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Renewables versus efficiency. A comparison for Spain

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Abstract

Along the last decades, renewable energy (especially wind) in Spain has undergone a significant development (lead by a small group of renewable promoters supported by institutional policies), contributing significantly to electric generation mix (42.8% renewable in 2014). On the contrary, the promotion of energy efficiency actions (accomplished by a large number of industrial and domestic consumers that are very poorly supported by energy policies), are still little explored. According to ODYSSEE-MURE, energy efficiency at the EU-28 level improved by 1.2%/year on average from 2000 to 2013, while for the case of Spain, the rate of improvement was only 0.6 %/year on average throughout that period (the lowest rate of energy efficiency improvement in the EU-28).
This work seeks to compare the integration of renewable production with energy efficiency plans, in order to advance their potential economic impact in the wholesale market and consumers. To reach that goal, the hourly market data retrieved from the Spanish/Iberian Market Operator (OMIE) for 2014 will be used as a base. Then, a set of pseudo-heuristic scenarios with integration of renewable production and energy efficiency (load saving) will be elaborated and analyzed to quantify what are expected to be the main effects on the Spanish electricity market and consumers.
The results will show that energy efficiency exhibits the best performance in terms of economic efficiency (less cost of the traded energy) and environmental sustainability (greater replacement of fossil fuels).

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Electricity markets; Renewable energy; Energy efficiency; Merit-order effect.

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1. Introduction

Over recent years there has been a significant effort in the electrical systems of the EU countries and many others worldwide, to fulfill the mandatory commitments derived from the Kyoto Protocol and its successors [1,2]. Thereby, the generation fleet has diversified significantly in terms of technology generation, mainly due to large-scale integration of production based on renewable energy. Consequently, electrical systems are evolving towards a generation fleet that is much more diverse, dispersed and decentralized, with a much larger number of generators, in which the renewable generation has a significant and growing share.

The reduction of the demand via the promotion of load saving programs or the enactment energy efficiency policies could also be another less explored tool to accomplish the commitments from the Kyoto Protocol. In fact, there exist a certain synergy between energy efficiency and renewables since when the demand decreases, a fixed amount of renewable production gives place to a greater share of renewables on the generation mix. In any case, most counties have chosen the development of renewables as a means to fulfill its environmental commitments.

This is the case of Spain where along the last decades, renewable energy (especially wind) has undergone a significant development. This growth has been led by a relatively small group of renewable promoters supported by institutional policies, and have made renewables to be a significant contributor to electric generation mix (42.8% renewable, 20.4% wind in 2014 [3]). On the contrary, the promotion of energy efficiency actions, accomplished by a large number of industrial and domestic consumers that are very poorly supported by energy policies, still are little explored. According to ODYSSEE-MURE [4], energy efficiency at the EU-28 level improved by 1.2%/year on average from 2000 to 2013 (about 15% over the period). However, the pace of progress has slowed down since the economic crisis: the annual gain between 2000 and 2007 has dropped from 1.3%/year to 1%/year between 2007 and 2013. For the case of Spain, energy efficiency only improved on average by 0.6 %/year throughout that period, which is the lowest rate of energy efficiency improvement in the EU-28. Moreover, energy conservation policies seem especially well suited for Spain due to its high level of energy dependence. According to Eurostat [5] the Spanish rate of gross energy dependency is always much higher than that of the EU average. For 2013, the level of gross dependence of Spain was 70.5% in 2013, well above the 53.2% of the UE average.

This work seeks to compare these two approaches for the Spanish case: the integration of renewable production and the development energy efficiency programs, in order to advance their potential impact on the electricity market. With this purpose, first a qualitative model, based on the linearization of the wholesale market around the clearing point, is used to examine some basic hypotheses. An appropriate set of empirical-based scenarios with renewables and energy efficiency are then generated from the retrieved historical information of the Iberian/Spanish Market Operator (OMIE) for the year 2014, in order to quantify the main effects on the market. The content of the paper is as follows. After the introduction, the Spanish/Iberian electricity market is briefly described and a qualitative model, based on the linearization of the market, is used to examine some basic hypothesis regarding the expected effects of renewables and energy efficiency. The hourly merit-order generation and demand curves throughout 2014, retrieved from the archive of the Market Operator (OMIE) are then used as source data for the generation of realistic renewables and energy efficiency scenarios. The main potential effects of renewables and energy efficiency on the market are then quantified and analyzed. Finally, the paper closes with the main findings of the comparison.

1.1. The Iberian market of electricity

OMIE is the Market Operator of the Iberian Electricity Market, which is the European regional market for Spain and Portugal. Although OMIE has been integrated into the European Price Coupling (EPC) since 2014, this does not affect the actual market rules [6]. The market is organized as a sequence of markets: the day-ahead market, the intra-day market, with six sessions a day, which operates close to real time, and the ancillary services market.

The daily market involves the scheduling of electricity transactions for the day ahead, which is performed through the submittal of electricity sale and purchase bids by market agents. The daily market is composed of 24 hourly markets that clear once a day. On the supply side, the Iberian electricity producers submit their bids specifying the price at which they are willing to produce a given amount of output from each of their production units, one day ahead. Similarly, demand agents submit their bids specifying the price at which they are willing to buy a given amount of energy. Once the supply and demand bids have been submitted by their agents, the Market Operator (OMIE) creates a merit-order dispatch, for every hour of the day ahead, by ordering the supply bids in ascending price order and demand bids in descending order. The hourly equilibrium price and the generation dispatch are determined through market clearing, i.e. by computing the intersection between the supply and demand curves. Conditional on being dispatched, the price to be received or paid by the market participants is set according to a uniform-price auction. Irrespective of their bids, the price producers receive, or the price paid by demand units is set equal to the highest accepted supply bid: the so-called system marginal price.

Two kinds of bids are considered in the Iberian Electricity Market: simple and complex bids. Simple bids are just simple price and amount of energy bids. Complex bids are bids (for generators only) which include any of the following conditions: indivisibility of blocks of energy, minimum income, programmed stops and load ramps. First, the simple matching procedure of the Market Operator (OMIE) finds a solution for simple bids (Fig. 1). An optimization algorithm, EUPHEMIA, then finds a new solution which takes complex offer bids into account [6]. Subsequently, the final clearing price and traded energy are set for the considered hour. Finally, the System Operator (REE – Red Eléctrica de España) validates the schedule of the units while considering the electrical system's technical constraints.

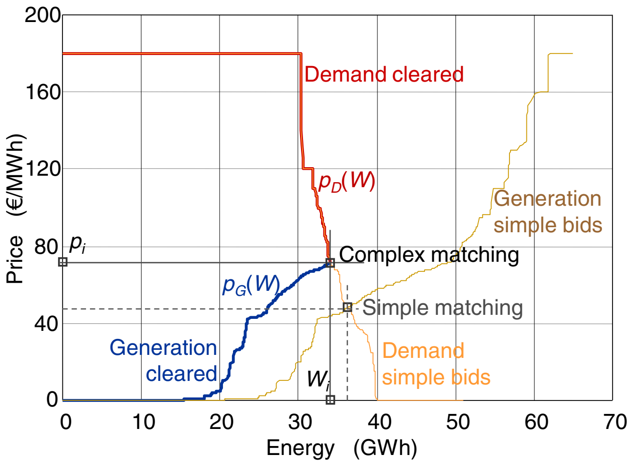

Fig. 1. Merit order generation and demand curves for a peak hour (20:00 h) in a winter working day (Tuesday, February 10, 2015) corresponding to the Iberian market, OMIE. Example of simple (trade energy, W_{is} = 36.81 GWh; clearing price, p_{is} = 49.57 €/MWh) and complex matching rules (traded energy, W_i = 34.18 GWh; clearing price, p_i = 71.00 €/MWh) [7]

As often happens in optimization problems, an increase in the number of restrictions leads to a degradation of the optimality of the solution. In the market case, complex offer bids (significantly) increase the final clearing price and (slightly) reduce the traded energy as shown in Fig. 1.

2. Qualitative Analysis of the Wholesale Market

In Fig. 2 can be seen both the merit-order generation curve, $p_G = p_G(W)$, and the demand curve, $p_D = p_D(W)$, as well as the traded energy (W_i = 34183.4 MWh) and the matching clearing price (p_i = 71.00 €/MWh) for a peak hour (20:00 h) on a winter workday (Tuesday, February 10, 2015) corresponding to the wholesale Iberian market [7]. By its own nature, the supply curve, $p_G = p_G(W)$, has a positive slope, and the demand curve, $p_D = p_D(W)$, has a very negative slope.

If the supply and demand curves were continuous (and not stepped) and $m_G = dp_G(W)/dW > 0$ and $m_D = dp_D(W)/dW << 0$ were, respectively, the slopes of the supply (m_G = 1.4 €/GWh) and demand curves (m_D = –13.5 €/GWh) at the initial clearing point (A in Fig. 2), then both the supply and demand curves could be linearly approximated, in the surroundings of the initial clearing point (W_i,p_i), as:

$$p_G(W) \approx p_i + m_G(W - W_i) = p_i - m_G W_i + m_G W = p_{Gi} + m_G W$$

$$p_D(W) \approx p_i + m_D(W - W_i) = p_i - m_D W_i + m_D W = p_{Di} + m_D W$$

Where the respective ordinates at the origin are $p_{Gi} = p_i - m_G W_i$ and $p_{Di} = p_i - m_D W_i$

The total initial income for the producers or the total initial cost for consumers, $C(W_i)$, derived from the energy trading in the wholesale market, considering only the market rules, is $C(W_i) = W_i \cdot p_i$:

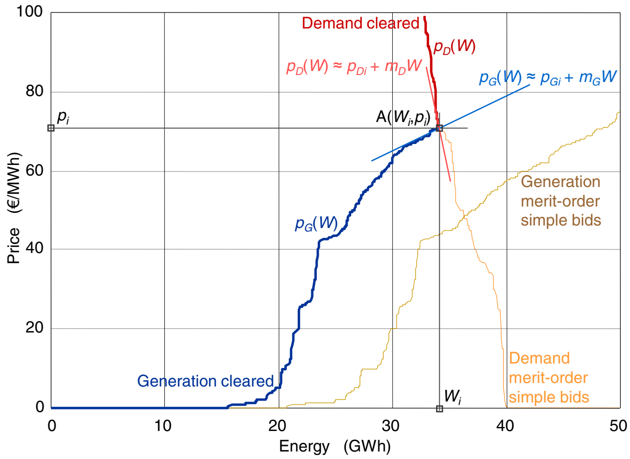

Fig. 2. Merit order generation, $p_G = p_G(W)$, and demand, $p_D = p_D(W)$, curves as well as the traded energy, W_i = 34.18 GWh, and the matching clearing price, p_i = 71.00 €/MWh, for a peak hour (20:00 h) in a winter working day (Tuesday, February 10, 2015) corresponding to the wholesale Iberian market [7]. Linearization of the market around the initial matching point

With this linearized market model around the clearing point, a comparison between the influence of the integration of renewable generation and DSM (energy efficiency) can be evaluated in order to advance of the potential effects of these measurements on the performance of the market. It must be remarked that since the wholesale market is a marginal market, the clearing point is the most important factor to know the impact of these measurements. Although the linear approximations of the merit-order curves ($p_G \approx p_{Gi} + m_G W$ and $p_D \approx p_{Di} + m_D W$) differ from the actual production and demand curves ($p_G = p_G(W)$ and $p_D = p_D(W)$), both sets of curves can lead to the same (or very close) clearing point. This finally determines the price that every buyer has to pay to producers and the amount of energy that generators have to deliver to the customers.

2.1. Integration of renewable energy

The Iberian market regulation currently requires the Market Operator to include all bids received from renewable generators as long as they cause no technical difficulty for the operation of the system. Therefore, the integration of new renewable generation bids ($\Delta E_R > 0$) at very low (or even null) marginal price yields a mainly right-hand-side shift of the initial merit-order generation curve. The linear approximation of this new supply curve, $p_{GR} = p_{GR}(W)$, is shown in Fig. 3 as a straight line parallel to the primitive generation curve:

$$p_{GR}(W) = p_G(W - \Delta E_R) \approx p_{Gi} + m_G(W - \Delta E_R) = p_{Gi} - m_G \Delta E_R + m_G W = p_{GRi} + m_G W$$

Where the ordinate at the origin is:

$$p_{GRi} = p_{Gi} - m_G \Delta E_R = p_i - m_G(W_i + \Delta E_R)$$

With this linearized market model, the new clearing price and traded energy (B shown in Fig. 3) can be obtained by equating the new generation curve with the demand curve:

$$p_{GR}(W) \approx p_{GRi} + m_G W = p_D(W) \approx p_{Di} + m_D W$$

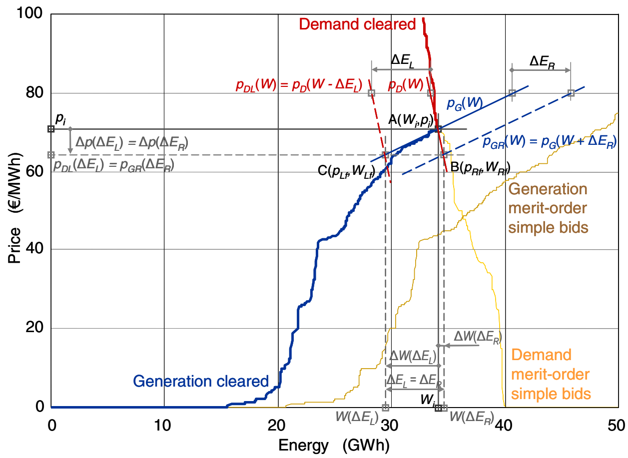

Fig. 3. Merit order generation, $p_G = p_G(W)$, and demand, $p_D = p_D(W)$, curves and matching clearing price (p_i = 71.00 €/MWh) and traded energy (W_i = 34.18 GWh) for a peak hour (20:00 h) in a winter working day (Tuesday, February 10, 2015) corresponding to the wholesale Iberian market [7]. Changes in the market-clearing price and energy traded due to the integration of new renewable generation and due to the reduction of the demand derived from the improvement of energy efficiency

The traded energy, $W = W(\Delta E_R)$, can now be expressed as:

$$W(\Delta E_R) \approx \frac{p_{Di} - p_{GRi}}{m_G - m_D} = \frac{p_i - m_D W_i - p_i + m_G(W_i + \Delta E_R)}{m_G - m_D} = W_i + \frac{m_G}{m_G - m_D}\Delta E_R = W_i + \Delta W(\Delta E_R)$$

As a result, the increment of traded energy can be approximated as:

$$\Delta W(\Delta E_R) \cong \frac{m_G}{m_G - m_D}\Delta E_R > 0$$

The clearing price, $p_{GR}(W) = p_D(W)$, becomes:

$$p_{GR}(W = W_i + \Delta W(\Delta E_R)) \cong p_{GRi} + m_G(W_i + \Delta W(\Delta E_R)) = p_i + \frac{m_G m_D}{m_G - m_D}\Delta E_R = p_i + \Delta p_R(\Delta E_R)$$

where the price variation (reduction) is:

$$\Delta p_R(\Delta E_R) = \frac{m_G m_D}{m_G - m_D}\Delta E_R < 0$$

It should be observed that, since the slope of the supply is smaller than that corresponding to the demand curve, in absolute values ($0 < m_G << |m_D|$), the increment in traded energy is significantly less than the increment in renewable energy bids integrated into the market:

$$0 < \frac{\Delta W(\Delta E_R)}{\Delta E_R} \cong \frac{m_G}{m_G - m_D} \ll 1$$

This means that the clearing of a certain amount of renewable energy bids, ΔE_R, by the Market Operator, leaves out almost the same amount of energy bids from other more expensive and probably polluting production technologies, $\Delta W(\Delta E_R) << \Delta E_R$, and leads to a reduction of the hourly clearing price proportional to the amount of cleared renewable energy. This is the base of the so-called merit-order effect of renewable energy [8-12].

2.2. Energy efficiency

The consumers that apply load saving or energy efficiency programs can profit from a reduction in the electricity energy bill, mainly due to a reduction of the demanded energy. The curtailment of certain amount of demand bids ($\Delta E_L > 0$) at high marginal price, where the energy efficiency actions would be more cost-efficient, mainly results in a left-shifting of the initial merit order demand curve. The linear approximation of this new demand curve, $p_{DL} = p_{DL}(W)$, is shown in Fig. 3 as a straight line parallel to the primitive demand curve:

$$p_{DL}(W) = p_D(W + \Delta E_L) \cong p_{Di} + m_D(W + \Delta E_L) = p_{Di} + m_D\Delta E_L + m_D W = p_{DLi} + m_D W$$

Where $p_{DLi} = p_{Di} + m_D\Delta E_L = p_i - m_D(W_i - \Delta E_L)$

The new clearing price and traded energy (C in Fig. 3) can now be obtained by equating the new (reduced) demand curve with the primitive generation curve. It is worth noting that, since the slope of the supply is less inclined than that corresponding to the demand curve, in absolute value ($0 < m_G << |m_D|$), the reduction in traded energy is similar to (but smaller than) that of the saved load bids:

$$0 > \frac{\Delta W(\Delta E_L)}{\Delta E_L} \cong \frac{m_D}{m_G - m_D} > -1$$

As a result, the reduction of an amount of demand bids resulting from a certain energy efficiency improvement of the load, ΔE_L, causes the Market Operator to leave out almost the same quantity of generation bids from production technologies of a more expensive nature, $W_L(\Delta E_L) \cong \Delta E_L$, and this leads to a reduction of the clearing price and cost of the traded energy proportional to the amount of saved energy bids. This forms the base of what could be called the merit-order effect of the energy efficiency, which is very similar to that corresponding to renewables. Finally, the following hypotheses are stated:

- The reductions in the clearing price for the renewable and energy efficiency scenarios are the same.
- The energy efficiency scenario leads to a reduction in the traded energy which is almost equal to that of saved energy, while the renewable scenario leads to a slight increment in the traded energy. This means that the energy efficiency is (slightly) more effective than renewables in eliminating (replacing) the more expensive and probably polluting generation technology.
- The reduction of the cost of the traded energy in the energy efficiency scenario is greater than that corresponding to the renewable scenario, since the reduction in the efficiency scenario profits from both the reduction in the clearing price and from the reduction in the amount of traded energy.

3. Methodology and Results

The hourly merit-order generation and demand curves for the year 2014 have been retrieved from the historic data archive of the Iberian Market Operator [7]. That means 8760 hourly markets with hundreds of production and demand bids taking part in each hourly market. This vast amount of hourly market bids handled for each scenario made desirable a simplification in the complex clearing rules of the Market Operator in order to simulate new scenarios. As a consequence, a simplified procedure similar to that used by the Market Operator (OMIE) is applied with the intention of performing a quantitative analysis of the scenarios.

For each new scenario analyzed, new hourly merit-order generation and/or demand curves are produced by first locating the bids of the type of agent under interest (i.e. renewables or consumers bids) in the hourly merit-order (generation and/or demand) curves. The bids under interest are then modified (amount of energy and price) by taking into account the appropriate characteristics of the scenario under consideration. The modified bids corresponding to the new scenario are subsequently inserted properly into the retrieved hourly merit-order curves: upward price order for bids in the generation curves, and downward order for the bids in the demand curves. When new market scenarios are developed through the modification of the supply and/or demand curves, it is necessary to consider that the bids of the other agents would remain the same when increasing or reducing new generation or demand bids. Fortunately, this hypothesis of a perfect market can be considered fulfilled since each market agent should elaborate their bids without any knowledge of the bids of the other agents. Finally, the matching point corresponding to the new scenario is determined as the intersection of the modified generation and demand curves.

For example, in order to consider the case of the integration of an amount of renewable energy, ΔE_R, first the original hourly merit-order generation ($p_G = p_G(W)$) and demand ($p_D = p_D(W)$) curves are retrieved, as shown in Fig. 4. Since renewable generators offer energy at a very low (even null) price, the original bids corresponding to the renewable generation units can be found in the initial flat region (first steps) of the merit-order generation curve. The original renewable bids are now proportionally increased until the targeted amount (ΔE_R) is reached.

When needed, the original hourly-cleared curves are completed with the single-bid curve from the initial clearing point onwards, as shown in Fig. 4. In this way, a new merit-order generation curve, $p_{GR} = p_{GR}(W)$, is created through the proper integration (upward price) of these modified bids in the generation curve. This new merit-order generation curve essentially results in a right-hand-shifting of the initial cleared supply curve by an amount equal to ΔE_R. Finally, the new clearing point (B in Fig. 4) can be determined as the crossing point of the new right-hand-shifted generation curve, $p_{GR} = p_{GR}(W)$, with the original demand curve, $p_D = p_D(W)$.

Fig. 4 also shows the case of the reduction of the demand in an amount of load, ΔE_L, due to, for example, energy saving for small consumers. Since small consumers demand energy at the highest price, their primitive bids are always found in the initial flat region of maximum price of the merit-order demand curve. The original bids of the small-consumer traders are then proportionally reduced until the targeted amount (ΔE_L) is reached. In this way, a new merit-order of reduced demand curve, $p_{DL} = p_{DL}(W)$, is created through the proper integration (downward price) of these modified bids in the demand curve. This new merit-order demand curve essentially results in a left-hand-shifting of the initial cleared demand curve by an amount equal to ΔE_L, as shown in Fig. 4.

Finally, the new clearing point (C in Fig. 4) can be determined as the intersection of the new left-hand-shifted reduced-demand curve, $p_{DL} = p_{DL}(W)$, with the original generation curve, $p_G = p_G(W)$.

Three scenarios are generated for 0.5%, 1% and 2% of load demand reduction as well as the symmetrical scenarios with 0.5%, 1% and 2% growing of renewable energy. That gives place to a total of $6 \cdot 8760 = 52560$ hourly markets scenarios which must be simulated using the methodology described above. The obtained results are summarized in Table 1 and 2.

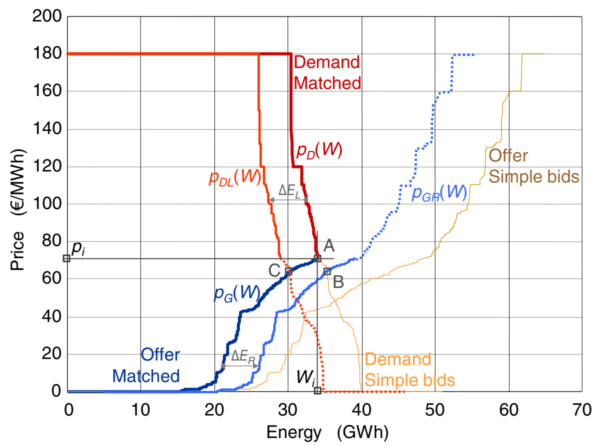

Fig. 4. Hourly merit-order generation, $p_G = p_G(W)$, and demand, $p_D = p_D(W)$, curves and creation of the new (right-shifted) renewable generation curve, $p_{GR} = p_{GR}(W)$, and of the new (left-shifted) reduced demand curve, $p_{DL} = p_{DL}(W)$.

More precisely, Table 1 summarizes the mean values of the variations of the annual traded energy, hourly clearing price and annual cost of the traded energy, while Table 2 shows the mean values of the rate of variation with the energy-saving and renewable bids of the annual traded energy, hourly clearing price and annual cost of the traded energy. As anticipated by the linear model approximation, the results lead to the following main conclusions:

- Energy efficiency: The mean values of the yearly traded energy, the hourly clearing price and the annual cost of the traded energy are always smaller than the corresponding to the base case, and their reductions grow almost linearly with the amount of load-saving bids.
- Renewables: The traded energy is always slightly greater that the corresponding to de base case and its increment grows with the amount of renewable bids. On the contrary, the clearing price and the cost of the traded energy are smaller than for the base case, and their reductions grow with the quantity of renewable bids.

For the same amount of load-saving and renewable bids ($\Delta E_R = \Delta E_L = \Delta E$):

- The clearing price (and its variation) for energy efficiency is almost the same than for the corresponding renewable scenario, $\Delta p(\Delta E_R = \Delta E) \approx \Delta p(\Delta E_L = \Delta E)$.
- The intensity of the variation of the traded energy (absolute value), $\Delta W(\Delta E)/\Delta E$, and cost of the traded energy, $\Delta C(\Delta E)/\Delta E$, is always stronger for energy efficiency than for the corresponding renewable scenario. More precisely, the intensities are $(\Delta W(\Delta E_R)/\Delta E_R)/(|\Delta W(\Delta E_L)|/\Delta E_L) \approx 2.4$ and $(\Delta C(\Delta E_R)/\Delta E_R)/(\Delta C(\Delta E_L)/\Delta E_L) \approx 1.6$, respectively.

Table 1. Mean values of the variations of the yearly traded energy, hourly clearing price and yearly cost of the traded energy

Spain 2014	Yearly mean	W = 221 TWh/y		p = 42.13 €/MWh		C = 9346 M€/y	
		ΔE = 0.5% Load (0.90 TWh/y)		ΔE = 1% Load (1.81 TWh/y)		ΔE = 2% Load (3.62 TWh/y)	
Small consumers	Units	Efficiency ΔE_L^*	Renewable ΔE_R^*	Efficiency ΔE_L^*	Renewable ΔE_R^*	Efficiency ΔE_L^*	Renewable ΔE_R^*
$\Delta W(\Delta E)$	GWh	-610.96	246.81	-1237.44	478.10	-2476.90	954.19
$\Delta p(\Delta E)$	€/MWh	-0.36	-0.36	-0.68	-0.68	-1.33	-1.33
$\Delta C(\Delta E)$	M€	-104.89	-66.56	-204.17	-128.09	-401.06	-251.22

$^*\Delta E_R = \Delta E_L = \Delta E$

Table 2. Mean values of the ratio of variation with the load saving or renewable bids of the annual traded energy, hourly clearing price and yearly cost of the traded energy

Spain 2014	Yearly mean	W = 221 TWh/y		p = 42.13 €/MWh		C = 9346 M€/y	
		ΔE = 0.5% Load (0.90 TWh/y)		ΔE = 1% Load (1.81 TWh/y)		ΔE = 2% Load (3.62 TWh/y)	
Small consumers	Units	Efficiency ΔE_L^*	Renewable ΔE_R^*	Efficiency ΔE_L^*	Renewable ΔE_R^*	Efficiency ΔE_L^*	Renewable ΔE_R^*
$\Delta W(\Delta E)/\Delta E$	-	-0.68	0.28	-0.67	0.28	-0.67	0.28
$\Delta p(\Delta E)/\Delta E$	€/MWh^2	$-3.81\cdot10^{-3}$	$-3.81\cdot10^{-3}$	$-3.34\cdot10^{-3}$	$-3.34\cdot10^{-3}$	$-3.05\cdot10^{-3}$	$-3.05\cdot10^{-3}$
$\Delta C(\Delta E)/\Delta E$	€/MWh	-116.54	-73.95	-112.80	-70.77	-110.79	-69.40

4. Conclusions

Renewables and energy efficiency put a downward pressure on the clearing price and the total cost of the traded energy in the wholesale market. These reductions are mainly related to the reduction of the cost of the fossil fuel necessary for the market operation, derived from the fossil fuel substituted (renewables) or avoided (energy efficiency).

This work has shown the results of comparing the potential economic impact in the Iberian electricity market of the integration of renewable production and energy efficiency. To reach that goal and to explore some basic hypotheses, first a qualitative model based on the linearization of the wholesale market, has been used. Then, the year 2014 has been analysed by using the hourly Iberian Market information. An appropriate set of heuristic-based scenarios have been generated including integration of renewable generation as well as energy efficiency, in order to foreseen the main quantitative effects on the market performance.

The quantitative results of the heuristic-based scenarios confirm that, for the same amount of renewable and load saving bids, the efficiency scenario exhibits the best economic (reduction of traded energy, clearing price and traded energy cost) and environmental performance (fossil fuel displacement). The intensity of the variation with the load saving of the traded energy and cost of the traded energy are always stronger than for the corresponding renewable scenarios.

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