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Comparison of the influence of biomass, solar–thermal and small hydraulic power on the Spanish electricity prices by means of artificial intelligence techniques

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HIGHLIGHTS

- Influence of biomass, solar–thermal and small hydraulic power on Spanish electricity prices.
- Artificial intelligence (algorithm M5P) used to model the behaviour of the Spanish spot market.
- Three fictional scenarios suppressing those technologies respectively from the mix are simulated.
- Price reduction and overall saving for the system due to each technology are obtained and analysed.

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ABSTRACT

This article is intended to analyse the influence of biomass, solar–thermal and small hydraulic power respectively (isolated from the rest of the special regime) on the final electricity prices of the Spanish Pool and the cost of electricity tariffs. Thus, their influence is compared resulting that the economic impact that they have on the system is uneven. For that analysis, artificial intelligence techniques are used to create a descriptive model of the Pool, by means of an ex-post analysis. Algorithms of different typologies are also analysed. Finally, tree models based on algorithm M5P are applied. The main conclusion is that biomass and small hydraulic power have reduced the energy prices of the Pool at 1.48 and 1.45 €/MW h, generating an overall saving for the system of € 50.7 and 200.6 million, and for the average domestic consumer of € 0.12 and 3.01 respectively in 2012. Regarding solar–thermal power, it has reduced the energy prices of the Pool at 1.05 €/MW h, generating an overall cost overrun for the system of € 648.2 million, and for the average domestic consumer of € 12.39.

1. Introduction

Popular belief states that renewable energies are expensive for the Spanish electrical system and are the main cause of the risings in the prices of the electricity bills in recent times. It is true that renewable energy generation technologies have not been, to this date, competitive enough to challenge the traditional thermoelectric power plants, which, under the framework of promotion of renewable energies, has made them earn bonuses from generation. It is also true that, the grid faces energy management problems and the need of backup plants to meet the demands in case of scarce wind, rainfall or solar radiation, since energy storage systems require cost reductions to be profitable for price arbitrage in real-time electric markets [1].

However renewable energies have in turn benefits for the system and the country as a whole; overall, the main impacts are in the environmental and socioeconomic are as [2,3]. The benefits to the system have remained unnoticed, although, they actually have a direct impact on the electricity bill. The ranking of renewable energies in the electricity Pool causes a reduction in the final matching price as they replace more expensive technologies out of the market. The fact that this auctioned market is marginal causes that the latest technology sets the price rate and then the rest of the technologies are paid to that price.

The facts above presented in general for renewable energies, in practice work in a very uneven way depending on the type of renewable energy one is referring to. This happens because, on the one hand, the bonuses for each technology are different and,

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on the other hand, their percentage of integration in the generation mix, and thus its influence on pricing, is uneven.

With regard to the reduction of the matching price in the Pool caused by renewable energies, there is a wide empirical literature of great importance. As a research experience, Jensen and Skytte [4] were the first to note that a significant deployment of renewable energies in the energy auction could push out of the Pool more expensive fossil technologies, thus reducing the final marginal price of energy, which could cause that the total energy savings allotted from the total demand could compensate the bonuses received for the percentage of renewable generation.

Sensfuß et al. [5] present a thoroughly detailed model of the German power Pool called "PowerACE Cluster System". In this model, the short-term perspective of the daily electricity trading is combined with the long-term investment decisions of the power plants. Thanks to the application of this model, they conclude that the ranking of the renewable energies in the pool caused the energy matching prices to drop to 7.83 €/MW h in 2006.

Weigt [6] analyzes the influence of wind power generation over the electricity price in the German spot market. He concludes how wind power caused a drop of the price in the spot market higher than the subsidies received, concluding that wind power is profitable from an economic standpoint.

Mulder and Scholten [7] studied the impact of renewable energy on electricity prices in the Netherlands. Their findings suggest that the intersection of the demand and supply curve in the Dutch market is hardly influenced by the merit order effect of renewable energy. The growth in renewable energy has moved the supply curve to the right, but this shift apparently is too small to affect the price level where the demand curve intersects the supply curve.

Moreno et al. [8] provides an empirical investigation into the electricity prices determinants in the European Union. In fact they develop econometric panel models to explore the relationship between the household electricity prices and variables related to the renewable energy sources and the competition in generation electricity market. Their results suggest that electricity prices increase with the deployment of renewables and with the expansion of greenhouse gas emissions produced by energy industries as a European Union CO^2 emission trading scheme exists.

Burgos-Payán et al. [9] analyse the costs and benefits of the renewable production of electricity in Spain. Their results show that the growing integration of renewable sources in the electricity market puts a clear downward pressure on the wholesale electricity price (although other causes could have contributed). During 2006–2011, the volume of renewable energy grew at a mean rate of 7.98 TW h/year, which resulted in a reduction of the wholesale price at a mean rate of 0.90 €/MW h. Therefore, on average, every terawatt-hour of renewable energy reduces the wholesale price by 0.11 €/MW h.

Regarding special regime as a whole, Gelabert et al. [10] determine that an increase of 1 GW h of generated electricity under the special regime causes a drop of nearly 2 €/MW h in the price of electricity.

Following the discussion in the preceding paragraphs, it is deduced that the influence of renewable energies on the price of electricity has been studied by several authors internationally. However, the authors of this paper consider that there is a lack in the literature of a detailed and individualised analysis of the influence of emerging renewable technologies:

biomass, solar–thermal and small hydraulic power. Most articles focus on technical–economic analysis of a facility or a group of facilities in concrete but not in their effect on the price of electricity in a country [11–14].

For that analysis, and due to the complexity of the electricity sector [15], the application of computational models seems to be necessary. In that way various approaches have been developed [16–18]. In particular, a growing attention in electricity price forecasting has appeared. Many different methods based on time series analysis and artificial intelligence techniques have been proposed in the literature. Parametric time series tools from financial econometrics have been typically used. The double seasonal ARIMA (Auto Regressive Integrated Moving Average) model [19], the exponential smoothing method for double seasonality [20], and the GARCH (Generalized Auto Regressive Conditional Heteroskedasticity) model [21] have been effectively applied for short-term forecasting. However, electricity time series tend to exhibit occasional large spikes and high volatility on a daily basis. So, the models accuracy is getting higher when accounting new inputs like wind power forecasting and the day of the week [22]. That is the reason why more complex artificial intelligence techniques have been applied. Artificial neural networks have received most interest in electricity price forecasting: Feed-forward network architectures have been used in [23], Fuzzy neural networks in [24], and Enhanced probability neural networks in [25]. Regarding other models based on artificial intelligence, the weighted nearest neighbours technique has been applied in [26].

According to the information presented above, artificial intelligence methods have been widely used for electricity prices forecasting by creating predictive models (ex-ante). Based on this, the authors of this paper aim to use artificial intelligence techniques to create a descriptive model (ex-post analysis) of the Pool, in order to obtain hidden knowledge about the influence of renewable technologies on the Spanish electricity prices. After all, tree model based on algorithm M5P is applied.

Finally, the research has also shown a lack of information in the scientific literature up to this date about the influence of biomass, solar–thermal and small hydraulic power over the final price of the electricity bill, in particular the main tariff in low voltage (Tariff of Last Resort – TUR). This paper is intended to fill the existing gap.

2. Approach

The aim of this paper is to determine the influence, in economic terms, of biomass, solar–thermal and small-hydraulic power on the Spanish electrical system. For that purpose, three separate fictional scenarios for energy generation will be presented for 2012.

- SCENARIO A – Mix of real generation excluding the energy coming from biomass power.
- SCENARIO B – Mix of real generation excluding the energy coming from solar–thermal power.
- SCENARIO C – Mix of real generation excluding the energy coming from small hydraulic power (large hydraulic receive no bonus).

Starting from the premise that electricity demands must always be met without supply outages or blackouts, a possible decrease in renewable generation would cause an increase in power generation of the power plants known as backup. According to the configuration of the Spanish electrical system, the only power plants capable of assuming that role due to its high capacity and reduced operating hours would be thermal plants, in particular, the power plants using coal and natural gas combined cycle.

The production in large hydroelectric plants will be the one observed during the period of 2012. Hydraulic resources are fully optimised to match their full generation hours with high demand hours. Based on that, this assumption is considered valid for the purpose of this article. On the other hand, the total generation is a consequence of the demand and the latter, in turn, depends on the stability of the matching between the curves of demand and supply. Certain agents, be it hydroelectric plants with pumping, manage electricity purchasing based on price and other variables. This means that a change in the generation mix excluding a renewable energy source will vary the supply curve to a higher matching price which will result in a lower demand. However, these effects are considered minimal and therefore, to consider a totally inelastic demand is acceptable and necessary for the article. Note that shifting consumer demand curve towards times of low electricity prices (elastic demand) is an ongoing topic with implications for wind power technology [27].

By placing in a dispersion graph the combined cycle and coal generation, a clear logarithmic tendency may be observed. At low generations, coal has a greater presence on the mix, though this presence decreases as the total generation to be covered increases, increasing the generation in combined gas cycles in a faster way than coal does. This is related to its installed capacity, which, in the case of coal is around 10 GW, while with the combined cycles it can exceed 25 GW. Based on the above stated, this logarithmic tendency is considered to be the best way of representing how the role of coal and combined cycle of the decreases in generation with renewables will be set in the three scenarios under study. For this purpose, six logarithmic equations will be used for the dispersion of points so that, for every hour, the increase of the generation with coal and combined cycle of natural gas will follow the tendency of the logarithmic equation that presents a lesser error.

Once the scenarios to be studied are fully defined, it is necessary to generate a model that simulates the matching process in the Pool. The authors of this article consider imperative to make a multi-variable analysis that takes into account parameters such as natural gas prices, total generation needed to meet the demands, generation by technology and available capacity by technology. For this multi-variable analysis, artificial intelligence techniques have been chosen. This is made based on the certainty that these techniques generate models with high accuracy and robustness as they are able to find key hidden knowledge.

Previously established a model that represents with enough accuracy the Spanish electricity Pool, the next step is to simulate the resulting new prices for each scenario. That will be done by applying the model on the three new databases that will consider the increase experienced by coal and combined cycle caused by the reduction of renewable generation in scenario A, B and C respectively.

Finally, for each scenario, the new Tariff of Last Resort is recalculated. The energy term of the TUR is composed of two components; on the one hand, the price of energy, which is recalculated for each scenario according to the stated in the preceding paragraphs; and on the other hand, access fees, which come to bear the fixed costs of the system (line maintenance, bonuses for special regime generation, etc.). The new access fees are obtained discounting from the actual ones the same percentage that the bonuses to the biomass, solar–thermal and small hydraulic power (depending on the scenario, A, B or C) posed on total revenue.

On the other hand, it should be noted that the effects described in previous articles about matching prices of the Pool make reference to the short-term and/or current situation. In this sense Moreno and Martinez-Val [28] exposed how the economic scenario of conventional thermal power plants (excluding nuclear facilities) has changed a lot in recent years due to the significant penetration of renewable energies going from being a base technology to play a secondary role of backup in the demand peaks or low wind power production. On the other hand, they state that for the 2020 scenario, with a renewable energies penetration of a 40% of the total demand, it will take a minimum of 8 GW of additional combined cycle to ensure backing up the demand. In this way, there have been several articles: Batlle and Pérez-Arriaga [29], Batlle and Rodilla [30], Rodilla and Battle [31] among others, who have expressed concern about the security of the energy supply facing the changes in market structure, occurred in recent years. This issue depends on the will of the governments to set the appropriate regulation to ensure long-term security of the energy supply.

3. Determination of the new final price of the pool in scenario A, B and C

As stated above, in order to determine the new resulting prices in fictional scenarios A, B and C respectively, a model that faithfully represents the behaviour of the Spanish electricity pool is created.

3.1. Starting data

For the creation of this model, hourly data from the year 2012 have been used for several variables (see Table 1) related to the electricity Pool [32], thus excluding bilateral energy contracts.

The final hourly price of electricity considered, includes the matching price in the Pool, the costs derived from the system operator, the intraday market and the extra costs arising from technical restrictions, other processes and capacity payments. The authors have opted for not considering the marginal matching price in order to include in the simulation the expenses due to adjustment in the intraday markets, as well as other factors that influence the final consumer price.

3.2. Selection of significant attributes

In a first performance, the attributes that do not act directly on process of matching of prices on the Pool are discarded. Based on the aforementioned, in a first performance some attributes, i.e. 'pumping', are discarded since they do not belong to the generation area but to the demand. The attributes 'total generation of thermal power plants' and 'total generation in ordinary regime' are discarded as they are just the result of other attributes. Besides, the attributes concerning special regime are discarded since as they always enter at zero cost, its influence on pricing is absorbed by the corresponding generation of each of the technologies from the ordinary regime.

For the rest of the attributes, feature selection techniques are used, the wrapper-based algorithm is applied to determine their influence on the final price of energy in the Pool. An excessive number of attributes could cause over fitting of the model making it unsuitable for the purpose of the article. To be more specific, the WrapperSubsetEval [35] method is used attached to a search procedure to generate possible groups of attributes called BestFirst [36]. Finally, the variables selected for the generation of the model were:

- Total generation (GW h).
- Generation of large hydraulic power plants (GW h).
- Generation of nuclear power plants (GW h).
- Generation of coal-fired thermal power plants (GW h).
- Generation of combined cycle thermal power plants (GW h).
- Available capacity based on nuclear thermal plants (GW).
- Available capacity based on combined cycle thermal power plants (GW).

3.3. Preliminary analysis

From a primary analysis of the significant attributes, and without applying any artificial intelligence tool to get hidden knowledge, interesting deductions can be made which, on the one hand, fit common logic, and on the other hand, will be

Table 1
Starting data used in the model.

Inputs (attributes)	Total generation (GW h)
	Total generation in special regime (GW h)
	Total generation in ordinary regime (GW h)
	Total generation in thermal power plants (GW h)
	Total generation in ordinary regime with bonus (GW h)
	Generation of large hydraulic power plants (GW h)
	Generation of nuclear power plants (GW h)
	Generation of coal-fired thermal power plants (GW h)
	Generation of combined cycle thermal power plants (GW h)
	Generation of small hydraulic power in special regime (GW h)
	Generation of wind power in special regime (GW h)
	Generation of photovoltaics in special regime (GW h)
	Generation of solar–thermal power in special regime (GW h)
	Generation with non-renewable thermal energy in special regime (GW h)
	Generation with renewable thermal energy in special regime (GW h)
	Electric potential available in the dams (GW h) [33]
	Pumping (GW h)
	International balance (GW h)
	Available capacity based on nuclear thermal power plants (GW)
	Available capacity based on coal-fired thermal power plants (GW)
	Available capacity based on combined cycle thermal power plants (GW)
	Available capacity based on large hydroelectric power plants (GW)
	Natural gas prices (USD/Million BTUs)
Output (class)	Final hourly price of electricity (€/MW h) [34]

supported by a more thorough analysis in subsequent sections by means of artificial intelligence techniques.

By presenting on a graph the hourly final electricity prices and the rate of integration of the special regime in the Pool (Fig. 1), it can be observed that there is an incredible inverse correlation between the two variables. This graph proves right the expectation of the article at the beginning that: technologies under the special regime push out of the energy auction the more expensive technologies by significantly lowering the final electricity price in the Pool.

Another interesting aspect to be observed is the existing relationship between hourly generation in combined cycle power plants and coal-fired ones over the final price of energy. Fig. 2 illustrates perfectly the large direct correlation existing. As the generation of coal-fired power plants and combined cycle ones increases, so does the price per MW h, and vice versa.

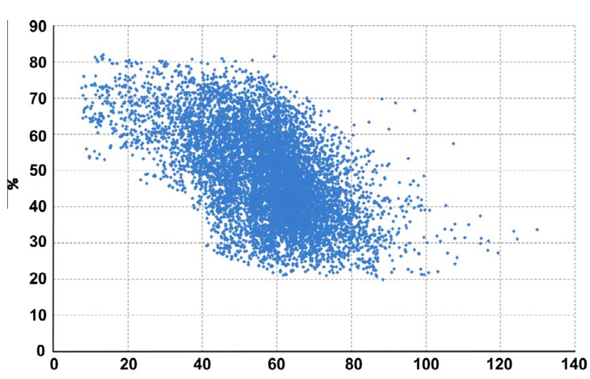

Fig. 1. Comparison between final energy prices and the rate of integration of the special regime in the Spanish spot market. Real hourly data from 2012. As inferred from the figure, there is an inverse relation between final energy prices and degree of special regimen integration in the electricity auction: the greater the integration, the lower the electricity prices.

In regard to the three renewable technologies under study (see Fig. 3), the daily biomass generation is constant; therefore no conclusions can be drawn concerning the price of energy. On the contrary, in the case of small hydraulic it is observed an inverse correlation, in the month of May, between the price of energy and small hydraulic power generation; however the authors believe that the price reduction is mainly due to the high level of wind power generation during that month. Regarding solar–thermal energy, no significant daily effects can be appreciated. The fact being evaluated three technologies with little penetration in the generation mix implies that no conclusions can be drawn a priori without carrying out a comprehensive multivariate analysis, which will be discussed in the next section.

3.4. Generation model

The model is generated thanks to the application of artificial intelligence techniques. The software used is WEKA (Waikato Environment for Knowledge Analysis) [37]. The database contains hourly data of the variables presented in the previous section between January 1st, 2012 and December 31st, 2012. The calculations were made by applying the cross-validation technique which constitutes an improvement of the holdout method. Several algorithms have been tested in order to determine their accuracy in predicting the final price of energy in the pool from the attributes discussed above:

- M5P algorithm [38,39]: This algorithm generates M5 model trees using the M5' algorithm, which was introduced by Wang and Witten [39]. It is an improvement from the original M5 algorithm by Quinlan [38]. The leaves of the tree M5P have a structure of type MLR (multiple linear regressions).
- M5 Rules [39,40]: This algorithm generates a decision list for regression problems using separate-and-conquer. A model tree is built for each iteration using M5 and the best leaf is made into to rule.
- Bagging [41]: Learning machine designed to improve stability and accuracy of automatic learning algorithms used in classification and statistic regression. It also reduces variance and helps to avoid over fitting. Although it is usually applied to tree decision methods, it may be used with any kind of method. In this case, it will be applied to the algorithm REPTree (REPT) [37]: it builds a regression tree using information gain/variance reduction and prunes it using reduced-error pruning.

The comparison is established with respect to the correlation factor (CORR) that determines the ability of the model to predict the final outcome from the input attributes, the Mean Absolute Error (MAE) and the Root Mean Squared Error (RMSE).

$$MAE = \frac{1}{n} \cdot \sum_{k=1}^{n} |m_k - p_k| \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(m_k - p_k)^2} \quad (2)$$

$$CORR = \frac{\sum_{k=1}^{n} \frac{(p_k-\overline{p})\cdot(m_k-\overline{m})}{n-1}}{\sqrt{\sum_{k=1}^{n} \frac{(p_k-\overline{p})^2}{n-1} \cdot \sum_{k=1}^{n} \frac{(m_k-\overline{m})^2}{n-1}}} \quad (3)$$

where m and p are, respectively, the measured and predicted outputs and n is the number of points of the database used to validate the models.

According to the information provided in Table 2, the three learning algorithms have a correlation factor higher than 0.8 which

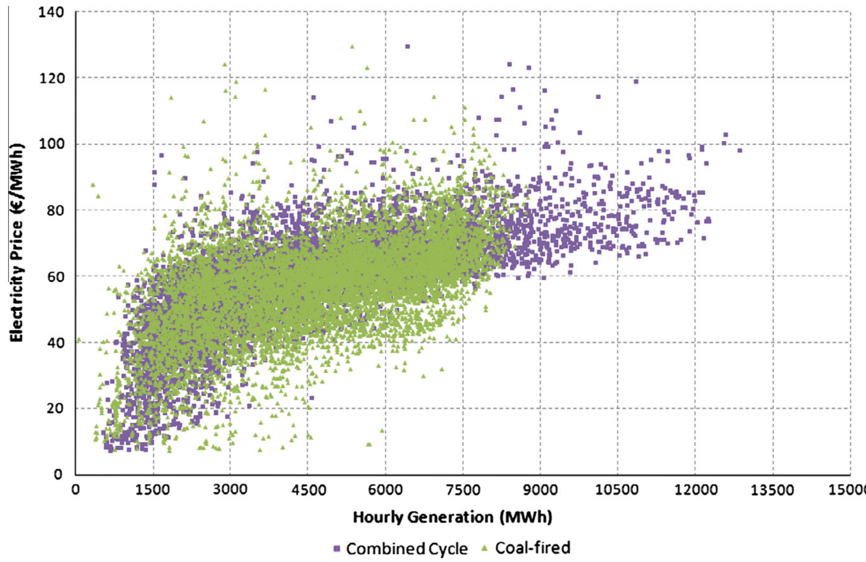

Fig. 2. Comparison between final energy prices and daily thermal generation in coal-fired and combined cycle power plants. Real hourly data from 2012. As inferred from the figure, there is a direct relation between final energy prices and electricity generation by conventional sources: the greater the production, the higher the electricity prices.

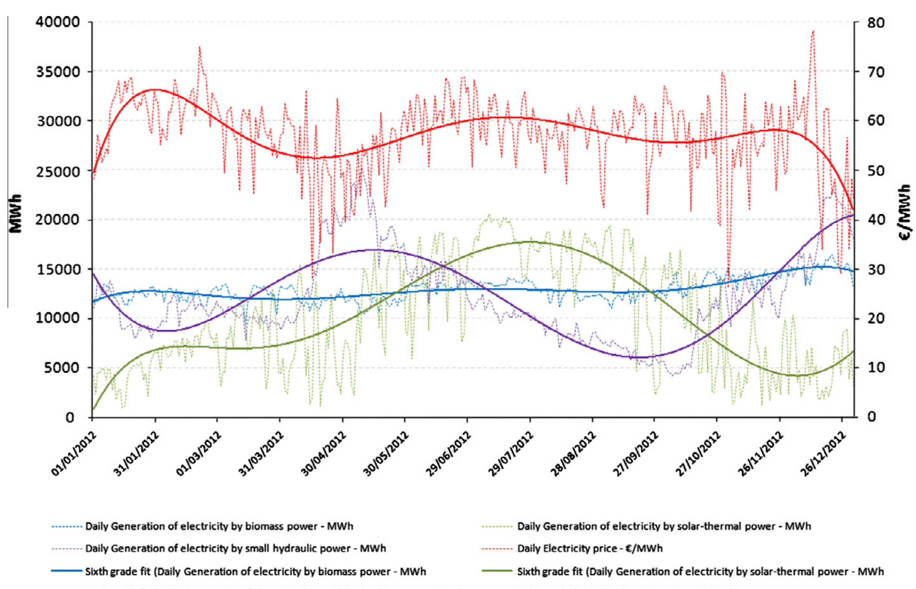

Fig. 3. Comparison between average final energy prices and biomass, solar–thermal, and small hydraulic daily generation. Real daily data from year 2012.

causes that the models created from them perfectly match the data. Even though the differences are small, M5P algorithm presents the best correlation factor, as well as, the smallest MAE and RMSE. From the parameters of the model, it is considered that this fits with enough accuracy to the real case. Therefore, this model is used to assess the scenarios without biomass power (scenario A), without solar–thermal power (scenario B) and without small hydraulic power (scenario C) respectively. Fig. 4 represents the tree model created by means of M5P algorithm.

3.5. Assessment model for scenarios without biomass, solar–thermal and small hydraulic power respectively

The created model is tested on three new databases, corresponding to scenarios A (without biomass power), B (without solar–thermal power) and C (without small hydraulic power) respectively. These new databases have been obtained from the original basis by increasing the generation of the backup power plants, i.e. coal-fired and combined cycle facilities, due to the disappearance of renewable generation in each scenario (see Fig. 5). These increases have been absorbed by them according to their logarithmic tendency as previously exhibited in section 2. Regarding this, and as inferred from Fig. 5, coal-fired and combined cycle

Table 2
Learning algorithms.

Tester: paired corrected T-tester
Confidence: 0.05 (two tailed)

	Trees.M5P	Rules.M5	Meta.Bagging
Correlation coefficient	0.85	0.84	0.83
Mean absolute error	5.72	5.76	6.01
Root mean squared error	7.70	7.75	8.09

generation for scenarios A, B, and C have been shifted up and right in a logarithmic way. Since the presence of biomass, solar–thermal, and small hydraulic power in the generation mix is small, the logarithmic shift is not large, but noticeable anyway.

The weighted final price of electricity obtained by the model for the real scenario is compared to that obtained by the model for scenarios A, B and C for every day of the year 2012 (see Fig. 6). The average results for a regular day during 2012 are shown in Fig. 7.

The conclusion that can be made from Figs. 6 and 7 is that the scenarios without biomass, solar–thermal or small hydraulic generation show higher final electricity prices in the Pool, which confirms what was anticipated previously: the ranking of renewable energies in the energy auction leads to a fall in the matching price in the Pool. In relation to biomass and small hydraulic power, their influence on the electricity price is constant all over the day according to their virtually flat load curve. Regarding solar–thermal power, one can clearly see the generation curve in the graphs of daytime generation, reaching a peak at around 15:00 – 16:00 h. It is also observed the influence of the solar–thermal energy storage plants on the electricity price during the night hours, although this influence is limited, according to the penetration of this type of plants in the generation mix.

Specifically, biomass, solar–thermal and small hydraulic power caused a weighted average decrease of 1.48, 1.05 and 1.45 €/MW h respectively in 2012.

4. Real repercussion of biomass, solar–thermal and small hydraulic technologies on the electricalsystem

Biomass, solar–thermal and small hydraulic power received, according to information from Spanish Energy Commission (CNE), a bonus of 344.0, 926.9 and € 184.1 million respectively during 2012 [42]. This bonus is what is considered to be the cost overrun caused by the system incentives to such renewable technologies.

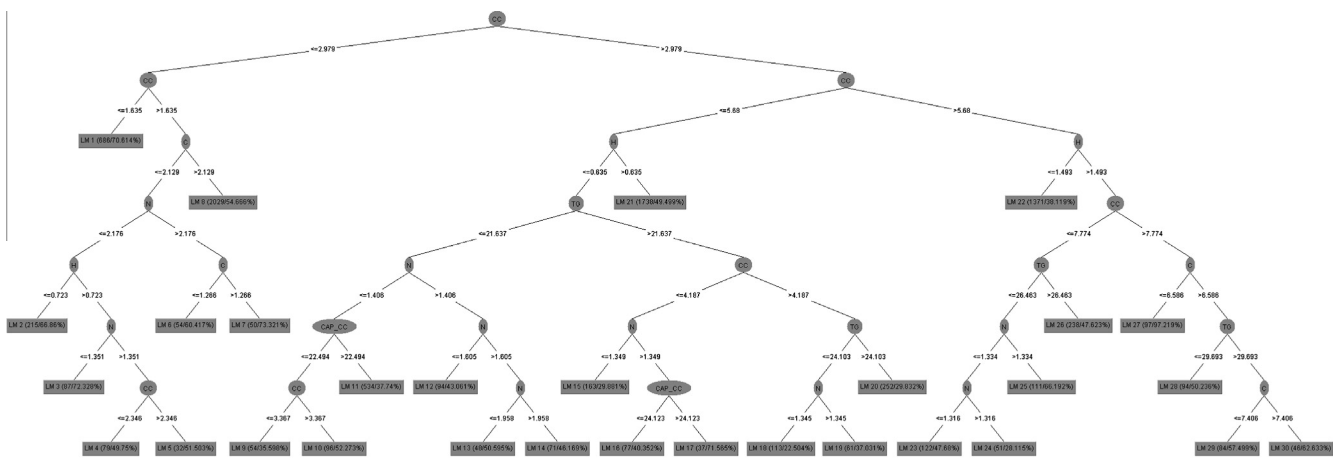

Fig. 4. Tree Model generated from the M5P algorithm, presenting a tree structure with 30 leaf nodes (30 LMs – multi linear regressions). MAE = 5.72; RMSE = 7.70; CORR = 0.85.

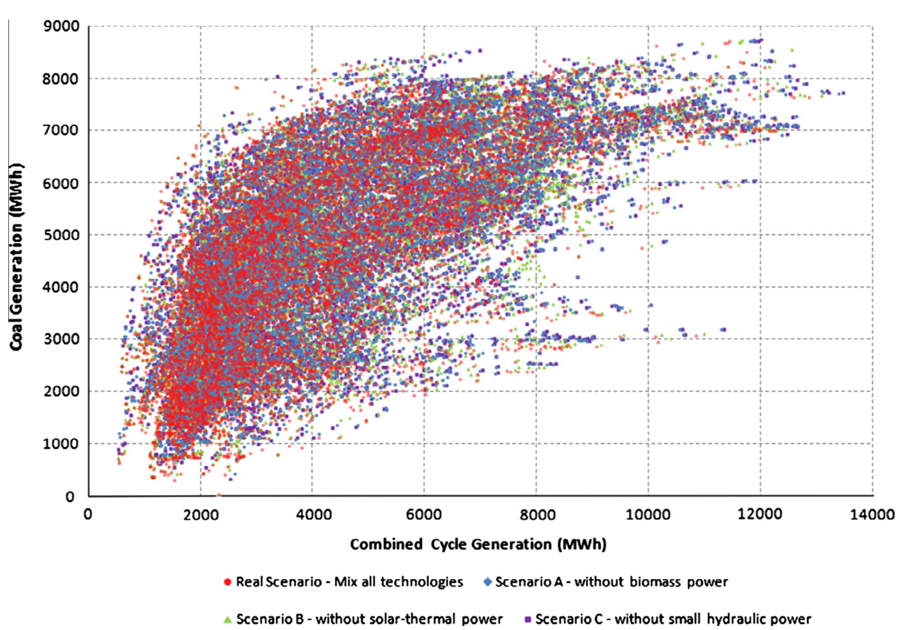

Fig. 5. Hourly generation by coal-fired and natural gas combined cycle power plants in the real scenario and scenario A, B and C for 2012. Data regarding real scenario has been collected from REE [32], and data related to the 3 fictional scenarios has been determined by shifting the points up and right from the real ones (following the logarithmic tendency shown in Section 2).

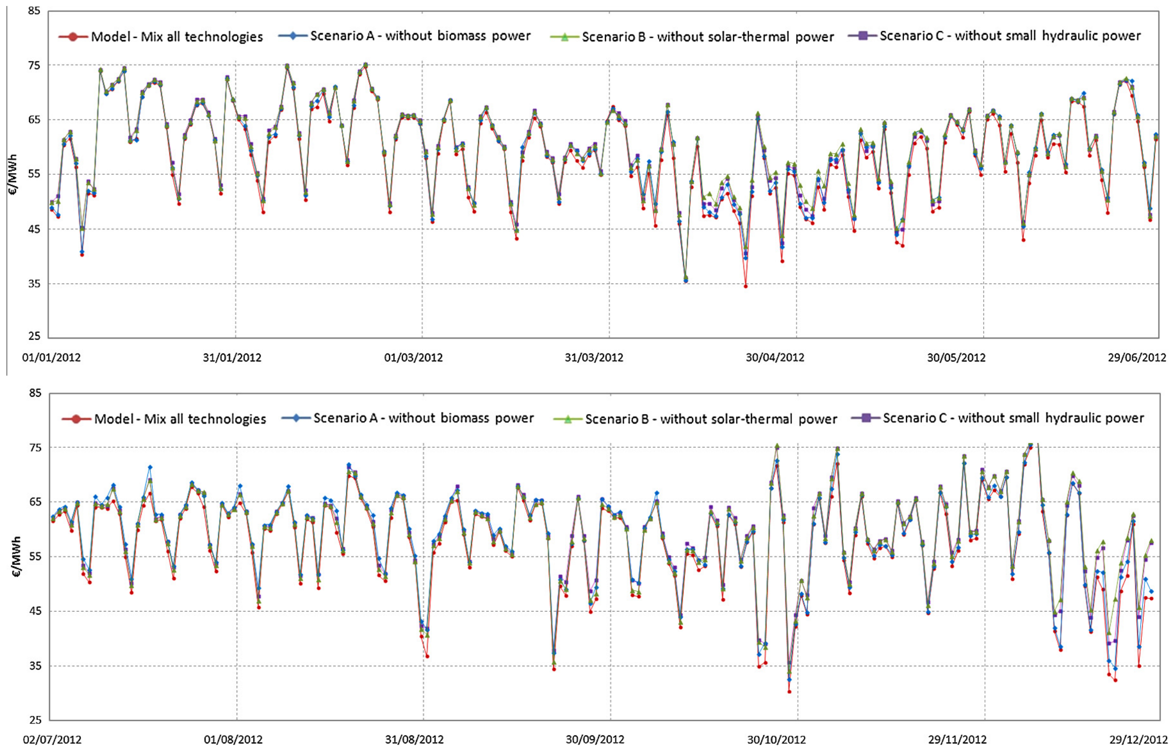

Fig. 6. Comparison of the weighted final daily energy price obtained by the model for the real scenario and scenarios A, B and C for 2012. Scenarios without biomass (A), solar–thermal (B), or small hydraulic generation (C) show higher electricity prices in the spot market.

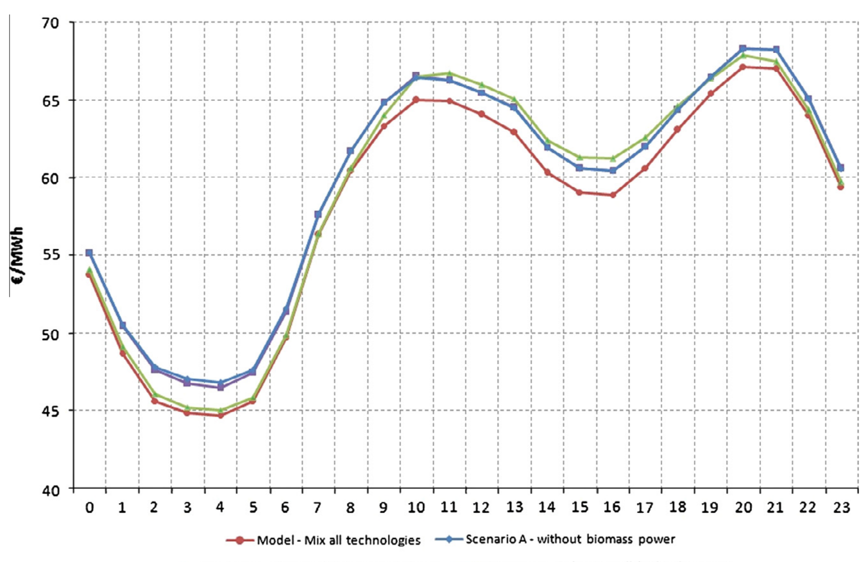

Fig. 7. Comparison of the weighted final hourly energy price obtained by the model for the real scenario and scenarios A, B and C for 2012. Scenarios without biomass (A), solar–thermal (B), or small hydraulic generation (C) show higher electricity prices in the spot market.

Table 3
Repercussion on the Spanish electric system of scenarios A, B and C for 2012.

Millions in euro	Scenario A	Scenario B	Scenario C
Feed-in-tariffs saving	−344.0	−926.9	−184.1
Total overrun	+394.7	+278.7	+384.7
Total	+50.7	−648.2	+200.6

Table 4
Comparison between the access fees of the *TUR* tariff for the real scenario and scenarios A, B and C for 2012.

€/kW h	Real scenario	Scenario A	Scenario B	Scenario C
1st Quarter	0.089395	0.087671	0.086236	0.088574
2nd Quarter	0.068998	0.067356	0.064114	0.067794
3rd Quarter	0.068998	0.067353	0.061895	0.068409
4th Quarter	0.068998	0.067168	0.065862	0.067961

On the other hand, as seen in the previous section, the decrease in the final price in the Pool due to the use of renewable energies generates a saving over all the energy auctioned in the Pool. This is what the authors consider direct savings. In addition, there are bilateral contracts whose energy does not enter into the data of the Pool, though they are actually affected indirectly by the pricing in the Pool. A drop in the pricing in the Pool will have a direct impact on the pricing on existing bilateral contracts making it drop as well and vice versa.

The savings, both direct and indirect, are determined from hourly data from:

- Total generation, which is the sum of the energy of the Pool and that of the bilateral contracts.
- Reduction of the final price of the auctioned energy in the Pool caused by renewable energies.

Taking into account the two points presented above in the appropriate way for the three fictional scenarios, biomass and solar–thermal produced a saving of 50.7 and € 200.6 million in the system in 2012 respectively. In the case of solar–thermal, it produced a cost overrun of € 648.2 million in the same period (see Table 3).

The above value should be taken as an approximate value. This is because the technologies covered under the special regime have two options to benefit from for selling their energy:

- Option 1: Receive a fixed rate, regardless of the matching price in the Pool.
- Option 2: Receive the current matching price of the market plus a differential. The total received, resulting from the sum of matching price and differential, will be a price around the bottom and the ceiling.

Those plants using the second option make the bonuses received vary based on the new market price. That is, the price increase in the Pool taking place in the scenarios without some renewable technologies make certain facilities to reach their bonus limit thereby reducing the bonus to be paid by the State. To know this variation, hourly data of the energy attached to option 2 is required for each technology of the special regime. This information is not accessible.

It is considered acceptable, for the objective of the article, to determine that all the generation units in special regime are assigned to option 1 (around 66% of the bonuses for the year 2012 correspond to option 1 [42], and therefore, the bonuses received for the special regime would not be reduced by higher matching prices in the Pool (a situation that occurs in the scenarios under study).

On the other hand, it should be noted that this value does not reflect other positive impacts caused by renewable energies, such as:

- Reduction of emissions of greenhouse gases.
- Reduction of energy dependence from foreign sources.
- Technology and know-how exports.

5. Direct repercussion of biomass, solar–thermal and small hydraulic power over the tariff of last resort

On June 30th, 2009, the existing integral tariff disappeared due to the European regulation that advocated a liberalised energy market. In this way, all consumers were subjected to the access fees set by the State, covering costs of the permanent activities of transportation and distribution of electricity, etc. Ever since, energy would be contracted by negotiating its price directly in the free market with an intermediary company. As an alternative, low voltage consumers of up to 10 kW of contracted power were given the option of contracting a Tariff of Last Resort regulated and controlled by the State. The only difference, though, from its counterpart in the free market is that the price of energy is set quarterly by means of the CESUR auctions. CESUR (In Spanish, Contratos de Energía para el Suministro de Último Recurso, meaning Energy Contracts for Last Resort Supply), it is an auction held before the beginning of the quarter which is intended to stabilize the cost of the Tariff of Last Resort making the acquisition cost of energy predictable to consumers that belong to the regulated supply, contrasting it with the unpredictability of the cost of energy if bought in the volatile daily market.

Therefore, and following the principle of additives, the term of energy of the TUR is composed of:

- Access fees equal to its equivalent in the free market.
- Price of energy calculated from the results of the CESUR auction.

To recalculate the new price of the TUR tariff for 2012, the two previous components are recalculated for the three scenarios.

5.1. Access fees: component 1 of the energy term

The quarterly revenue from access fees for the year 2012 is considered 4148.0, 3560.0, 3560.0 and 3560.0 million euros respectively [43]. In addition, bonuses to special regime are fully paid from the takings. In this way, assuming that the tariff deficit does not vary in the scenarios under study, the influence of the renewable energies on the access fees can be assessed. Specifically, over the four quarters of the year 2012, the bonuses involved: 80.0, 84.7, 84.9 and 94.4 million euros in the case of biomass power, 146.6, 252.0, 366.5 and 161.8 million euros in the case of solar–thermal power and 38.1, 62.1, 30.4 and 53.5 million euros in the case of small hydraulic power [42].

Therefore, if the influence of the above mentioned bonuses is eliminated, the access fees related to the term of energy in scenario A, B and C should be reduced in the corresponding percentage. With this premise, the access fees are thus as shown in the Table 4.

5.2. Energy price in the CESUR auction: component 2 of the energy term

The dependence between the energy price in the CESUR auction and the price in the Pool is evident. Renewable energies reduce the matching price in the Pool and therefore that of the CESUR auction.

Starting from the matching price of the CESUR auction, an estimate is made of the energy cost in the TUR tariff for each quarter in the models without renewable generation. This has been calculated in accordance with Article 9 of the Order ITC/1659/2009 of June 22 (and subsequent modification in 2010, Order ITC/1601/2010). With the purpose of not prolonging the article too much, nor losing the argument line through formulation, the needed calculations will not be displayed. For that reason, the authors refer the reader to check the regulations shown above, to see the formulation. The results are shown in Table 5.

5.3. Calculation of the TUR tariff

Once both components of the energy term are calculated separately, the TUR tariff is, after adding them up, as follows (Table 6).

The above results vouch for what was above mentioned in the article: biomass and small hydraulic power means a direct saving to the system in general and specifically to the final consumer, while solar–thermal power causes a slight cost overrun.

Table 5
Comparison between the energy prices of the *TUR* tariff for the real scenario and scenarios A, B and C for 2012.

€/kW h	Real scenario	Scenario A	Scenario B	Scenario C
January, February and March	0.07868	0.07999	0.07940	0.07977
April and May	0.07314	0.07477	0.07468	0.07528
June	0.07321	0.07484	0.07476	0.07536
July, August and September	0.08020	0.08156	0.08191	0.08114
October, November and December	0.07658	0.07923	0.07767	0.07924

Table 6
Comparison between the final price of the energy term for the *TUR* tariff for the real scenario and scenarios A, B and C for 2012.

€/kW h	Real scenario	Scenario A	Scenario B	Scenario C
January, February and March	0.168075	0.167661	0.165633	0.168347
April and May	0.142138	0.142125	0.138798	0.143076
June	0.142208	0.142201	0.138873	0.143152
July, August and September	0.149198	0.148912	0.143803	0.149553
October, November and December	0.145578	0.146400	0.143528	0.147201

The price of the electricity bill for a contract in TUR without time discrimination between January 1st and December 31st, 2012 is shown below (Table 7). As average customer of the TUR without time discrimination, an average contracted power of 4 kW and a monthly consumption of 250 kW h [44] is established. The values reflect the amount of the bill once the power tax is applied (IE = 5.1127%) and value-added tax (VAT = 18% until 31/08/2012, and of a 21% thereafter).

From the above stated, it can be asserted that, if by January 1st, 2012, biomass and small hydraulic power had been removed from the generation mix, the average consumer in TUR tariff would have had to pay 0.12 and € 3.01 respectively in total in his/her electricity bill for the year 2012. That is, biomass and small hydraulic power caused a 0.02% and 0.43% decrease in the TUR tariff, also respectively.

Likewise, if by January 1st, 2012, solar–thermal power had been removed from the generation mix, the average TUR consumer would have saved € 12.39 in total in his/her electricity bill for the year 2012. That is, solar–thermal power caused an increase of 1.82% in the TUR tariff.

It should be noted that the economic influence of the two aforementioned renewable technologies is more positive or less negative, as appropriate, on the system as a whole than on the TUR. This happens because the renewable bonuses are passed on directly to the access fees, being the ones for the TUR the highest of all of the electricity tariffs.

Table 7
Comparison between the final cost for a *TUR* type consumer for the real scenario and scenarios A, B and C for 2012.

€	Real scenario	Scenario A	Scenario B	Scenario C
1st Quarter	191.89	191.50	189.62	192.14
2nd Quarter	161.26	161.25	158.15	162.13
3rd Quarter	169.54	169.27	164.48	169.88
4th Quarter	168.94	169.73	166.99	170.49
Total	691.63	691.75	679.24	694.64

6. Conclusions

Spain is at the forefront of renewable energies worldwide, reaching a percentage of integration of renewable energies in its generation mix of 31.8% (including large hydraulic power) in 2012 [32]. This has put Spain in a situation which the other countries that are investing in renewable energies will be facing in a short–medium term.

However, active policies to support renewable energies have been losing strength in recent times. A clear example is that the Royal Decree 1614/2010 established limited equivalent hours with right to bonus for solar–thermal power and the Royal Decree 1/2012 proceeded to the suspension of pre-allocation procedures for the redistribution of new facilities equivalent to the special regime, which, in practice imposed a moratorium on new facilities operating under the special regime. Following that, Law 15/2012 imposes a new tax of 7% on all sources of power generation including those operating under special regime. The Royal Decree-Law 2/2013 takes, in practice, the renewable energies out of the market and makes them receive the regulated tariff. A regulated tariff will no longer be updated by the Consumer Price Index (IPC) but by the Consumer Price Index at constant tax excluding unprocessed food and energy products. Finally, the Royal Decree-Law 9/2013 retroactively replaces the concept of bonus, as known so far, for the “reasonable” revenue of 7.5% for the renewable facilities. All these measures, most of which have focused exclusively on renewable energies, are aimed at increasing the incomes of the Spanish electrical system and thus reduce the existing deficit.

The authors of this article know the importance that the energy cost and the electrical system as a whole have over the competitiveness of a country and over the purchasing power of their citizens. Based on the above stated, this article was intended to:

To create a descriptive model of the Spanish Pool, by applying artificial intelligence techniques (algorithm M5P) in an ex-post way (unlike the predictive models created for day-ahead electricity price forecasting), in order to determine the influence of renewable technologies on the Spanish electricity prices.

To show, for the first time ever, the real economic influence that biomass, solar–thermal and small hydraulic power have over the Spanish electricity Pool.

To move to the next level and find out also from the influence of them on the Pool, the tariff to be paid by the average consumer thereby filling the gap of the lack of literature on the subject up to this date.

Finally, the conclusion is that, during the year 2012:

Biomass power received bonuses for a value of € 344.0 million and reduced the weighted average final electricity price of the Pool at 1.48 €/MW h equivalent to € 394.7 million in savings. This meant an overall saving for the system of € 50.7 million and for the average TUR tariff consumer of € 0.12.

Solar–thermal power received bonuses of € 926.9 million and reduced the weighted average final electricity price of the Pool at 1.05 €/MW h equivalent to € 278.7 million in savings. This generated an overall cost overrun for the system of € 648.2 million and for the average TUR tariff consumer of 12.39 euros.

Small hydraulic power received bonuses for a value of € 184.1 million and reduced the weighted average final electricity price of the Pool at 1.45 €/MW h equivalent to € 384.7 million in savings. This meant an overall saving for the system of € 200.6 million and for the average TUR tariff consumer of € 3.01.

The authors will intend to determine in future works, using the same or a similar methodology, the economic impact on the Spanish electrical system of the rest of the main renewable technologies operating under the special regime, i.e. photovoltaic and wind power.

It has not been the purpose of this article to assess or quantify the following benefits: reduction of polluting emissions, helping to enforce the Kyoto commitment, reduction of the dependence on foreign energy, technology and know-how exports in the field of biomass, solar–thermal and small hydraulic power.

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