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The Merit-Order Effect of Energy Efficiency

Juan-Manuel Roldan-Fernandez[a] a*, Manuel Burgos-Payan[a], Jesus-Manuel Riquelme-Santos[a] and Angel-Luis Trigo-Garcia[a]

[a]*University of Sevilla, Camino de los Descubrimientos, s/n. Sevilla 41092, Spain*

Abstract

The integration of certain amount of renewable generation in the wholesale market right-shifted the merit-order generation curve, which produces a noticeable reduction of the clearing price while slightly increases the traded energy (almost inelastic demand curve). The downward pressure on the clearing price is mainly due to the fact that the introduction of renewable generation bids with very low (even null) marginal cost, displaces to the right all kinds of conventional technologies (with higher marginal cost), including the technology which would otherwise have set the clearing market price. This right-shifted displacement of the merit-order generation curve leads to a lower wholesale clearing price, a small increment of the traded energy and a reduction of the total cost of the traded energy in the wholesale market. This is the key mechanism and its main effects on the market of the very well-known merit-order effect of the renewables. The promotion of energy-efficiency plans (industry and domestic) by policy-makers is expected to yield a reduction of the demand. As a result of the reduction of demand bids, the merit-order demand curve would experience a left-sifted displacement, which would produce a reduction of both the clearing price and the amount of traded energy. Consequently, the total cost of the traded energy also would diminish. As can be seen, the parallelism of the main effects on the market between the integration of renewable and energy efficiency evidences the existence of what can be called the merit-order effect of energy efficiency. To analyze the characteristics of this merit-order effect of the energy efficiency, a simplified model, based on the linearization of the market around the clearing point, is developed. This simplified model is also used to compare the merit-order effect of energy efficiency and renewables. A set of scenarios with energy efficiency and renewables have been generated in order to quantify the main effects on the Spanish/Iberian market for the year 2014.

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

* Corresponding author. Tel.: +34 954487283; fax: +34 954487284.
E-mail address: jmroldan@us.es.

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1. Introduction

Once the supply and demand bids have been elaborated and submitted by the corresponding generation and demand agents, the Market Operator elaborates, for every hour of the day-ahead, a merit order dispatch by ordering the supply bids in ascending price order and demand bids in descending order. After that, and simplifying the complex optimization process that takes place, the Market Operator carries out the matching clearing point by the intersection of the merit order supply curve with the demand curve.

Since renewable generators extract the energy from a natural source (wind or sun, e.g.), they can produce electric power with very low operating costs. This allows renewable generators to submit their bids offering energy at very low (even null) marginal cost.

The methodology of elaboration of the merit order generation dispatch made that when a renewable generator offer a bid with certain amount of energy at very low cost, the Market Operator inserts the renewable bid by right-shifting the merit order generation/sale curve. This right-shifting produces a noticeable reduction of the clearing price while only slightly increases the traded energy, due to the characteristic lack of elasticity of the demand/buy curves.

As can be seen the downward pressure of the renewable generators on the clearing price is mainly due to the fact that the introduction of renewable generation bids with very low (even null) marginal cost, displaces to the right all kinds of conventional technologies (with higher marginal cost), including the technology which would otherwise have set the market clearing price. The integration of renewable induces a displacement of the operating point of the wholesale market towards a lower clearing price, a small increment of the traded energy and, as a consequence, a reduction of the total cost of the traded energy in the wholesale market. This is the key mechanism, and its main effects, on the market of the very well-known merit-order effect of renewables. The avoided amount of burned fossil fuel and the consequent reduction of CO_2 emissions due to the shifted fossil fuel generation leads to a secondary mechanism for reducing the clearing price of energy, as the reduction of the demand of fossil fuel and CO_2 emission allowances reduces the demand of both the fuel (in the international market) as well as of the CO_2 emission allowances, putting a downward pressure on its prices and thus reducing the costs of the remainder cleared fossil fuel-based generators.

The interest of consumers (industry and domestic) to reduce their energy bills and the promotion of energy-efficiency plans by policy-makers is expected to yield a reduction of the demand. As a result of the reduction of demand bids, the merit order demand/buy curve would experience a left-shifted displacement, which would produce a reduction of both the clearing price and the amount of traded energy. Consequently, the total cost of the traded energy would also diminish. Again, the avoided burning of fossil fuel and CO_2 emissions due to the fossil fuel not required lead to a secondary via for reducing the clearing price of energy, as this reduces the costs of the remainder cleared fossil fuel-based generators.

As can be seen, the parallelism of the effects on the market between the integration of renewable and energy efficiency demonstrates the existence of what could be called the merit-order effect of energy efficiency. This work seeks to analyze the characteristics of this merit-order effect of the energy efficiency and carry out a comparison with the corresponding characteristics of the merit-order effect of renewables. To achieve that purpose, a simplified model, based on the linearization of the market around the clearing point, will be used to explore some basic conjectures. Then an appropriate set of empirical-based scenarios with energy-efficiency as well as integration of renewables have been generated from the retrieved historic information of the Market Operator (OMIE) for the year 2014, in order to quantify the main effects on the Spanish/Iberian market. After the introduction, the content of the paper is as follows. First the Spanish/Iberian electricity market is shortly surveyed and a simplified model, based on the linearization of the market around the clearing point, is used to check some hypothesis regarding the expected effects of energy-efficiency and renewables. Next, the hourly merit-order generation and demand curves for 2014 are used as source data for the design of feasible energy-efficiency and renewable scenarios. After that, the main potential effects on the wholesale market are quantified and analyzed. The paper ends with the main findings of the comparison.

2. The Spanish/Iberian wholesale market

The joint European regional market for Spain (OMEL - Market Operator of the Spanish pole) and Portugal (OMIP - Market Operator of the Portuguese pole) is organized by OMIE (Operador del Mercado Ibérico de la Energía), the Market Operator of the Iberian Electricity Market. OMIE is integrated in the European Multi-Regional Coupling (MRC) since 2014, and its market clearing regulation is under the rules of EUPHEMIA (EU + Pan-European Hybrid Electricity Market Integration Algorithm) [1].

The daily market is composed of 24 hourly markets that are cleared once a day by the Market Operator. The purpose of the daily market is the scheduling of electricity transactions for the day ahead which is performed through the submittal of electricity sale (generation) and purchase (demand) bids by their respective market agents. Two kinds of bids are considered in the Spanish/Iberian Electricity Market: simple and complex bids. Simple bids are just simple price and energy bids. Complex bids, only allowed for generation units, are bids which include any of the following conditions: indivisibility of blocks of energy, minimum income, scheduled stops and load gradient.

Once the supply and demand bids have been submitted by the agents, the Market Operator (OMIE) elaborates, for every hour of the day-ahead, a merit order dispatch by ordering (by merit) the supply bids in ascending price order and demand bids in descending order. Firstly only the simple bids are considered to elaborate the merit order (aggregated) supply and demand curves. After that, the Market Operator carries out the simple matching clearing point by the intersection of the merit order supply curve with the demand curve. After that an iterative optimization algorithm finds a new solution, including the restrictions of the generation complex bids. After finishing the optimization procedure by means of EUPHEMIA, the final clearing price and traded energy are set for each hour of the day ahead. Finally, the System Operator (REE – Red Eléctrica de España) validates units schedule considering the technical constraints of the electrical system.

As often happens in optimization problems, as the number of restrictions increases the optimal solution impairs. In the case of the electricity market, complex offer generation bids (significantly) increase the final clearing price and (slightly) reduces the traded energy. Conditionally on being dispatched, the price to be received or paid by the market participants is set according to a uniform-price auction. Irrespectively of their bids, the price producers receive or demand units pay is set equal to the highest accepted supply bid, the so-called system marginal price.

3. A simplified analysis of the price formation in the wholesale market

Fig. 1 shows both the merit order generation, $p_G = p_G(W)$, and demand, $p_D = p_D(W)$, curves 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) in a winter working day (Tuesday, February 10, 2015) corresponding to OMIE [2]. By its own nature, the supply curve, $p_G = p_G(W)$, has a (gentle) positive slope, while the demand curve, $p_D = p_D(W)$, has a very negative slope, as usually. If the supply and demand curves were continuous (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^2) and demand curves (m_D = –13.5 €/GWh^2) at the initial clearing point (A in Fig. 1), both the supply and demand curves could be linearly approximated, in the surrounding of the initial clearing point (W_i,p_i), as:

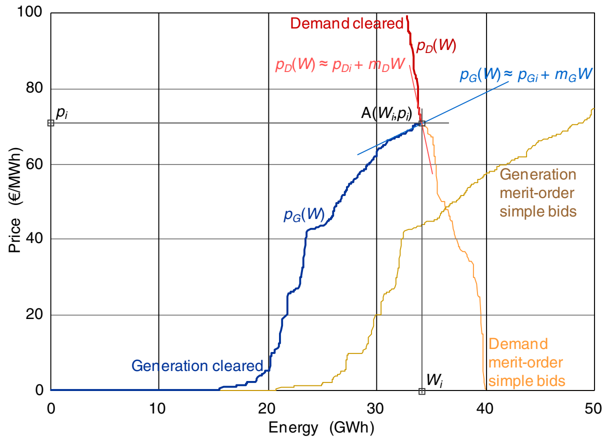

Fig. 1. Merit order generation, $p_G = p_G(W)$, and demand, $p_D = p_D(W)$, curves as well as the traded energy, W_i = 34.18 GWh, and the matching clearing price, p_i = 71.00 €/MWh, for a peak hour (20:00 h) in a winter working day (Tuesday, February 10, 2015) corresponding to OMIE [2]. Linearization of the market around the initial matching point.

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

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

Where the respective ordinates at the origin of the linear approximations are:

$$p_{Gi} = p_i - m_G W_i \text{ and } p_{Di} = p_i - m_D W_i$$

The total income for the producers (generators) or the total cost for consumers derived from the energy traded at the wholesale market, when only the market rules are considered, can be expressed as $C(W_i) = W_i \cdot p_i$. With this linearized market model around the clearing point, both the merit-order effect of renewable and energy efficiency are surveyed and compared in order to get a qualitative advance of the potential effects of these measurements on the performance of the market stakeholders.

Table 1. Data for the linearization of the market around the initial clearing point corresponding to the merit order generation and demand curves for a winter working day (Tuesday, February 10, 2015; 20:00 h) corresponding to OMIE [2].

Magnitud (unit)	Value
Energy traded (GWh)	W_i = 34.18
Clearing price (€/MWh)	p_i = 71.00
Generation slope (€/GWh^2)	m_G = 1.4
Demand slope (€/GWh^2)	m_D = -13.5

Given that the wholesale market is a marginal market, the clearing point is the only thing that matters. This means that although the linear approximations of the merit order curves ($p_G \approx p_{Gi} + m_G W$ and $p_D \approx p_{Di} + m_D W$) are quite different of the actual generation 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.

Table 1 summarized the data corresponding to a peak hour (20:00 h) of a winter working day (Tuesday, February 10, 2015) in the wholesale Iberian market (OMIE) used in the following illustrative examples [2].

3.1. Renewables

Currently, the Spanish/Iberian market regulation requires that the Market Operator includes, preferably, all bids received from renewable generators, as long as it does not cause any risk or technical difficulty for the safe operation of the system. As a consequence, the integration of new renewable generation bids ($\Delta E_R > 0$) at very low (or even null) marginal price results mainly in a right-side shifting of the initial merit order generation curve. The linear approximation of this new offer curve, $p_{GR} = p_{GR}(W)$, is shown in Fig. 2 as a straight line parallel to the linear approximation of 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 of the new linear approximation 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 in Fig. 2) can be obtained equalling the new generation curve with the demand curve, as:

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

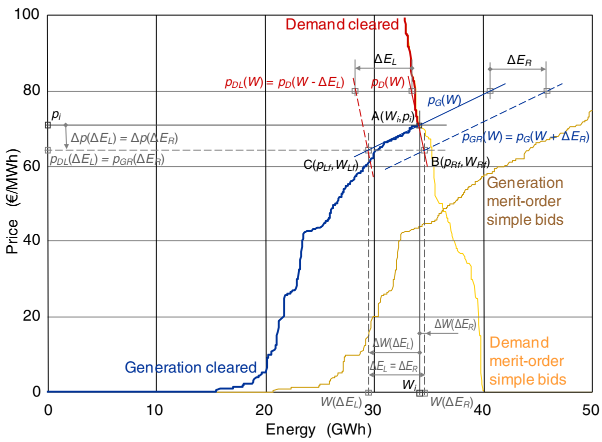

Fig. 2. Merit order generation, $p_G = p_G(W)$, and demand, $p_D = p_D(W)$, curves and matching clearing price (p_i = 71.00 €/MWh) and traded energy (W_i = 34.18 GWh) for a peak hour (20:00 h) in a winter working day (Tuesday, February 10, 2015) corresponding to the wholesale Iberian market [2]. Changes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

Table 2. Linearized market model estimation of the variation of the traded energy, price and cost derived from the integration of certain amount of renewable energy, ΔE_R, and from the curtailment of certain amount of demand due to energy efficiency improvement, ΔE_L. (Data corresponding to a peak hour (20:00 h) in a winter working day (Tuesday, February 10, 2015) of the wholesale Iberian market [2]).

	Renewables	
Relative variation of the traded energy	$\frac{\Delta W(\Delta E_R)}{\Delta E_R} \approx \frac{m_G}{m_G - m_D} > 0$	0.09
Relative variation of the clearing price (€/MWh^2)	$\frac{\Delta p_R(\Delta E_R)}{\Delta E_R} \approx \frac{m_G m_D}{m_G - m_D} < 0$	-1.27·10-3
Relative variation of the cost of the energy traded (€/MWh)	$\frac{\Delta C(\Delta E_R)}{\Delta E_R} \approx \frac{(W_i m_D + p_i) m_G}{m_G - m_D} \square\ 0$	-36.7
	Energy efficiency	
Relative variation of the traded energy	$\frac{\Delta W(\Delta E_L)}{\Delta E_L} \approx \frac{m_D}{m_G - m_D} < 0$	-0.91
Relative variation of the clearing price (€/MWh^2)	$\frac{\Delta p_L(\Delta E_L)}{\Delta E_L} \approx \frac{m_G m_D}{m_G - m_D} < 0$	-1.27·10-3
Relative variation of the cost of the energy traded (€/MWh)	$\frac{\Delta C(\Delta E_L)}{\Delta E_L} \approx \frac{(W_i m_G + p_i) m_D}{m_G - m_D} \square\ 0$	-107.7
	Comparison	
Relative variation of the traded energy	$\frac{\Delta W(\Delta E_R = \Delta E)}{\Delta W(\Delta E_L = \Delta E)} \approx \frac{m_G}{m_D} < 0$	-0.1
Relative variation of the clearing price	$\frac{\Delta p_R(\Delta E_R = \Delta E)}{\Delta p_L(\Delta E_L = \Delta E)} \approx \frac{m_G m_D}{m_G - m_D} \frac{m_G - m_D}{m_G m_D} = 1$	1.00
Relative variation of the cost of the traded energy	$\frac{\Delta C(\Delta E_R = \Delta E)}{\Delta C(\Delta E_L = \Delta E)} \approx \frac{(W_i m_D + p_i) m_G}{(W_i m_G + p_i) m_D} < 1$	0.34
Relative variation of the sum of the traded energy	$\frac{\Delta W(\Delta E_R = \Delta E) - \Delta W(\Delta E_L = \Delta E)}{\Delta E} \approx \frac{m_G - m_D}{m_G - m_D} = 1$	1.00

Now the traded energy, $W = W(\Delta E_R)$, can 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 the traded energy can be approximated as:

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

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

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

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 the absolute value of the corresponding to the demand curve ($0 < m_G << |m_D|$), the increment of traded energy result very much lesser than the increment of renewable energy bids integrated in the market:

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

This means that the clearing of 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 renewable energy integrated. This is the base of the so-called merit-order effect of the renewable energy [3-6].

Therefore, the integration of certain quantity of renewable energy bids, ΔE_R, by the Market Operator yields a reduction of the cost of the traded energy ($\Delta C(\Delta E_R) << 0$) which is proportional to the amount of renewable energy integrated. As an example, Table 2 summarized the results corresponding to the variation of the traded energy, clearing price and economic volume of the traded energy derived from the integration of certain amount of renewable energy, ΔE_R, for the illustrative example (Table 1).

3.2. Energy Efficiency

Consumers that apply for energy efficiency programs expect to save in the electricity energy bill, mainly due to the projected energy saving [7-10]. 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, produces 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. 2 as a straight line parallel to the primitive linear approximation of the demand curve:

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

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

Now, the new clearing price and traded energy (C in Fig. 2) can be obtained equaling the new (reduced) demand curve with the primitive generation curve. As an example, central part of Table 2 summarized the results corresponding to the illustrative example (Table 1). Since the slope of the supply is much smaller than the corresponding to the demand curve, in absolute value ($0 < m_G << |m_D|$), the reduction of traded energy result almost equal (but something smaller) than the avoided demand bids:

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

Hence, the saving of some quantity of demand bids resulting from certain energy efficiency improvement of the consumers, ΔE_L, makes the Market Operator leaving out almost the same amount of generation bids from more expensive production technologies, $W_L(\Delta E_L) \cong \Delta E_L$, and yields a reduction of the clearing price and of the cost of the traded energy which are proportional to the amount of saved energy bids. This is the base of the merit-order effect of the energy efficiency which is very similar to the corresponding to renewables. Finally, the variation (reduction) of the cost of the energy traded in the market can also be approximate as:

$$\Delta C(\Delta E_R) \,\square\, \frac{(W_i m_D + p_i) m_G}{m_G - m_D} \Delta E_R \,\square\, 0$$

Therefore, the curtailment of some amount of demand bids resulting from energy efficiency improvement of the consumers, ΔE_L, yields a reduction of the total cost of the traded energy ($\Delta C(\Delta E_L) << 0$) which is proportional to the amount of saved energy bids.

Finally, comparing the intensity of the merit-order effect of energy efficiency and renewables ($\Delta E_R = \Delta E_L = \Delta E$, bottom part of Table 2), the following conclusions can be stated:

Finally, a comparison of the intensity of the merit-order effect of energy efficiency and the corresponding to renewables ($\Delta E_R = \Delta E_L = \Delta E$, bottom part of Table 2), allows the following conclusions:

- The reduction of the market clearing price is the same for both the energy efficiency and the renewable scenarios.
- The energy efficiency scenario leads to a reduction of the traded energy which is almost equal to the saved energy while the renewable case leads to a slight increment of the traded energy. This means that the energy efficiency is a more effective tool at removing the more expensive and probably polluting generation technologies.
- The reduction of the total cost of the traded energy in the energy efficiency scenario is greater than the corresponding to the renewable case, since the reduction in the efficiency scenario benefits from the reduction of the clearing price but also from the reduction of the traded energy.

4. Results

Tables 3 and 4 summarized the results of the energy efficiency (small consumers) and renewable cases for Spain along 2014. More precisely, Table 4 summarizes the mean values of the variations of the annual traded energy, hourly clearing price and annual cost of the traded energy, while Table 5 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.

Table 3. 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	-607.59	250.18	-1207.66	507.88	-2417.48	1013.61
$\Delta p(\Delta E)$	€/MWh	-0.39	-0.39	-0.69	-0.69	-1.26	-1.26
$\Delta C(\Delta E)$	M€	-121.62	-82.97	-206.32	-129.02	-387.58	-232.99

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

Table 4. Mean values of the rate 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	0.27	-0.68	0.26	-0.68	0.26
$\Delta p(\Delta E)/\Delta E$	€/MWh^2	$-3.46\cdot10^{-3}$	$-3.46\cdot10^{-3}$	$-3.30\cdot10^{-3}$	$-3.30\cdot10^{-3}$	$-3.21\cdot10^{-3}$	$-3.21\cdot10^{-3}$
$\Delta C(\Delta E)/\Delta E$	€/MWh	-135.14	-92.19	-113.99	-71.28	-107.07	-64.36

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

As anticipated by the linear model approximation, the results lead to the following main conclusions:

- For the energy efficiency scenarios, 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.
- For the corresponding renewable cases 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.

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

- The clearing price (and its variation) for energy efficiency is almost the same than for renewables, $\Delta p(\Delta E_R = \Delta E) \approx \Delta p(\Delta E_L = \Delta E)$.
- 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 renewables. 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.
- The addition of the reduction of the traded energy for the efficiency scenario and the increment of the traded energy for the corresponding renewable scenario is almost equal to the amount of saving load bids or the renewable energy bids, $\Delta W(\Delta E_R) - \Delta W(\Delta E_L) \approx \Delta E$.

5. Conclusions

The high and growing cost of the energy, the interest of both domestic and industrial consumers on reducing their energy bills or the promotion of energy-efficiency plans by policy-makers are expected to work as drivers for a reduction of the demand. Such a reduction of demand bids will produce a left-shifted displacement of the merit order demand/buy curve, which will produce a reduction of the clearing price, the amount of traded energy and, as a consequence, a reduction of the total cost of the traded energy.

The downward pressure of load saving and energy efficiency tools on the clearing price is mainly due to the fact that the displacement to the left of the merit order demand/buy curve produced by the reduction of demand bids, displaces the operating point of the wholesale market in such a way that the resulting clearing technology has a lower marginal costs than the technology which otherwise would have set the market clearing price. This is the key mechanism, and its main effects, on the market of merit-order effect of the energy efficiency which is very similar to the very well-known merit-order effect of renewables.

This work has introduced a simplified market model, based on the linearization of the wholesale market around the clearing point, to describe and quantify the merit-order effect of energy efficiency. This simplified tool has also been used to compare the intensity of the merit-order effect of energy efficiency and renewables. After that, a set of heuristic-based scenarios considering energy efficiency and renewable generation have been generated and analyzed to estimate its main quantitative effects on the market.

The results confirm that, for the same amount of renewable and load saving bids, the intensity of the merit-order effect of energy efficiency (reduction of the traded energy, clearing price and traded energy cost) is even stronger than the corresponding to renewables. As a result, it can be concluded that energy efficiency scenario exhibits the best economic performance and environmental sustainability.

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References

[1] OMIE - Operador del Mercado Ibérico de la Electricidad (Market Operator of the Iberian Electricity Market), 2014. *Daily and Intraday Electricity Market Operating Rules*. http://www.omie.es/files/20140509_reglas_v11_ingles.pdf

[2] OMIE - Operador del Mercado Ibérico de la Electricidad (Market Operator of the Iberian Electricity Market). Market Results (online data). http://www.omie.es/files/flash/ResultadosMercado.swf

[3] Sensfuss, M. Ragwitz, M. Genoese, (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany, Energy Policy, Volume 36, Issue 8, August 2008, Pages 3086-3094, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2008.03.035.

[4] Saénz de Miera, G., del Río González, P., Vizcaíno, I., (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain, Energy Policy, Volume 36, Issue 9, September 2008, Pages 3345-3359, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2008.04.022.

[5] Burgos Payán, M., Roldán Fernández, J.M., Trigo García, Á.L., Bermúdez Ríos, J.M., Riquelme Santos, J.M., (2013). Costs and benefits of the renewable production of electricity in Spain, Energy Policy, Volume 56, May 2013, Pages 259-270, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2012.12.047.

[6] Roldan-Fernandez, J.-M.; Burgos-Payan, M.; Trigo-Garcia, A.-L.; Diaz-Garcia, J.-L.; Riquelme-Santos, J.-M., (2014). Impact of renewable generation in the Spanish Electricity Market, 2014 11th International Conference on the European Energy Market (EEM), Krakow, Poland , vol., no., pp.1,5, 28-30 May 2014. doi: 10.1109/EEM.2014.6861239

[7] Darby S., (2006). The effectiveness of feedback on energy consumption. A review for DEFRA of literature on metering, billing and direct displays. Environmental Change Institute, University of Oxford. http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf

[8] Darby, S., (2010). "Smart Metering: What Potential for Householder Engagement?" Building Research and Information, Vol. 38, No. 5, 2010, pp. 442-457. doi:10.1080/09613218.2010.492660.

[9] A. Faruqui, S. Sergici and A. Sharif, (2010). The impact of informational feedback on energy consumption—A survey of the experimental evidence, Energy, Volume 35, Issue 4, April 2010, Pages 1598-1608, ISSN 0360-5442, http://dx.doi.org/10.1016/j.energy.2009.07.042.

[10] Vine, D., Buys, L. and Morris, P., (2013). The Effectiveness of Energy Feedback for Conservation and Peak Demand: A Literature Review. Open Journal of Energy Efficiency, 2, 7-15. doi: 10.4236/ojee.2013.21002.