intersect.

RES-E is physically integrated into the market and will influence wholesale electricity price. These production technologies are characterized by having lower short-term marginal cost than other conventional technologies.

Therefore, their entrance in the electricity markets can allow the reduction of the wholesale electricity prices because they displace the marginal technology based on nuclear and fossil fuel. The introduction of RES-E thus changes the structure of power supply shifting the whole curve to the right and decreases marginal prices, due to the increased supply at low variable costs as we can see in Figure 3.

In addition, environmental costs related to CO_2 emissions in electricity generation usually have a significant negative effect on electricity price as a CO_2 emission trading scheme (ETS) exists. The substitution of conventional electricity generation by renewable energies could reduce the costs derived from environmental emissions and the electricity price.

Additional RES-E substitute electricity from fossil fuels, and thus CO_2-emissions are reduced. The demand for emission reductions is lowered; as a result the CO_2 price is also reduced and consequently the wholesale price for electricity decreases (Rathmann, 2007).

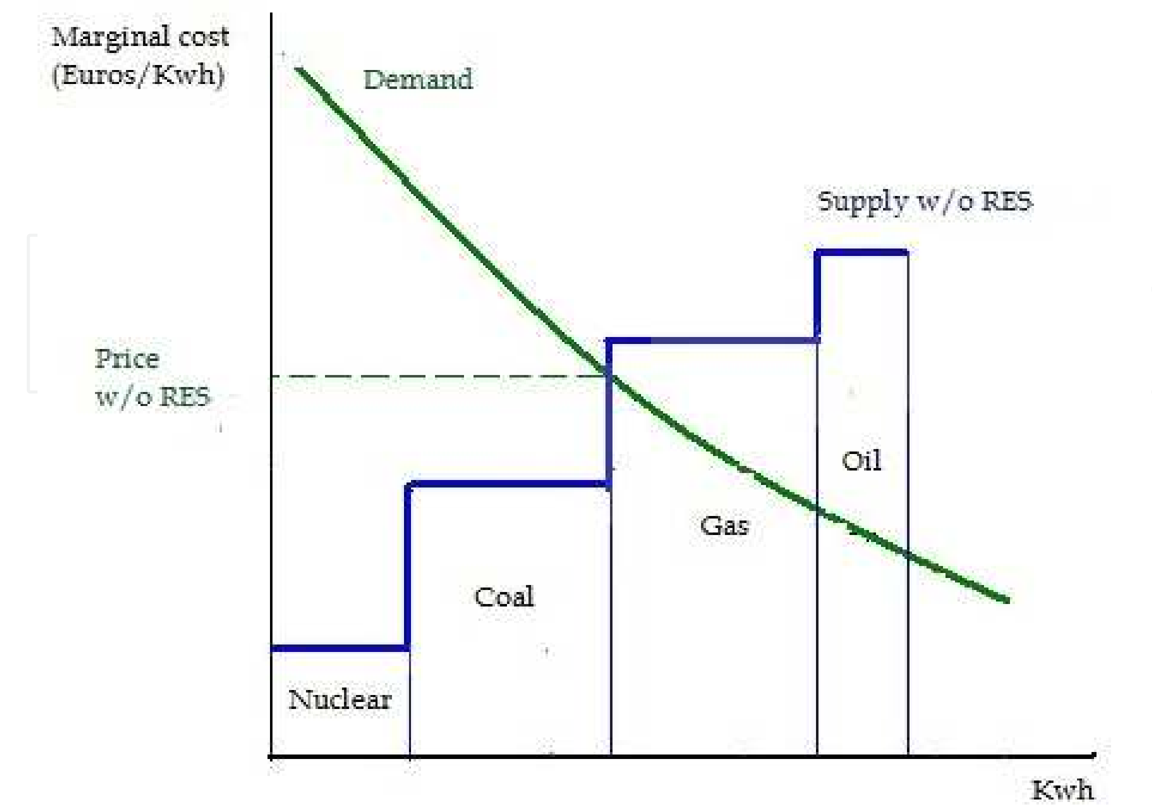


Fig. 2. Wholesale Electricity market without RES-E

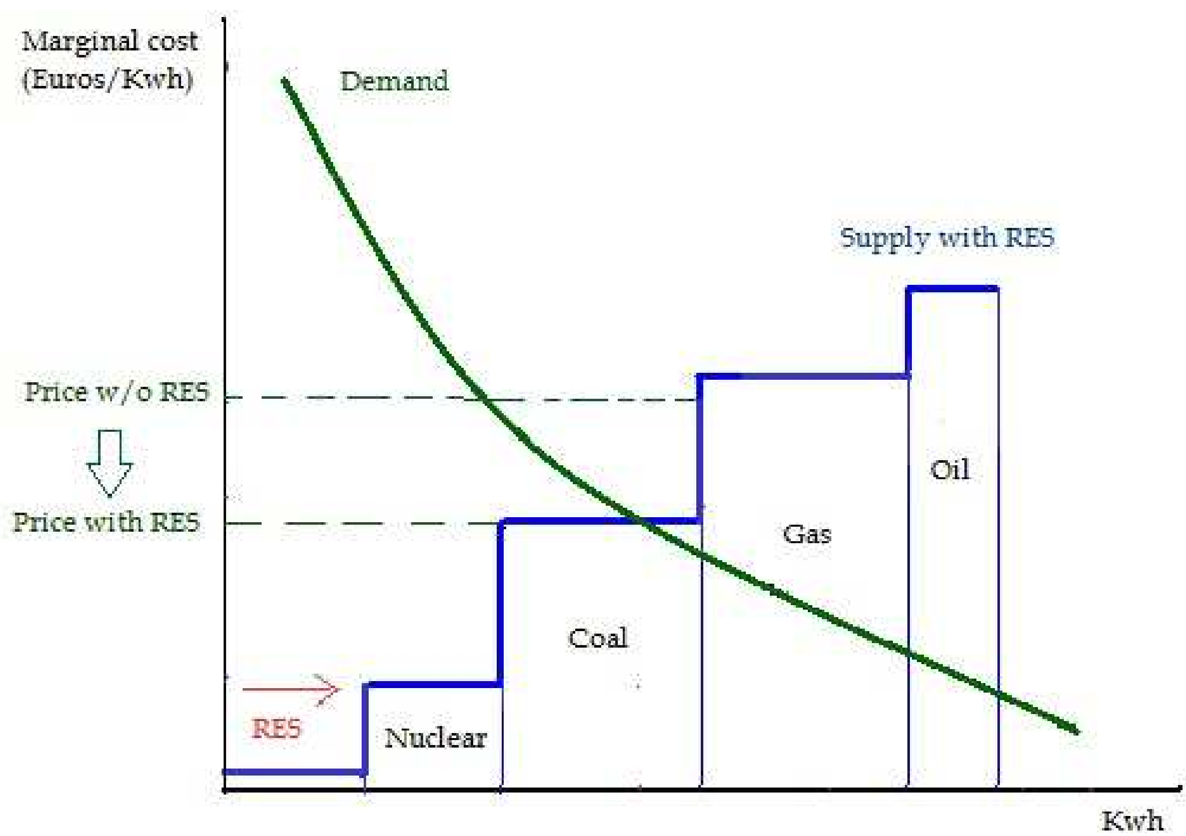


Fig. 3. Wholesale Electricity market with RES-E

With increasing RES-E, the effect on wholesale market prices is starting to become significant in some countries, notably Denmark, Spain, and Germany (Klessmann et al., 2008, Sáenz de Miera et al., 2008). However, there is not clear evidence about the effect of the development of renewable energies entail on the final electricity prices.

A large share of RES-E power generally gives lower electricity prices, as it has been shown, reducing the profitability of investing in new electricity capacity (RES are characterised by high capital investment). If RES-E generators are exposed to market prices, it directly affects their market revenues.

In this context, the participation of the governments is necessary in the initial phase of the introduction of the new production technologies. It will allow to secure their development and to protect them from the direct competition of the conventional technologies.

Reiche & Bechberger (2004) identify a number of success conditions for an increased use of RES: long-term planning security for investors, technology-specific remuneration for green power, strong efforts in the field of the power supply systems (grid extension, fair access to the grid, etc.) and measures to reduce local resistance against RES projects.

Therefore a higher use of renewable energies could reduce the wholesale electricity prices but as the development of RES-E is mainly driven by public renewable support schemes, which are financed via the electricity market, it could increased the final price paid by consumers.

3. The promotion of the renewable energies in spain in the framework of the European Union

Therefore, as the majority of renewable energy technologies are not profitable at current energy prices, their development is mainly driven by different public renewable support schemes: feed in tariffs, quota obligations, green-certificate trading, fiscal measures as tax benefits, investment grants, etc (a classification of the existing promotion strategies for renewals is provided in Haas et al., 2011).

Directive 2009/77/CE allows to each member state for the choice of mechanism of renewable energy promotion that can be better adapted to its characteristics. A revision of these measurements, in EU, shows the establishment of three types of mechanisms:

- feed-in tariffs,
- competitive auctions and
- the quotas of negotiable green certificates.

By means of the *feed-in tariffs*, renewable energy generators have right to sell all their production in the electricity wholesale market and to obtain, for it, a retribution based on a fixed price or in the daily price of electricity market plus an incentive that compensates the environmental value of the renewable production.

With the *competitive auction systems*, the regulator reserves a proportion of market for the production of renewable energy and develops the competition between generators that use these resources. Distributors have the obligation of acquiring the total of produced quantity in that reserved market. Therefore, by means of this mechanism, competition is centered on the price due to the production offers are sorted in an increasing order of prices until the proposal quantity was reached.

The objective of the *quotas of negotiable green certificates* is that the produced energy from renewable sources can be converted in an integral part of the electricity market. For it, the government establishes the obligation that distributors have to acquire a certain percentage of their supply, generally that increases in the time, from renewable energy (fixed quota of electricity).

Feed in tariffs promotion support is placed in most of the European Union countries (see Table 1) with the exception of UK, Sweden, Italy, Belgium, and Poland where Quota-based systems are now in place (European Commission, 2008).

	Feed-in tariffs	Quotas of negotiable green certificates	Auctions
Austria	X		
Belgium		X	
Bulgaria	X		
Chipre	X		
Czech Republic	X		
Denmark	X		X (wind)
Estonia	X		
France	X		X (>12, except wind)
Germany	X		
Greece	X		
Hungary	X	(Possible in the future)	
IreGeothermal	X		
Italy	X (photovoltaic solar)	X	
Latvia	X	X	X (wind)
Lithuania	X		
Luxembourg	X		
Malta	X		
HolGeothermal	X		
PoGeothermal		X	
Portugal	X		
Romania		X	
Slovakia	X		
Slovenia	X		
Spain	X		
Sweden		X	
UK		X	

Source: European Comission, 2008.

Table 1. Mechanisms of renewable energy promotion used in European Union

Therefore, the countries of European Union have introduced various support mechanisms to the renewable production technologies as there is not a consensus about which instrument is the most suitable. However, the experience shows that the development of a feed-in tariff system, that allows to guarantee an attractive profitability of the renewable installations, is effective in the promotion of the renewable energies.

It is the case of Spain that has been characterized by introducing this mechanism from the first phases of the promotion in the renewable production technologies.The feed-in tariff[1] , in this country, entails two possibilities in the sale of electricity generated by renewable energies:

- to sell their surplus of electricity energy to a distributor where the reward will be given in the way of a feed-in tariff and it is calculated as a percentage of the medium or reference electricity tariff every year (see Table 2) or
- to sell their production surplus in the electricity production market or by means of a bilateral contract where the reward will be given by the negotiated market price, an incentive for their participation and a fixed premium.

Production Technology	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007 R.D. 436**	**2007 R.D. 661**
Photovoltaic solar										
< 5 kW	39,6	39,6	39,6	39,6	39,6					
> 5 kW	21,6	21,6	21,6	21,6	21,6					
<= 100 kW						41,441	42,149	44,038	44,038	44,038
> 100 kW and <= 10 MW						21,621	21,991	22,976	22,976	41,75
> 10 MW and <= 50 Mw						21,621	21,991	22,976	22,976	22,976
Thermal solar						21,621	21,991	22,976	22,976	26,937
Wind										
Geothermal <= 5 MW	6,62	6,26	6,26	6,28	6,21	6,486	6,597	6,892	6,892	7,322
Geothermal > 5 MW and <= 50 MW						6,486	6,597	6,892		
Sea <= 5 MW						6,486	6,597	6,892		
Sea >= 5 MW						6,486	6,597	6,892	6,892	7,8
Biomass										
Energy crops	6,5	6,15	6,15	6,17	6,85	6,486	6,597	6,892	6,892	15,889
Biomass from agricultural wastes										
Biomass from forestry wastes	6,73	6,36	6,36	6,38	6,49	6,486	6,597	6,892	6,892	6,89

Source: Del Río (2008).

Table 2. Feed-in tariffs established in the Spanish electricity industry (sale option to distributor) (in hundredth part of Euro/kWh).

[1]The current legal framework of renewable energy in Spain is the Royal-Decree 661/2007. Later, Royal Decree 1578/2008 establishes a new tariff system for the photovoltaic solar energy. The new feed-in tariff system is based on the location of this type of plants: plants located on covers (type I) and plants located on the ground (type II). Order ITC/1723/2009 establishes an actualization of the tariffs and the premiums fixed for the renewable production technologies based on cogeneration and wastes. Likewise, the Royal Decree 1614/2010 establishes a restriction of the equivalent hours of functioning in the installations of wind production and thermal solar with right to premium and it supposes an updating of their premiums.

By means of this new regulation, the reward of each renewable production technology is not homogenous but is given by the produced amount and the temporal horizon of each plant. Likewise, a reference premium and the upper and lower limits are established for every renewable production technology that participates in the wholesale market (see Table 3).

Production Technology	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007 R.D. 436**	**2007 R.D. 661 Reference**	**2007 R.D. 661 Upper limit**	**2007 R.D. 661 Lower limit**
Photovoltaic solar												
< 5 kW	36	36	36	36	36							
> 5 kW	18	18	18	18	18							
<= 100 kW						a	a	a	a			
> 100 kW and <= 10 MW						18,74	19,059	19,912	19,912			
> 10 MW and <= 50 MW						18,74	19,059	19,912	19,912			
Thermal solar	0,03	0,03	0,03	12	12	18,74	19,059	19,912	19,912	25,4	34,397	25,403
Wind												
Geothermal <= 5 MW	3,16	2,87	2,87	2,89	2,66	3,603	3,665	3,829	3,829	2,929	8,494	7,127
Geothermal > 5 MW and <= 50 MW						3,603	3,665	3,829	3,829			
Sea <= 5 MW						3,603	3,665	3,829	3,829	8,43	16,4	
Sea >= 5 MW												
Biomass												
Energy crops	3,04	2,76	2,76	2,78	3,32	3,603	3,655	3,829	3,829	11,529	16,63	15,41
Biomass from agricultural wastes										8,211	13,31	12,09
Biomass from forestry wastes										8,211	13,31	12,09

(a) Photovoltaic solar plants under R.D. 661 and below 100 kW under R.D. 436 do not have the premium option.
Source: Del Río (2008).

Table 3. Fixed premiums established in the Spanish electricity industry (sales to market) (in hundredth part of Euro/kWh).

In Spain the government support of renewable energies has suppose that Spain becomes a pioneering and leader country in the integration of renewable energies

The importance of renewable energies in Spain is observed in Figure 4. It shows the electricity generated by sources as percentage of the total in the year 2009.

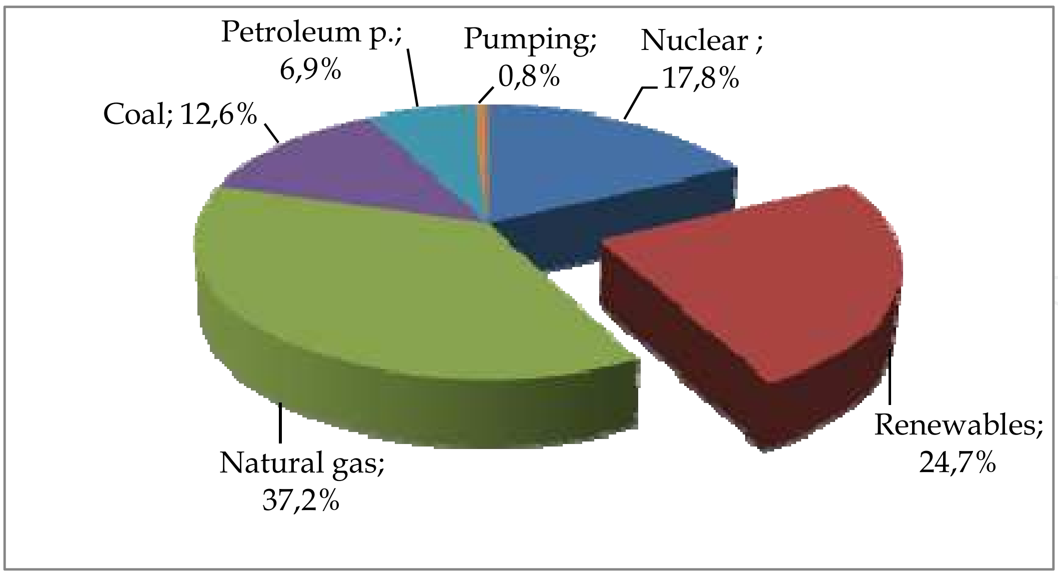


Fig. 4. Electricity generation by source (2009).

In fact, Spain is the second European country in terms of wind installed capacity and production, only behind Germany as we can see in Table 4. Spain is the fourth country in the world in terms of installed wind power after the US, Germany and China

The Spanish Renewable Energy Plan 2011-2020 processed by the Industry and Energy Council of the Spanish government and the Spanish Institute for Energy Diversification and Saving-IDEA shows that wind energy will continue to play a dominant role, accounting for 52% of renewable electricity production in 2020 (on- and offshore considered jointly).

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Germany	8754	11994	14609	16629	18415	20622	22475	23903	25777
Spain	3397	4891	5945	8317	10028	11630	15151	16740	19149
Italy	697	788	904	1132	1718	2123	2726	3737	4185
France	94	153	249	382	756	1737	2482	3542	4521
Sweden	293	328	399	452	493	519	831	1021	1560
Unitd Kingdom	474	552	649	933	1565	1961	2477	3406	4051
Portugal	125	194	297	537	1047	1681	2150	2862	3535
Denmark	2417	2889	3115	3125	3129	3135	3142	3166	3481

Table 4. Installed wind energy (MW). Source: Eurobserver

4. The impact of RES-E on electricity prices. A maximum entropy econometric estimated model

Therefore, the increased participation of renewable energies is an important factor to explain the final electricity price in the liberalized electricity market. In this section, the effect of RES-E on electricity prices in Spain is explored by using a maximum entropy econometric model. The used data set are provided by Eurostat during the period 2003-2008 (available at the web site http://epp.eurostat.ec.europa.eu).

Spanish electricity market liberalization has been progressively adopted since 1998 and finished 1st of July 2007.

The liberalization has the purpose of increasing efficiency of the energy sector following in a reduction of electricity prices. However, as we have seen previously RES-E affects the electricity prices in the liberalized market. We investigate this effect over the period 2003-2008 as legal opening electricity market in Spain finish in 2003.

Additionally, it is important to account others electricity generation technologies in empirical analysis as different technologies will result in different marginal costs and then different electricity prices. As it is showed in figure 5, generation is greatest proportion of electricity tariff costs, so the majority of variation in end-user prices should be accounted for by generation prices.

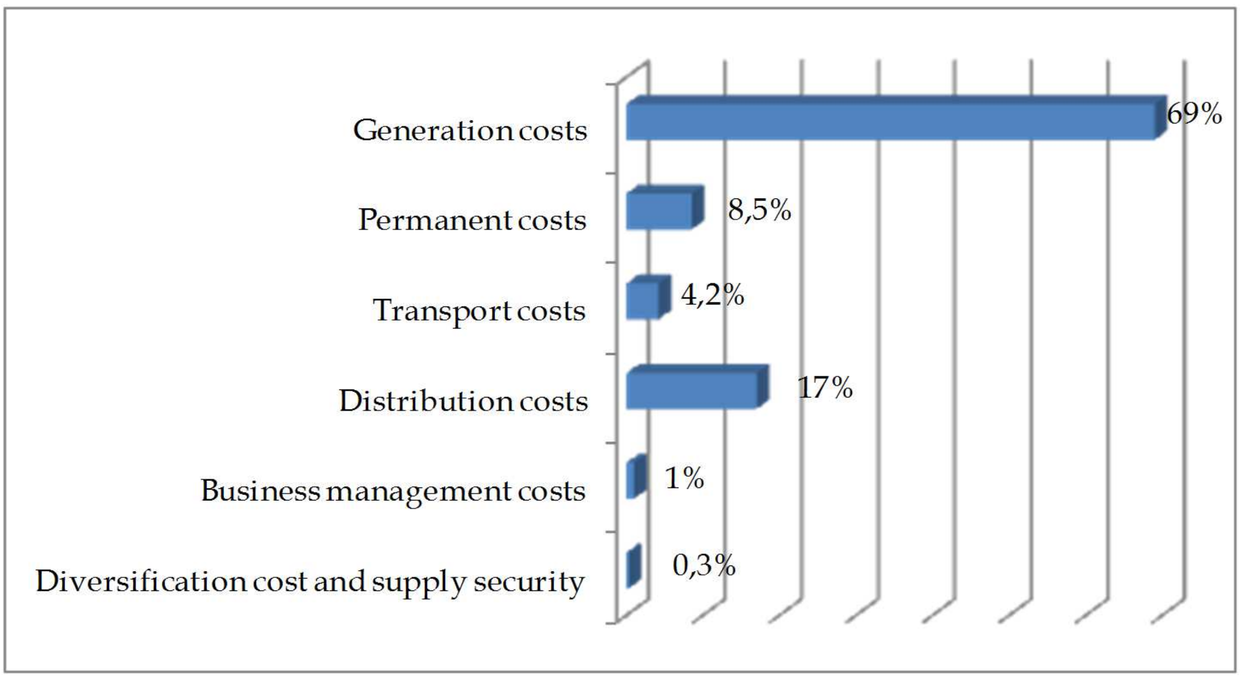


Fig. 5. Breakdown of electricity tariff costs. 2008

The goal of this section is to estimate the effect of several variables (m) related to electricity generation by RES and other sources on electricity prices (y) by using data of several years (2003-2008, T=6): $y = X\beta + u$, being X a matrix TXm, y a matrix TX1, β the vector of coefficients to be estimated (vector (m+1)x1, included a constant term) and u the vector of disturbances.

As dependent variable we use the *Electricity prices for Household consumers* (y). This indicator measures electricity prices charged to final consumers, which are defined as follows: Average national price in Euro per MWh without taxes applicable for the first semester of each year for medium size household consumers (Consumption Band Dc with annual consumption between 2500 and 5000 kWh).

The following explanatory variables (m) related to the participation of different energies in the electricity generation and thus in the wholesale electricity market are proposed:

- *Electricity generated from renewable sources- % Total gross electricity generation.*
- *Electricity generated from nuclear- % Total gross electricity generation*
- *Electricity generated from natural gas- % Total gross electricity generation*
- *Electricity generated from petroleum - % Total gross electricity generation*
- *Electricity generated from hard coal- % Total gross electricity generation.*

Moreover, the following variables are also used:

- *Greenhouse gas emissions by Energy industries* as a total of Greenhouse gas emissions. The emission trading schemes affect the short-term marginal cost of energy industries, increasing the wholesale electricity prices and thus, the household electricity price. *Ceteris paribus*, a positive effect of this variable on electricity prices is expected.
- *Gross Domestic Product per capita*, GDP per capita: This variable aims to study the effect of the general economic activity on electricity prices. A positive effect of this variable on electricity prices is expected by keeping constant both known and unknown factors that may also influence the relationship between household electricity price and the GDP independent variables.
- *Energy dependency*: Spain has a high dependence (around 80% levels) on imported resources such as crude oil and natural gas, therefore electricity prices are linked to such international energy commodities prices.

The estimation of β by regression techniques requires that the number of observations was superior to the number of independent variables (T>m). Nevertheless, information is limited (T=6 and m=9-including a constant term) and when trying to estimate the electricity price models through regression procedures a dimensionality problem arises. Therefore, in a situation of limited sample data the estimation of the model by regression procedures (OLS) is not possible as the problem is undetermined or ill-posed. However, when these circumstances of small amount of information available make it unfeasible to estimate the model $y = X\beta + u$ through OLS procedures the Maximum Entropy Econometric approach allows to recover the estimates of $\beta_1, \beta_2, ..., \beta_m$ in the corresponding parameterized model without making distributional assumptions. The approach consists of developing a non-linear inversion procedure (Golan et al. 1996) which requires the application of the tools provided by the Information Theory (Shannon, 1948; Jaynes 1957a, 1957b).

4.1 Maximum entropy econometric approach

Consider a regression-based method: $y = X\beta + u$ in a situation of limited sample data where m>T. A probability distribution should be used in order to represent partial and limited information regarding the individual observations so they are consistent with the observed sample data. Therefore, following Golan et al. 1996 it is possible to define an inverse general problem for recovering β defined as: $y = X\beta + u = XP + u$, where $P:(p_1,\ldots,p_m)'$ is a m-dimensional vector of unknown terms related to the probability distribution. The main objective is to estimate a probability distribution P given the limited information and minimal distributional assumptions and therefore recover β as $\hat{P} = \hat{\beta}$.

However, as the number of observations (T) is smaller than the number of independent variables (m), in order to recover P by using traditional procedures of mathematical inversion, there is more than one vector P making the solution feasible. Therefore the problem is ill-posed and there is no basis for picking a particular solution vector for P from the feasible set. Thus, by asking for a particular set of probabilities considered as most likely, it seems reasonable to favour the one that could have been generated in the greatest number of ways given the available data.

The definition of the entropy measure H(P) and the formulation of the Entropy Maximization problem can help to estimate a unique P distribution since the principle of Maximum Entropy provides a basis for transforming the sample information into a probability distribution that reflects the uncertainty about the individual outcomes.

The measures of entropy H(P) quantify the uncertainty associated with a random experiment. In particular, given a random variable X with values xi and probability distribution $P=(p_1,...,p_n)$ with $p_i \geq 0$ (i=1..., n) and $\sum_{i=1}^{n} p_i = 1$, Shannon's measure of entropy (Shannon 1948) is defined as: $H_S(P)=H_S(p_1,...,p_n)=-\sum_{i=1}^{n} p_i \log p_i$.

The value of the entropy is maximum when all the values x_i have the same probability (and then P is a uniform distribution). This situation would be justified by the Laplace Indifference Principle, according to which the uniform distribution is the most suitable representation of the knowledge when the random variable is completely unknown. Nevertheless, sometimes the ignorance of the probability distribution of X is not absolute and there is some partial information on the distribution such as the mean, variance, moments or some characteristics which can be formulated as equality constraints. In such a case, it is possible to estimate the probability distribution through the application of the Maximum Entropy principle (Jaynes 1957) choosing the distribution for which the available information is just sufficient to obtain the probability assignment.

Thus, if certain values a_r (r=1..., s) associated with functions $g_r(X)$ of the values of X are known but its distribution is unknown, the problem consists of estimating a nonnegative distribution that fulfils the conditions $p_i \geq 0$ for i=1..., n and $\sum_{i=1}^{n} p_i = 1$, maximizing the value of the entropy.

By solving the maximization problem it is possible to obtain the estimated probabilities $\hat{P}=\{\hat{p}_1,\ldots,\hat{p}_n\}$. The maximum entropy distribution does not have a closed-form solution and therefore numerical optimization techniques must be used to compute the probabilities.

Working towards a criterion for recovering the parameters of the regression model related to electricity price in the general inverse problem $y = X\beta + u = XP + u$, if there is no evidence that a specific independent variable is more significant than others, the related probability distribution (P) would be the uniform (according to Laplace Indifference Principle). However, the principle of maximum entropy provides a basis for using the sample information in a probability distribution P that reflects the uncertainty about the individual independent variable. Therefore, the problem consists of estimating a nonnegative distribution P by maximizing the value of the entropy H(P) subject to the available information. By solving the optimization problem the estimated probability distribution $\hat{P}$ is obtained.

A general inverse problem $y = X\beta + u = XP + u$ it is considered where the goal is to determine the unknown and unobservable frequencies $P = (p_1,...,p_m)'$, representing the data generating process. Then, within the possible sets of probabilities fulfilling $\sum_{i=1}^{m} p_i = 1$, $p_i \geq 0$, a single vector must be chosen. Through the application of the principle of maximum entropy H(P) is maximized under the restrictions of information consistency $y = X\beta + u$, and the adding up-normalization constraint for P: $P'\ell = 1$.

If the vector of disturbances, u, is assumed to be a random vector with finite location and scale parameters, it is possible to represent the uncertainty about it by treating each u_t (t=1, ..., T) as a finite and discrete random variable with $2 \leq J \leq \infty$ possible outcomes.

Thus, it is assumed that each u_t is limited by an interval (v_{t1}, v_{tJ}), whose probability, $\Pr(v_{t1} < u_t < v_{tJ})$, can become as small as it is wanted. For example, for J=2, the error can be defined as: $u_t = w_t v_{t1} + (1 - w_t) v_{tJ}$ where each $w_t \in [0,1]$ is a vector of error weights. Furthermore, $J \geq 2$ can be used to assume certain characteristics of symmetry and kurtosis about the error distribution.

Because there may be different levels of uncertainty underlying each β_i, for more general inferential purposes, point estimates may be limiting and unrealistic. Consequently, it is possible to generalize the maximum entropy problem to permit a discrete probability distribution to be specified and obtained for each β_i. Rather than search for the point estimates of β, each β_i is viewed as the mean value of some well defined random variable z.

Then, for each β_i, it is assumed there exists a discrete probability distribution that is defined over a parameter space $\mathbb{R}^K$ by a set of equally distanced discrete points $z_i = [z_1,\ldots,z_K]'$ with corresponding probabilities $p_i = [p_{i1},\ldots,p_{iK}]'$ and with $K \geq 2$. Therefore: $\beta_i = E_{P_i}[z_i]$ or $\beta = E_P[z]$.

Using the Maximum entropy econometric approach, one investigates how "far" the data pull the estimates away from a state of complete ignorance (uniform distribution). In order to measure the reduction in the initial uncertainty, the information index entropy measure R is defined (Golan, 1994; Soofi 1992, 1994) and where $R \in [0,1]$. Higher is the value of R better is the estimated model.

Moreover, some measures are defined to evaluate the information in each one of the variables i = 1,2,..., m as the normalized entropy: $S(\hat{p}_i)$. These variable-specific information measures reflect the relative contribution (of explaining the dependent variable) to the independent variable. Where $S(\hat{p}_i) \in [0,1]$, zero reflects no uncertainty while one reflects total uncertainty in the sense that P is uniformly distributed.

4.2 Maximum entropy econometric estimated model

For the solution of the optimization the GAMS program version 21.3 (*General Algebraic Modeling System*) is used. This is a programming language which allows diverse optimization problems to be solved.

A general maximum entropy model with a reparametrized error is considered.

Firstly, it is necessary to establish an a priori range for the possible values that may be assumed by u error in the model, which may be employed to assume certain characteristics of its distribution: V. Since this decision is arbitrary, a support vector for the errors (-v, -v/2, 0, v/2, v) for v>0 it is assigned. It guarantees error´s symmetry around zero. The decision regarding the amplitude of the range of values which it may assume is arbitrary. According with Pukelsheim (1994) support vector v can be assessed if the variability presented on y was knonwn and it would be possible to use the *three standard deviation rule* as estimation for v. In fact, the proposal of Golan et al (1997) who use the sample variance of y as an estimate for v is used. In sample data used the variance of y is 9,6 (euros/MWh) and then v=16,15. However, as a widening of the error bound by increasing v the estimated weights converge on the uniform distribution (the difference between the weights of the variables is reduced), the most reduced v that makes the solution feasible (v=18) is used.

Moreover, a priori range for the possible values that may be assumed by β in the model is also established. Thus, the support space Z has to be chosen, and then use the data to estimate the P which in turn yields β. The restrictions imposed on the parameter space through Z should reflect the prior knowledge about the unknown parameters. However, such knowledge is not available as the estimated models are scarce, and a variety plausible bound on β may want to be entertained.

However, a vector support symmetrical and centered on zero is considered according with the value ranking that the independent variables may take. Moreover, as an initial approximation, a covariate matrix was calculated and negative values in β was finding. So, Z= (-z, 0, z) was considered (z>0 which guarantees its symmetry around zero). The same z for all coefficients (z=0.6) was located. It implies to be very cautious in the interpretation of the estimated $\hat{\beta}$. As $S(\hat{p}_i)$ are reported and $S(\hat{p}_i) \cong 1$ implies $\beta_i \cong 0$ a natural criterion for identification of the information content of a given x_i is just the normalized entropy.

Table 5 shows estimated weights for the electricity price (β) under the reparameterized system.

The reported estimated coefficients for the model correspond with highest R obtained. The results are those obtained under the narrowest V vector.

The estimated information index R=0,67 indicates a reduction of the uncertainty by using the maximization entropy approach, however, the findings yield that the variable Electricity generated from renewable energies (RES-E) have sense to explain electricity prices as $S(\hat{p}_i) \cong 0{,}38$. Electricity from RES contributes a reduce prices as negative sign is found.

Also natural gas and energy dependency contributes to explain the increasing in electricity prices.

Variables	$\widehat{\beta}_i$	$S(\hat{p}_i)$
Electricity generated from RES	-0,516	0,383
Electricity generated from nuclear	0,522	0,366
Electricity generated from natural gas	0,503	0,425
Electricity generated from petroleum	0,596	0,035
Electricity generated from hard coal	-0,323	0,790
GHG energy indutries	0,477	0,496
GDP per capita	-0,323	0,790
Energy dependency	0,598	0,014
Support vector for the errors (-v, -v/2, 0, v/2, v)	v=	18
Support space for coefficients (-z, 0, z)	z=	0,6
Estimated information index	R=	0,67

Table 5. Estimated Household electricity price model by Maximum entropy econometric approach

Energy dependency has also an important effect. Spain has a high rate of energy dependency due to the scant presence of primary fossil fuel deposits. That great dependence introduces some risk to energy generation related to volatility of international market prices.

5. Conclusion

The creation on the wholesale electricity market is one of the key concepts in the Spanish electricity industry liberalization process (Law 54/1997 and Law 17/2007). Theoretically, competitive markets should lead to efficiency gains in the economy. However, the real benefits from increasing the competition are object of debate because the market´s opening–up does not necessary imply market efficiency and competitive prices. It depends on the characteristics of the electricity supply and the electricity demand.

Regarding the supply side, the generation from renewable sources became an important share of the total electricity generation. Over the last years Spanish electricity generation from renewable sources (RES-E) has rapidly risen accounted for approximately 25% of total electricity generation in 2009. The largest part of the electricity generation by RES is devoted to wind power and hydro which are in the forefront accounting for over 86% of total renewable electricity (52% and 36% respectively). It follows by solar photovoltaic (8%), biomass (3.2%), municipal solid waste (1,2%) and solar thermoelectric (0,1%).

According to the Spanish Renewable Energy Plan 2011-2020 processed by the Industry and Energy Council of the Spanish government and the Spanish Institute for Energy Diversification and Saving-IDEA these renewable resources will meet 36% of electricity demand in 2020.

Therefore, the electricity generated from renewable energies become more integrated into the wholesale electricity market and can influence electricity market efficiency and competitiveness.

An electricity generation technology based on renewable energies produce a least-cost merit order in the wholesale electricity market and its associated efficiency gains should also lead to lower electricity prices. However, there is not clear evidence about the effect of renewable energies on the final electricity prices.

A large share of RES-E power generally gives lower electricity prices reducing the profitability of investing in new electricity capacity. If RES-E generators are exposed to market prices, it directly affects their market revenues.

In this context, the participation of the governments is necessary in the initial phase of the introduction of the renewable electricity generation technologies for securing their development and protecting them of the direct competition that suppose the conventional technologies.

In Spain, the public support in electricity generation using renewable energies is the feed-in tariff which guarantees a price higher than that existing in the wholesale market for the renewable technology employed. This cost increment is financed by electricity tariffs.

Therefore, although large share of RES-E power generally gives lower wholesale electricity prices, a controversial debate has arisen about the RES-E effects on final electricity prices.

In order to contribute to this debate, in this chapter we propose a maximum entropy econometric model with the aim of explaining the electricity prices as a function of variables related to renewable energy sources and other electricity generation sources.

The sample data regarding the introduction of renewables in the wholesale is limited and when trying to estimate models through regression procedures a dimensionality problem arises. As an alternative to estimate the model, when a dimensionality problem arises, we propose a Maximum Entropy Econometric approach.

The obtained results show that electricity generated by reneawable energies contributes to increase final electricity prices. But also, the most important variables affecting prices is energy dependency. Spain has a high dependence (around 80% levels) on imported resources such as crude oil and natural gas (100%), therefore electricity prices are linked to such international energy commodities prices and introduces some risk to energy generation related to volatility of international market prices.

6. References

Del Río, P. (2008). Ten years of renewable electricity policies in Spain: An analysis of successive feed-in tariff reforms. *Energy Policy*, Vol. 36, (August, 2008), pp. (2917-2929), ISSN 0301-4215.

Deloitte-Appa (2009). *Estudio macroeconómico del impacto de las energías renovables en la economía española*, Asociación de Productores de Energía Renovable, Madrid.

European Commission (2009*). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources* *and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*. Official Journal of the European Union OJ L140 of the 5/6/2009 p. 16-62: 2009, Brussels.

European Commission (2008). *The Support of Electricity from Renewable Energy Sources Accompanying Document to the Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources*, COM(2008) 19, SEC(2008) 57: 2008, Brussels.

European Commission (2001). *Directive 2001/77/EC of the European Parliament and the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market. L283/33-40*. Official Journal of the European Union OJ L283 of the 17/10/2011, Brussels.

European Commission (1996). *Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity*. Official Journal of the European Union OJ L27 of the 30/1/1997, Brussels.

Golan, A. (2002). Information and entropy econometrics –Editor´s view. *Journal of Econometrics*, Vol. 107, (January, 2002), pp. (1-15), ISSN 0304-4076.

Golan, A., Judge, G. and Perloff, D. (1997). Estimation and inference with censored and ordered multinomial response data. *Journal of Econometrics*, Vol. 79, (July, 1997), pp 23-51. ISSN 0304-4076.

Golan, A., Judge, G. & Miller, D. (1996). *Maximum Entropy Econometrics: robust estimation with limited data,* John Wiley & Sons Ltd, ISBN 0-471-95311-3, London.

Golan, A. (1994). A multi-variable stochastic theory size distribution of firms with empirical evidence. *Advances in Econometrics*, Vol. 10, (December, 1994), pp (1-46), ISSN 1-55938-461-1.

Haas, R., Resch, G., Panzer, C., Busch, S., Ragwitz, M. & Held, A. (2011). Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources: Lessons from EU countries. *Energy,* Vol. 36, (April, 2011), pp (2186-2193), ISSN 0360-5542.

Jaynes, E.T. (1957a). Information Theory and Statistical Mechanics I. *Physics Review*, Vol. 196, (December,1957), pp (620-630), ISSN 0360-5442.

Jaynes, E.T. (1957b). Information Theory and Statistical Mechanics II. *Physics Review*, Vol. 108, (October, 1957), pp (171-190), ISSN 0360-5442.

Jensen, S. & Skytte, K. (2003). Simultaneous attainment of energy goals by means of green certificates and emission permits. *Energy Policy*, Vol. 31, (January, 2003), pp. (63-71), ISSN 0301-4215.

Klessmann, C., Nabe, C. & Burges, K. (2008). Pros and cons of exposing renewables to electricity market risks. A comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy*, Vol. 36, (October, 2008), pp (3646-3661), ISSN 0301-4215

Moreno, B. & López, A.J. (2008). The effects of renewable energy on employment. The case of Asturias (Spain). *Renewable & Sustainable Energy Reviews*, Vol. 12, (April, 2008), pp. (732-751), ISSN 1364-0321.

Pukelsheim, F. (1994). The three sigma rule. *The American Statician*, Vol. 48, (May, 1994), pp 88-91, ISSN 0003-1305.

Rathmann, M. (2007). Do support systems for RES-E reduce EU-ETS-driven electricity prices?. *Energy Policy* , Vol. 35, (January, 2007) pp (342–349), ISSN 0301-4215.

Reiche, D. & Bechberger, M. (2004). Policy differences in the promotion of renewable energies in the EU member states. *Energy Policy*, Vol. 32, (May, 2004), pp. (843-849), ISSN 0301-4215.

Sáenz de Miera, G., del Río P. & Vizcaíno, I. (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy* , Vol. 36, (September, 2008), pp (3345-3359), ISSN 0301-4215.

Shannon, C.E. (1948). A Mathematical Theory of Communication. *Bell System Technology Journal*, Vol. 27, (1948), pp (379-423).

Soofi, E.S. (1994). Capturing the intangible concept of information. *Journal of the American Statistical Association*, Vol. 89, (July, 1994), pp 1243-1254, ISSN 0163-6804..

Soofi, E.S. (1992). A generalizable formulation of conditional logit with diagnostics. *Journal of the American Statistical Association*, Vol. 89, (December, 1992), pp (1243-1254), ISSN 0162-1459.

Spanish Government (2010). *Royal-Decree 1614/2010, concerning the regulation and modification and change of various aspects relative to electricity production activity from solar and wind technologies*. Madrid.

Spanish Government (2009). *Order ITC/1723/2009, concerning the revision of access tolls from 1th January 2009 and the tariffs and feed-inn of various installations of the special regime*. Madrid.

Spanish Government (2008). *Royal-Decree 1578/2008, on the payment for the electric production activity from solar photovoltaic technology*. Madrid.

Spanish Government (2007). *Royal-Decree 661/2007, which regulates the production of electricity under a special regime applicable to electricity produced from renewable energy sources*. Madrid.

Spanish Government (2007). *Law 17/2007 of the 4 of July amending the Law 54/1997, of the 27 of November related to electricity sector to adapt it to Directive 2003/54/CE of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity*. Madrid.

Spanish Government (2004). *Royal-Decree 436/2004, establishing the methodology for the updating and systematization of the legal and economic regime for electric power production in the special regime*. Madrid.

Spanish Government (1997). *Law 54/1997 of the 27 of November concerning rules for the Electricity Sector. Official Journal of the Spanish Government*. Madrid.

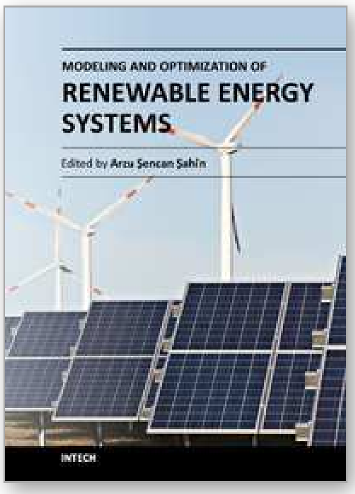
Spanish Government (1990). *National Energetic Plan 1990-2000*.Madrid,

Spanish Ministry of Industry, Tourism and Trade and Institute for Energy Diversification and Energy Saving (IDEA) (2012). *Spanish Renewable Energy Action Plan for 2011-2020*. IDEA, Madrid

Spanish Ministry of Industry, Tourism and Trade and Institute for Energy Diversification and Energy Saving (IDEA) (2005). *Spanish Renewable Energy Plan 2005-2010*. IDEA, Madrid.

United Nations Framework Convention on Climate Change (2007). *Kyoto Protocol*. Japan.

Weigt, H. (2009). Germany's wind energy: The potential for fossil capacity replacement and cost saving. *Applied Energy*, Vol. 86, (October, 2009), pp (1857-1863), ISSN 0306-2619.



Modeling and Optimization of Renewable Energy Systems

Edited by Dr. Arzu Şencan

ISBN 978-953-51-0600-5
Hard cover, 298 pages
Publisher InTech
Published online 11, May, 2012
Published in print edition May, 2012

This book includes solar energy, wind energy, hybrid systems, biofuels, energy management and efficiency, optimization of renewable energy systems and much more. Subsequently, the book presents the physical and technical principles of promising ways of utilizing renewable energies. The authors provide the important data and parameter sets for the major possibilities of renewable energies utilization which allow an economic and environmental assessment. Such an assessment enables us to judge the chances and limits of the multiple options utilizing renewable energy sources. It will provide useful insights in the modeling and optimization of different renewable systems. The primary target audience for the book includes students, researchers, and people working on renewable energy systems.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Blanca Moreno and María Teresa García-Álvarez (2012). An Analysis of the Effect of Renewable Energies on Spanish Electricity Market Efficiency, Modeling and Optimization of Renewable Energy Systems, Dr. Arzu Şencan (Ed.), ISBN: 978-953-51-0600-5, InTech, Available from: http://www.intechopen.com/books/modeling-and-optimization-of-renewable-energy-systems/an-analysis-of-the-effect-of-renewable-energies-on-spanish-electricity-market-efficiency

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821