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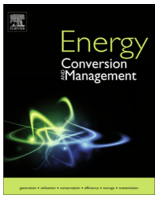

Wind power merit-order and feed-in-tariffs effect: A variability analysis of the Spanish electricity market

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ABSTRACT

The incipient large-scale energy-storage technologies are not sufficiently developed yet, which means that the wind power production depends on the wind speed at every moment. This, along with the fact that the wind resource is not constant over time, makes wind power production quite variable. Therefore, an artificial intelligence-based technique (M5P algorithm) is applied to empirical hourly data to determine the influence of wind power technology on the spot market for different levels of wind resource in 2012. It concludes that wind power depressed the spot prices between 7.42 and 10.94 €/MW h for a wind power production of 90% and 110% of the real one, respectively. Furthermore, taking into account the important presence of wind power in the Spanish generation mix, the above range has been extended up to 0% in order to determine the worst and best level of wind power production for the Spanish electrical system (from an economical point of view). To do so, both feed-in-tariffs and wind power impact on spot market (merit order effect) have been accounted in accordance with the different levels of wind power production. Since empirical data from 2012 have been used to conduct the research, the results presented in this paper may provide policy makers with a worst and best-case scenario to discuss about the convenience of the last cutting expenses over wind power technology in Spain.

1. Introduction

1.1. Fluctuating wind resource

Wind power has turned into one of the most important energy sources of the last decades for several regions of the world [1]. In the case of Spain, it covered a 16% of the net generation in 2010 and 2011, while reaching 18.1% in 2012 [2]; which makes it rank as third most important technology in terms of generation level, and first if the traditional thermal power plants are not taken into account: coal-fired, combined cycle, and nuclear.

Nevertheless, the great challenge faced by wind power technology in the next years lies in the current impossibility of storing electricity at a large scale. This means that wind power production depends completely on wind speed at any particular moment. This, along with the fact that the wind speed vector is not constant in time—with some months and years being windier than others are—makes wind power generation quite variable.

The aforementioned fact is clearly reflected in the evolution of the equivalent functioning hours of the Spanish wind power farms during the period of 2006–2012. It is worth noting that the equivalent hours are the result of dividing the total generated energy by the installed capacity, being one of the best indicators (in the absence of a global measurement campaign) of the average wind speed for that period.

As seen in Fig. 1, wind power has a marked seasonal tendency. The wind resource is higher in winter months, gradually decreasing during spring and reaching the lowest values in summer, and then goes back up in autumn. Regarding the annual variation (see Fig. 2), it can be seen how years 2010 and 2012 were the windiest of the period 2006–2012, with a total of equivalent hours near 2250; followed, at a distance, by the years 2007 and 2009 respectively. However, 2011 was the least windy year of the period, slightly over 2000 equivalent hours. Taking as a reference the year 2012, the equivalent hours have moved around the range 94–102%.

As outlined above, the fluctuating wind resource imply that it is worth not only analyzing wind power influence on the spot market (what has been termed as merit order effect, i.e. wind generation substitutes expensive technologies and hence depresses the spot

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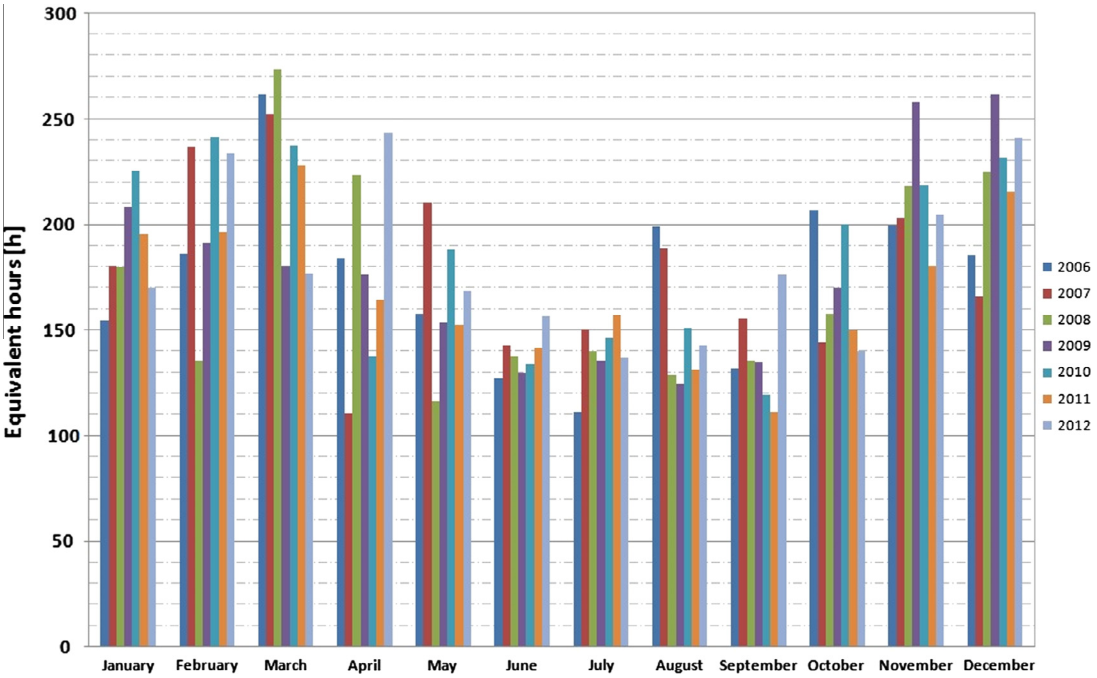

Fig. 1. Monthly evolution of the average equivalent hours of the Spanish wind farm (2006–2012) [33].

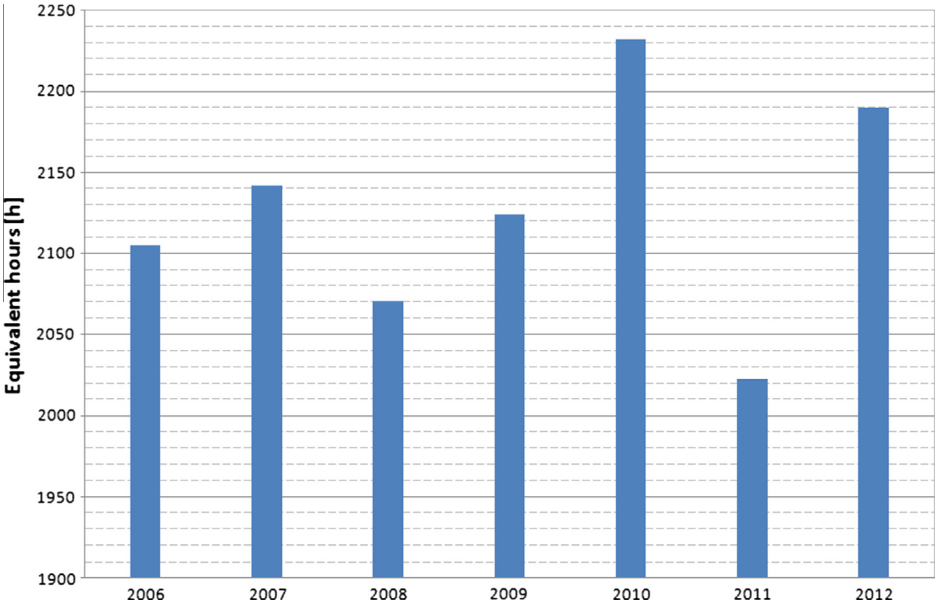

Fig. 2. Annual evolution of the average equivalent hours of the Spanish wind farm (2006–2012) [33].

prices) for a fixed condition, but also studying its influence for several wind resource scenarios.

1.2. Literature review

Regarding the merit order effect, there is a significant number of scientific works; the main contributions related to them are presented below:

Sensfuß et al. [3] present a model of the German Power Grid called "Power ACE Cluster System". The results, generated by an agent-based simulation platform, indicate that the privileged renewable electricity generation (mainly wind power) in the German spot market caused a drop of the electricity price of 7.83 €/MW h.

Weigt [4] analyzes the influence of wind power over the energy price in the German electricity market. The model, designed to minimize costs, including unit commitment and start-up costs, is analyzed with and without wind input to estimate the net savings. He also determines how wind power caused a drop of the price in the spot market of 6.26 €/MW h in 2006, 10.47 €/MW h in 2007 and 13.13 €/MW h in the first half of 2008. Based on these results, and taking into account the subsidies received by wind power technologies (5.4 €/MW h in 2006 and 7 €/MW h in 2007), the conclusion is that wind power is profitable for the system in economic terms. Woo et al. [5] use regression modelling techniques to look at the impact of wind generation concluding a similar finding for the State of Texas in the United States. And Munksgaard and Morthost [6] find that the total revenue received by wind power is, to some extent, compensated by price depression in the Danish electricity market.

Forrest and MacGill [7] determine how the merit order effect of wind power on the Australian electricity market caused an electricity price drop of $8.05/MW h for South Australia and of $2.73/MW h for the Victorian zone in the period 1/3/2009–28/2/2011. They apply econometric analysis techniques to the estimation of the impact of wind output on prices based on empirical data. On the other hand, they show how a higher drop of the energy price in the spot market, caused by a higher integration of wind power, turn into a limitation for its development. In this regard, Cutler et al. [8] suggest that for the South Australian region such limit could be close to happen. O'Mahoney and Denny [9] use similar approach estimating the cost savings in the spot market arising from wind generation effect by using OLS regression model. They conclude that the value of wind power to the spot market dispatch has outcome in savings of € 141 million (significantly greater than the subsidies received).

Regarding the specific case of the Spanish market, Sáenz de Miera et al. [10] present an analysis of the energy price drop caused by wind power in the Spanish market. They simulate the spot market dispatch in order to estimate the difference between the prices simulated with and without wind generation. They conclude that wind power generation caused a drop of 7.08 €/MW h in 2005, 4.75 €/MW h in 2006 and 12.44 €/MW h in the first four months of 2007. Taking into account the feed-in-tariff received by wind power in the period, the net savings obtained by the system are of 942 M€ in 2005, 306 M€ in 2006, and 898 M€ up to May 2007.

Gil et al. [11] simplify the multi-variable model establishing the spot price in the spot market from the degree of integration of wind power in the generation mix. Three different analysis methods are used: least-squares regression (OLS), robust locally weighted regression (RLWR) and conditional expectation sampling (CES). Starting from the fact that the average energy price for the real case with wind power generation during the period of study (04/2007–12/2010) was of 44.9 €/MW h, wind power generation caused a drop of 9.72 €/MW h in the spot price. Excluding the subsidies, the total saving produced by wind power for the electrical system was of 2.2 G€. As concerns the multi-scenario approach:

Hirth and Ueckerdt [12] find that renewable support schemes increase consumer surplus for the range analyzed (0–30% wind power integration), while CO_2 pricing does the opposite. The conclusion regarding the former, derived from an analytical model of electricity markets and a calibrated numerical model (EMMA), is that consumer surplus is 7 €/MW h (considering both the merit order effect and wind subsidies) when increasing wind penetration from zero to 30%.

Olsina et al. [13] analyzed the influence of wind power on a liberalized electricity market by means of stochastic simulation techniques. The investigation reveals that the addition of wind power capacity results in a dramatic reduction of the power prices (from 37.6 to 18.9 €/MW h for a wind power capacity of 1 and 20 GW, respectively). Based on the non-linear decline of the expected power prices for wind power integration, and considering a market-based manner (i.e. in absence of feed-in-tariffs for wind power); it is concluded that the optimal wind power capacity that should be accommodated is about 7.12 GW. It is worth noting that the authors also point that the profitability of future investments in conventional power plants is an ongoing topic due to a need for backup plants to keep the energy supply in situations of high demand and low wind. For further information regarding this, see Rodilla and Batlle [14], Mount et al. [15], Maddaloni et al. [16] and Moreno and Martínez-Val [17] for the Spanish case.

1.3. Goals and main contributions

Most of the works shown above have used simulated models of the electricity market rather than attempting to estimate the merit order effect through empirical analysis of market data. By contrast, the research presented in this paper is based on hourly data of 23 different attributes affecting the final price in the spot market for 2012.

The final price contribution of the main agents involved in the spot market has been detected by using artificial intelligence techniques. Specifically, M5P algorithm has been applied for the first time to create a 30 rule tree model that weighs the main price drivers in order to come up with the final price [18].

Based on what was previously exposed, the variation analysis presented in this paper intends to determine the influence of wind power on the spot prices and the Spanish electrical system for 2012, for different level of wind resource (entailing a variation in the national wind power generation between 90% and 110% of the real one). Additionally, considering the significant production of wind power in the Spanish generation mix, the wind resource window has been extended up to zero level in order to determine the worst and best level of wind power production for the Spanish electrical system (from the economic standpoint).

Note that the impact on economical viability of backup plants has not been analyzed, since the research is focused on 2012, when such plants were already in operation (see Moreno and Martínez-Val [17] for further details about considerations in the long-run).

The paper presents in Section 2, right after this introduction, the methodology followed to create the tree model of the Spanish electricity market, the hypothetical scenarios studied, as well as the feed-in-tariff recalculation. Section 3 presents the results obtained for each scenario; and finally, Section 4 presents the main findings of the research.

2. Methodology

2.1. Creation of a descriptive model of the spot market

The first work consists on generating a descriptive model of the process of setting the final price [19] of electricity in the spot market. This is intended to obtain information of the influence of the main agents involved in the auction in the establishment of the price of electricity.

Computational techniques have been and are widely used, when dealing with spot market bidding [20]. Artificial intelligence tools have already been applied with great success in the prediction (ex-ante) of the electricity price. Neural Network has been used in [21], Least Square Support Vector Machine in [22] and Autoregressive Integrated Moving Average model in [23]. Specifically, artificial intelligence techniques have also been used for price forecasting in the Spanish spot market [24–26].

However, in the case that concerns this paper, artificial intelligence has not been used for day-ahead electricity price forecasting, but to generate a descriptive model of the spot market by means of an ex-post analysis.

The objective is to quantify the influence of the main drivers involved in the final price of electricity. Specifically, decision trees based on the M5P algorithm are used [27]; this generates M5 model trees using the M5' algorithm, introduced by Wang and Witten [28] and improves the M5 algorithm by Quinlan. The M5P algorithm splits the instances space depending on the attributes in order to minimize the error. The model obtained presents a tree diagram in which every leaf node has an MLR-type structure (Multiple Linear Regressions – known as LM). In each LM, the attributes are then weighed by means of specific coefficients in order to cobtain the final class. Fig. 3 presents a generic 3 attributes model obtained by using M5P algorithm.

Regarding the case being analyzed, initially, there were 23 (being the Class the final electricity price): available capacity in thermal plants; pumping, international balance; production in hydraulic power plants; total production in Special Regime, thermal plants and Ordinary Regime, etc.; production in coal-fired, combined cycle and nuclear; production of wind power, solar thermal, biomass, small hydraulic, etc., among others. However, to use a high number of them may cause an over-fitting of the model. Therefore a data pre-processing is conducted to reduce the final number of attributes used to create the model. The aim is to choose those attributes, among the ones available, that best describe the behavior of the market while stating the price.

Some attributes have been directly discarded, such as pumping, since it is related to the electrical consumption side and not the generation one. Or the ones that refer to the Special Regime production, because, as getting into the auction at zero price, their influence on the final electricity price is indirect, being included in the Ordinary Regime attributes. That is, their effect is not due to what they produce (Special Regime), but what this production reduces in the production of the other ones (Ordinary Regime).

After this first basic pre-process, artificial intelligence techniques have been applied to detect those attributes, among the ones left, that influence the final electricity price the most. The search method used is the Best First [29] and the attribute quality surveyor Wrapper Subset Eval. [30] that assesses the group of attributes by means of a learning algorithm, in this case M5P. Finally, the attributes that have remained left after the data-preprocessing read as follows:

- Total generation (GW h) – TG.
- Generation in hydraulic power plants (GW h) – H.
- Generation in nuclear power plants (GW h) – N.
- Generation in coal-fired thermal power plants (GW h) – C.
- Generation in combined cycle thermal power plants (GW h) – CC.
- Available capacity by means of nuclear power plants (GW) – CAP_N.
- Available capacity by means of combined cycle thermal power plants (GW) – CAP_CC.

The learning algorithm has been trained over the attributes shown above by using the computational tool WEKA [31]. Furthermore, the cross-validation technique, which constitutes an improvement of the classic hold out method, has been applied. The hold out method consists on dividing the sample data into two complementary groups, making an analysis of a subgroup (training set) and validating it with the other subgroup (test set). In this way, the approximation function is only adjusted with the group of training data and from that point are calculated the output values of the test data group (values that have not been analyzed before). The evaluation may depend greatly on how the division between the training and test data is, and therefore may be significantly different depending on how the division is made. Due to these shortages appears the concept of cross-validation. In the cross-validation of k iterations (in this case 10) or k-fold cross-validation, the sample data are divided into k subgroups. One of the subgroups is used as test data and the rest ($k-1$) as training data. The process of cross-validation is repeated for k iterations, with each of the possible subgroups of test data. Finally, the arithmetic average of the results is made for each iteration to obtain a unique result. This method is very accurate as it makes the assessment starting from k combinations of training data.

The model obtained, after applying M5P algorithm under the considerations shown above, presents a tree structure with 30 leaf nodes (which mean 30 final LMs). Hence, the final electricity price, for each of the 8760 h of 2012 (instances), is then obtained by applying its corresponding LM (selected out of the 30 ones in accordance with the values of its attributes).

Table 1 provides further details for some of the 30 rules of the model. Specifically, entry conditions and Multiple Linear Regression parameters for rules 1, 2 and 30 are given. Note that information regarding only 3 rules has been provided in order not to enlarge the paper with details regarding the whole model (30 rules).

Fig. 4 shows the adjustment obtained. As inferred from the figure, the model is capable of adjusting its response to the price changes over the year. Specifically, the model accurately responds to the falls in the electricity price during weekends (it is worth noting that this is achieved despite none of the attributes used to train the model refers to the type of day: i.e. week day or weekend) and extreme prices (e.g. last days of November and the whole of month of December). The correlation factor obtained is 0.85 with an absolute average error of 5.72. Based on that and on the parameters of the model as such, the model is considered to adapt to the real scenario and, therefore, can be used to determine the

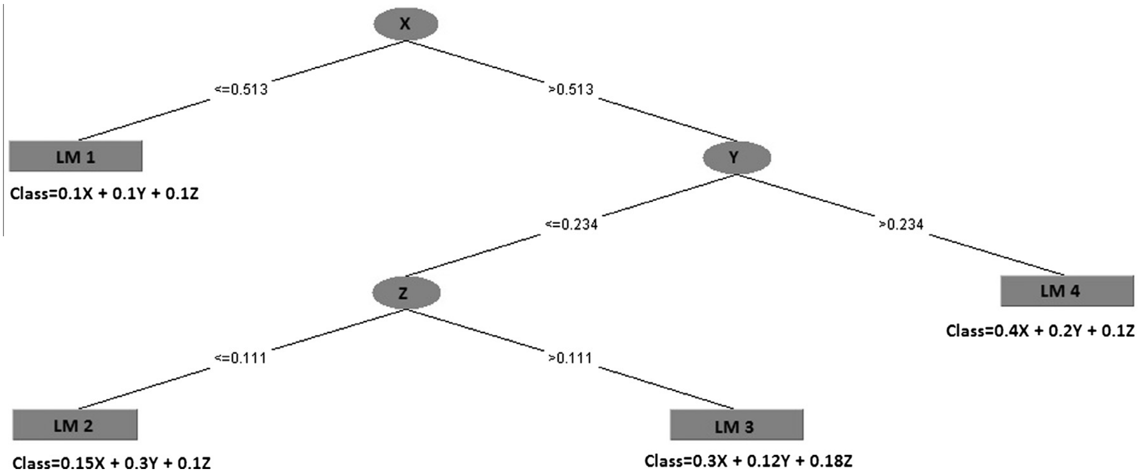

Fig. 3. Generic tree model created by means of M5P algorithm.

Table 1
Entry conditions and Multiple Linear Regression for some of the 30 rules of the descriptive model.

Rule	Conditions	Multiple Linear Regression
1st	$CC \leqq 1.635$: $1.635 < CC \leqq 2.979$;	$P = 5.2891 \ast H - 4.6547\,^{*}\,N + 2.4713\,^{*}\,C + 16.5041\,^{*}\,CC - 0.349\,^{*}\,TG + 1.4057\,^{*}\,CAP\_N - 1.7183\,^{*}\,CAP\_CC + 49.5573$
2nd	$C \leqq 2.129$; $N \leqq 2.176$; $H \leqq 0.723$	$P = 0.6223 \ast H + 3.9188 \ast N + 0.3813 \ast C + 5.4436 \ast CC + 0.0082 \ast TG + 0.0797 \ast CAP\_N - 0.0202 \ast CAP\_CC + 23.5711$
. . .	–	–
30th	$CC > 7.774$ $C > 7.406$ $H > 1.493$ $TG > 29.693$	$P = 0.0997 \ast H - 0.0461 \ast N + 1.6151 \ast C + 0.1594 \ast CC + 0.2269 \ast TG - 0.0338 \ast CAP\_N - 0.0039 \ast CAP\_CC + 66.2057$

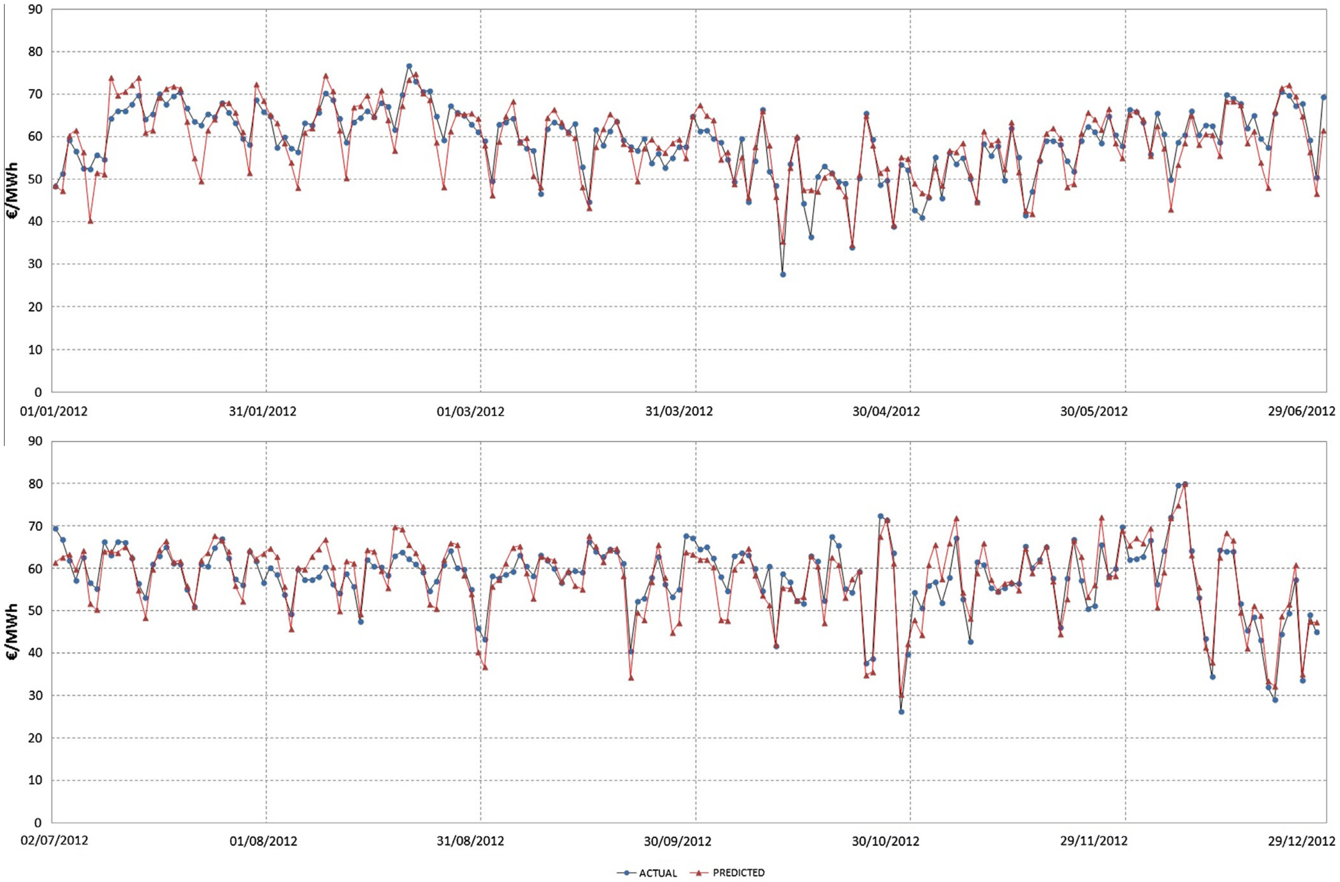

Fig. 4. Comparison between the actual daily average final weighed price of electricity in the spot market and the one predicted by the model (M5P algorithm-based) for 2012.

new prices of energy in different alternative scenarios of wind power generation for 2012.

2.2. Scenarios analyzed

The scenarios presented have intended to cover the following premise

- Influence of wind power on the spot market for different levels of wind resource in 2012. In particular, wind power levels ranging between 90% and 110% of the real one have been analyzed.
- Taking into account the significant integration of wind power in the Spanish generation mix, the range shown above has been extended to 0% in order to determine the worst and best level of wind power production for the Spanish electrical system (from a economical point of view – discounting from the feed-in-tariffs received the saving generated in the spot market).

Based on that, 111 scenarios (110 fictitious scenarios plus the real scenario) that go from 0% to 110% of wind power generation have been established, corresponding the latter to a wind power generation level 10% higher than the real one for 2012 (considering the 100%).

2.3. Feed-in-tariffs recalculation

According to the Spanish feed-in-tariff framework, different wind farms had different remuneration modalities during 2012.

However, this work is not focused on a specific wind farm but the Spanish wind farm as a whole. Therefore, the real feed-in-tariffs [32] received by the wind power have been assigned to the real scenario (known as 100%); and the feed-in-tariffs for the rest of scenarios have then been calculated by applying direct proportionality, i.e. the scenario with 110% of wind power production receive a total subsidy 10% higher than the real one (100% wind power production). The authors truly believe that the above feed-in-tariffs recalculation methodology is successfully supported by two reasons:

- For an installed capacity (whatever the wind farms distribution over the remuneration modalities) higher wind resource (scenarios from 101% to 110%) will imply higher production as well as higher remuneration keeping direct proportionality. The same goes for lower wind resource (scenarios from 90% to 100%).
- Scenarios with a wind power production lower than 90% cannot be related to lower wind resource (since wind resource is not expected to be that low). However that situation can be linked to reductions in the installed capacity keeping a proportional relation (the same capacity reduction is applied for the different remuneration modalities). This implies that the proportionality regarding remuneration is kept as well.

In addition, and according to what is stated by the Royal Decree 1614/2010, the maximum number of equivalent hours entitled to feed-in-tariffs for the Spanish wind farm in 2012 is 2350 h. On the basis that the real equivalent hours reached by the national wind farm were 2190 h [33], scenarios 108–110% are beyond the limits stated above, and the subsidies received for them are fixed to the allowed maximum by feed-in-tariff scheme.

Nevertheless one assumption has been made. Certain technologies under the Special Regime have the option of receiving the market spot price plus a differential (the total received is between top and down). This means that a rise in the price causes some facilities to reach the bonus top before its time, thus reducing the bonus to be paid by the State. To know this variation, it is necessary to have the hourly data of the energy belonging to that modality for each technology of the Special Regime, even though this information is no directly attainable. Considering this, around 66% of the facilities under the Special Regime (80% discounting wind power) receive a fixed value, independent of the market price [32]. It is considered acceptable, for the purposes of this paper, to assume that the feed in tariffs received for Special Regime would not be reduced by a higher spot price.

2.4. Database generation

As presented in Section 2.1, the descriptive model is generated starting from the following variables: total generation, generation in hydraulic power plants, generation in nuclear power plants, generation in coal-fired thermal power plants, generation in combined cycle thermal power plants, available capacity in nuclear power plants, and available capacity in combined cycle power plants. The objective is to recalculate the previous variables for each of the databases corresponding to the 111 scenarios under study.

At the time of generating the new databases, two main assumptions are made. The first one considers that the slight variations that could derive from the new cassation point of supply and demand in the new scenarios are sufficiently small, which allows accepting the demand curve as inelastic (and therefore the total generation) for the analysis made. Regarding the second assumption, the production in hydraulic power plants will be considered the one observed during 2012, without the repercussions of wind power variations. This argument is because even though hydraulic energy is a highly manageable technology thanks to dams, it is already fully optimized to coincide its generation hours mainly with the peak demand hours. Based on that, such assumption is considered valid for the intended purpose.

As mentioned previously, the variations experienced by wind power in each of the scenarios presented should be cushioned by the backup plants, in order to ensure the energy supply. Due to the configuration of the Spanish electrical System, the backup plants used are the coal-fired and combined cycle thermal power plants. It becomes necessary to determine how the backup power plants will cover these variations. According to Fig. 5 (real scenario – 100%), the clear logarithmic tendency is considered the most suitable way of representing the existing relation between coal-fired and combined cycle production in the Spanish system. For

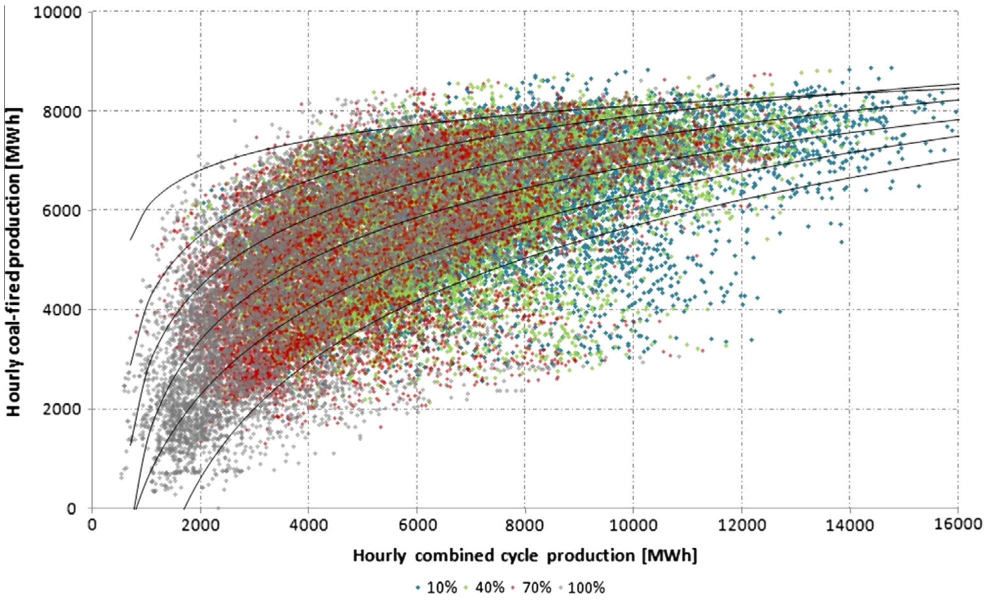

Fig. 5. Coal-fired and combined cycle production for a selection of the analyzed scenarios for 2012 (real scenario named 100% and 3 fictional scenarios named 10%, 40% and 70% respectively); as well as the 6 logarithmic curves in accordance with the trend between coal-fired and combined cycle production.

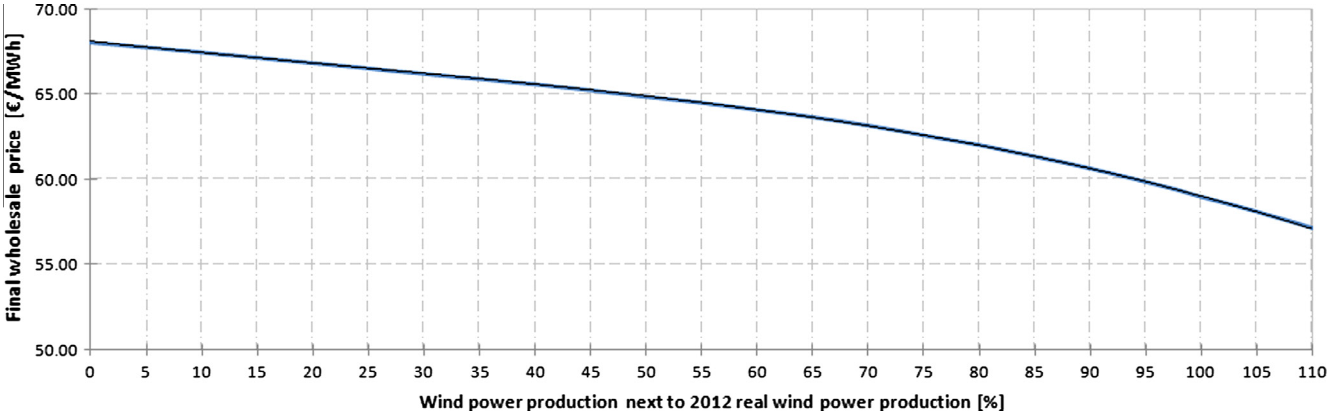

Fig. 6. Final electricity price as a function of wind power production (next to the real production of 2012).

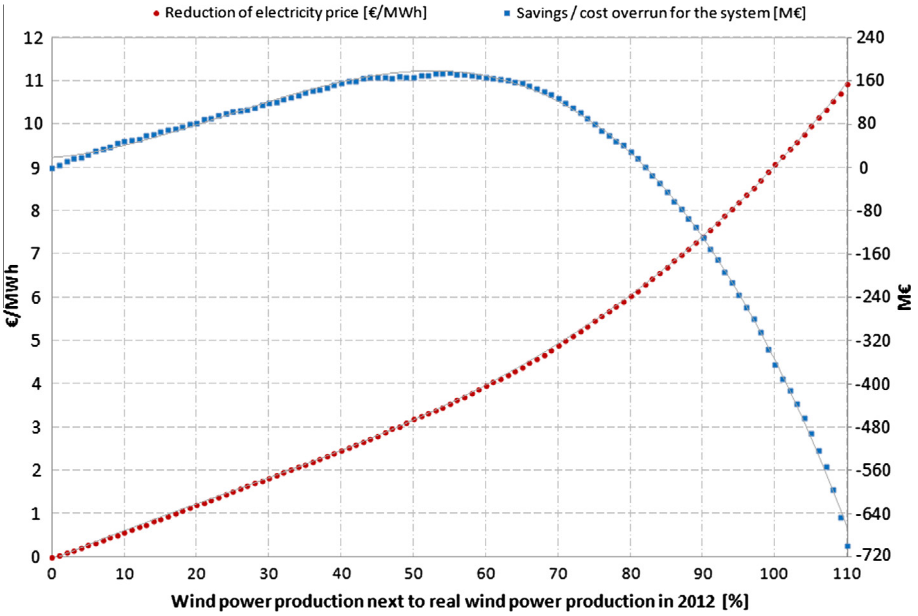

Fig. 7. Energy price variation and savings/cost for the Spanish electrical system as a function of wind power production (percentages shown in *X*-axis refer to the real wind power production of 2012).

that purpose, six logarithmic equations will be placed throughout the dispersion of points (see Fig. 5), in such a way that the increase experienced by coal and combined cycle (due to wind power depression) will follow the logarithmic slope with lower error margin. Fig. 5 also presents coal-fired and combined cycle production for some of the fictitious scenarios under study: 10%, 40% and 70% (the 107 scenarios left have been not represented for clarity reasons).

For those databases with wind power higher than the 100%, it should be taken into account that coal-fired and combined cycle give in generation to wind power, instead of taking it, as they are the technologies being driven off the auction when there are high levels of wind power production.

3. Results

The new final price for each of the scenarios is obtained by applying the descriptive model over the 111 databases corresponding to the analyzed scenarios. The results obtained are shown in Fig. 6. From the analysis of the scenarios presented, it can be stated that when wind power generation decreases, the final price rises in a reversely proportional way according to the equation shown in Table 1 (i.e. the final electricity price is 68.06, 64.86, 60.64, and 57.13 €/MW h for scenarios 0%, 50%, 90% and 110% respectively).

The price rise or drop generated by the different levels of wind power production in the spot market is shown in Fig. 7, taking as a reference the zero wind power in 2012 (denominated as 0%), According to the variation of the wind resource, if the generation had been of 90%, the price drop generated by wind power would have been of 7.42 €/MW h, being of 10.94 €/MW h for a 110% of wind power generation.

Regarding the economic influence on the electrical system (see Fig. 7), and also taking as a reference the wind power generation of 0%, another significant conclusion is inferred: wind power would have been profitable to the electrical system as long as its generation level had been equal or higher than the 83% of the real generation of 2012 (from that level on, the savings on the spot market produced by wind power are greater than the feed-in-tariffs received). Indeed, the best scenario for the Spanish electrical system, from the economic standpoint, is reached for a wind power production 10% higher than the real one, involving a total saving for the system of € 697.8 million. On the other hand, the worst

Table 2
Coefficients and R^2 of the adjustment polynomials represented in Figs. 5 and 6.

	R^2	$A \cdot x^3$	$B \cdot x^2$	$C \cdot x$	D
Final price in the spot market	0.999959	−0.000007	0.000447	−0.070444	68.116002
Variation of the price of electricity	0.999959	−0.000007	0.000447	−0.070444	– 0.055573
Variation of the cost/saving to the Spanish electrical system	0.999152	−0.001802	0.131430	1.120973	18.328592

scenario is reached for a wind power production of 55% of the real one, involving a cost overrun of € 175.4 million (at this point the difference between the subsidies received by wind power and the savings produced by it in the spot market reach its maximum). Please note that the scenarios shown as “best” and “worst” are the best and worst scenarios among the 111 ones studied.

Finally, it is also worth mentioning that the adjustment achieved by a third degree polynomial on the data (see Figs. 6 and 7) outline the fact that the output function of the model is smooth and continuous (see Table 2).

4. Conclusions

Wind power generation in Spain has gone from 23.1 TW h in 2006 to 48.2 TW h in 2012 [33], representing nowadays almost the 20% of the total national generation. However, an unfavourable situation for this technology has been taking place in recent years. The Royal Decree 1614/2010 limited the equivalent hours of the national wind farms, the Royal Decree-Law 1/2012 placed a moratorium on new facilities, and finally the Royal Decree-Law 9/2013 retroactively replaces the concept of feed-in-tariff, as known to date, for the “reasonable” revenue of 7.5% for the renewable plants. All these policies, focused on reducing the Spanish electrical system deficit – accounting M€ 26,000 to date, are mainly trimming subsidies for renewable technologies.

However, as documented in the scientific literature to date [10,11], wind power has been beneficial (from an economical point of view) for the Spanish electrical system during the period 2005–2010, since the savings produced over the spot market have been higher than the subsidies received. This paper aims to go beyond and evaluate the influence of wind power under several wind power production scenarios. Since empirical data from 2012 have been used for conducting the research, the results presented in this paper may provide policy makers with a worst and best-case scenario to be used as a starting point for discussing about the convenience of some cutting expenses over wind power technology.

In order to carry out the investigation, 111 scenarios have been analyzed, going from zero production of wind power to a 110% of the real generation of 2012. The conclusions reached are:

- According to the variation in the wind resource, if 2012 had been less windy, involving a wind power generation of 90%, the price energy reduction would have been of 7.42 €/MW h and the saving over the system of € 128.2 million. On the contrary, if the year 2012 had been windier, involving a generation of 110%, the energy price reduction would have been of 10.94 €/MW h and the saving over the system of € 697.8 million. The above statement implies that wind power is beneficial to the Spanish electrical system under any feasible wind resource (as savings in the spot market are greater than subsidies).
- The worst level of wind power generation, in economic terms, coincides with a 55% of the real generation. Under this scenario, the total cost overrun caused by wind power to the system is of € 175.3 million since the variation between the feed-in-tariffs and the savings produced due to the merit order effect is maximum).
- Nevertheless, wind power generation is beneficial to the Spanish electrical system (from the economic standpoint) as long as its generation level is equal or higher than 83% of the real one.

Finally, the best level of wind power generation, in economic terms, coincides with a 110% of the real generation. Under this scenario, the total saving produced by wind power to the system is of € 697.8 million. It is worth mentioning that the best level of integration of wind power coincides with the highest level studied; therefore, higher savings can be expected for higher generation levels. Nevertheless, it has been decided to limit the maximum to a 110%, in order not to divert the current spot market and provoke problems related to the curse of dimensionality. In any case, the conclusion arising from the output data is that the best level is above the current production level. It is worth noting that the values presented in these previous paragraphs must be cautiously analyzed, due to, on the one hand, possible errors inherent to the descriptive model generated; and on the other hand, to the assumptions made: hourly hydraulic production has been the one observed in the period; the total demand has been kept constant throughout the 111 scenarios analyzed, and the feed-in-tariffs received have been considered invariable based on the electricity market price.

This paper has not been intended to assess other benefits (reduction of polluting emissions, reduction of dependency on foreign energy, technology and know-how export, etc.) of wind power; nor the implications that a progressive integration of wind power will have on the stability of the power system at a medium term.

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