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The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices ☆

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HIGHLIGHTS

- We find empirical evidence of the merit-order effect in the Italian market.
- 1 GWh from solar and wind (hourly average) reduces prices by 2.3€/MW and 4.2€/MWh.
- The impact of RES on price has declined as RES production has increased.
- Monetary savings from solar production do not compensate the cost of the incentives.
- Monetary savings from wind production are higher than the cost of the incentives.

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ABSTRACT

Italy promoted one of the most generous renewable support schemes worldwide which resulted in a high increase of solar power generation. We analyze the Italian day-ahead wholesale electricity market, finding empirical evidence of the merit-order effect. Over the period 2005–2013 an increase of 1 GWh in the hourly average of daily production from solar and wind sources has, on average, reduced wholesale electricity prices by respectively 2.3€/MWh and 4.2€/MWh and has amplified their volatility. The impact on prices has decreased over time in correspondence with the increase in solar and wind electricity production. We estimate that, over the period 2009–2013, solar production has generated higher monetary savings than wind production, mainly because the former is more prominent than the latter. However, in the solar case, monetary savings are not sufficient to compensate the cost of the related supporting schemes which are entirely internalized within end-user tariffs, causing a reduction of the consumer surplus, while the opposite occurs in the case of wind.

1. Introduction

The Italian power market has undergone significant changes in recent years. Among these changes, one of the most relevant is the growth in wind and photovoltaic (PV) power capacity promoted by national support schemes for renewable energy sources (RES). While wind power capacity has been mainly supported through a Green Certificates Scheme, solar power capacity has been directly subsidized through a Feed-in Premium, known as Conto Energia. The Conto Energia represents one of the most impressive PV supporting schemes in the world (IEA, 2011). Thanks to massive investments in wind and solar installed capacity[2] (EPIA, 2012; IEA, 2013), wind and solar power generation substantially increased – by 23 TWh from 2008 to 2013 – constituting "an undisputed world record" according to the IEA (IEA, 2013). Over the same period, energy demand decreased by 43 TWh in conjunction with the financial crisis and the subsequent economic recession (Fig. 1).

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[1] The views expressed in the paper are those of the authors and do not necessarily reflect those of the MEF and the DT

[2] In a first phase 2005–2007, RES support schemes promoted some initial investments in intermittent RES power capacity which, however, covered only a marginal position: 3 GW in 2007 or 1.6% of total installed power capacity according to data on power installed capacity provided by the Italian Transmission system operator (Terna s.p.a.). In the period 2008–2010, wind and solar power capacity grew from 4 GW to 9 GW (+49% annual average growth rate), while in the years 2011–2012, it surged from 9 GW to 25 GW, covering 12% of total national power capacity. At the time of writing this article, official data on installed capacity for 2013 were not yet available.

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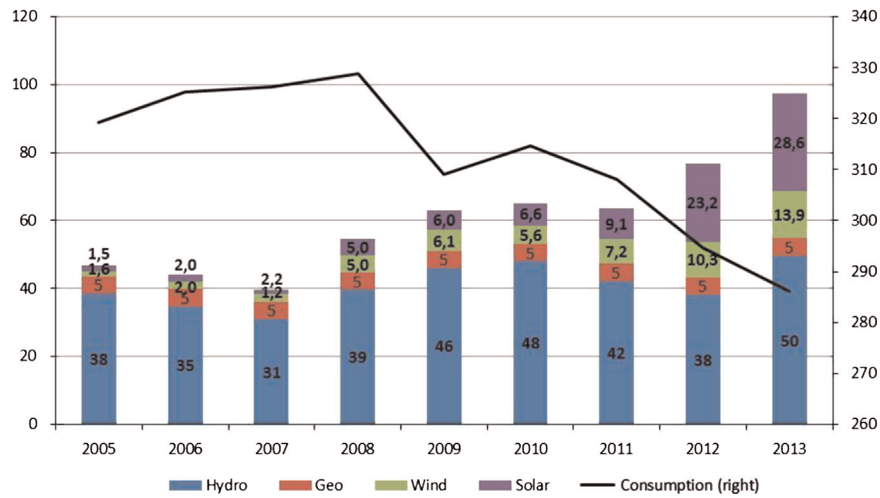

Fig. 1. RES power generation by source in the day-ahead Italian market (2013 data refer to the period January–October) (TWh). *Source*: own elaboration on GME.

The contraction in electricity consumption as well as the significant growth in solar and wind power generation have drastically changed the Italian electricity mix, with a sharp increase in the RES share. Indeed, in less than ten years, the share of RES in the day-ahead power market increased from 17% in 2005 to 40% in 2013.[3] This growth comes almost entirely from non-programmable wind and solar RES.

These changes on both the demand and supply side of the day-ahead power market had a non-negligible impact on the Italian wholesale electricity price. Subsequently to the bullish trend over the period 2005–2008, the wholesale electricity price sharply collapsed during the financial crisis. Then, following a subsequent recovery, from the beginning of 2012 the price trended again downward, in conjunction with both the economic recession and RES penetration (Fig. 2).

The penetration of intermittent RES can explain part of this decline. Wind and solar energy sources have very low operational costs and they are dispatched on a legal priority basis with respect to electricity generated by non-renewable sources. In particular, the GSE (Gestore dei Servizi Energetici)[4] works as a non-programmable RES collector as it bids in the day-ahead market at a zero price an amount of electricity equal to the forecasting of the intermittent RES power generation.[5] Thus, wind and solar power generation effectively enters the day-ahead market at the base of the merit-order function and shifts it to the right (the same process is described by Ketterer, 2012; Nicolosi and Fürsch, 2009; Zachman, 2013). Most expensive marginal plants are driven out of the market, thus favoring a decline in the clearing wholesale electricity price (Fischer, 2006).[6] Various papers find empirical evidence of the merit-order effect in various countries: Germany (Ketterer, 2012; Würzburg et al., 2013), Spain (Gelabert et al., 2011), Israel (Milstein and Tishler, 2011), Denmark (Jonsson et al., 2010), Texas (Woo et al., 2011) and Ireland (O'Mahoney and Denny, 2011). These studies differ with respect to econometric approach, types of renewable sources and country analyzed, as well as frequency of the data used; but they all converge towards the conclusion that RES penetration has lowered wholesale electricity prices.[7] For the purpose of this paper, we recall that Gelabert et al. (2011) and Würzburg et al. (2013) both find that the reduction in wholesale electricity prices induced by higher RES production offsets the increase in final electricity retail prices induced by RES support schemes (subsidies directly paid by consumers in the final energy bill). They respectively conclude that in Spain and Germany the increase in electricity production from RES has generated a net benefit to consumers.

Our paper aims to extend this empirical literature by assessing the merit-order effect in the Italian day-ahead wholesale power market over the period 2005–2013. Since Italian RES supporting policies have been subject to political debate due to the cost of the subsidies internalized within end-user tariffs, we are interested in assessing to what extent the penetration of solar and wind electricity sources has lowered day-ahead wholesale electricity prices and whether such a reduction has been sufficient to offset the cost of the RES support schemes borne by final consumers.

Based on a consolidated empirical approach (Woo et al., 2011), we develop a quantitative analysis to assess the extent to which variations in consumption patterns and in the energy mix have had an impact on the national wholesale electricity price (PUN).[8] While existing literature has mainly focused on wind generation, or has treated wind and solar generation jointly (named intermittent RES), we disentangle the differential impact of solar and wind generation on Italian day-ahead wholesale electricity prices over the period 2005–2013. Moreover, as RES production has increased greatly from year to year during the considered period, we are interested in understanding whether the impact of

[3] Details on the energy mix by source and its change over time are reported in the Appendix A.

[4] The GSE (Gestore dei Servizi Energetici) is the public institution which directly pays the economic incentives to the producers of power generated by renewable sources.

[5] When the day-ahead forecasting deviates from the day-of effective RES power generation, traditional sources are called to cover the gap in the day-of balancing market (mercato di aggiustamento), whose analysis goes beyond the scope of this paper.

[6] This effect has been represented also in an alternative way: an increase in RES power generation shifts the residual demand function to the left along a given supply curve (Sensfuss et al., 2008, Hirth, 2013, O'Mahoney and Denny, 2011). At the same time, self-produced and consumed electricity reduces the net demand and shifts it to the left along a given supply curve. While these representations are equivalent in terms of market equilibrium, we opt to represent the merit-order effect in terms of supply curve shift (see Fig. 3–5), because RES generation effectively bids via the GSE in the day-ahead market and enters the market at the base of the merit-order function.

[7] Würzburg et al. (2013) develop an exhaustive review of this literature and a meta-analysis of various studies on the German market and conclude that 1 additional GWh produced by wind technology reduces the German wholesale electricity price between 0.5 and 2.0 €/MWh. A similar result is found by Gelabert et al. (2011) concerning the Spanish market.

[8] Prezzo Unico Nazionale (Single National Price).

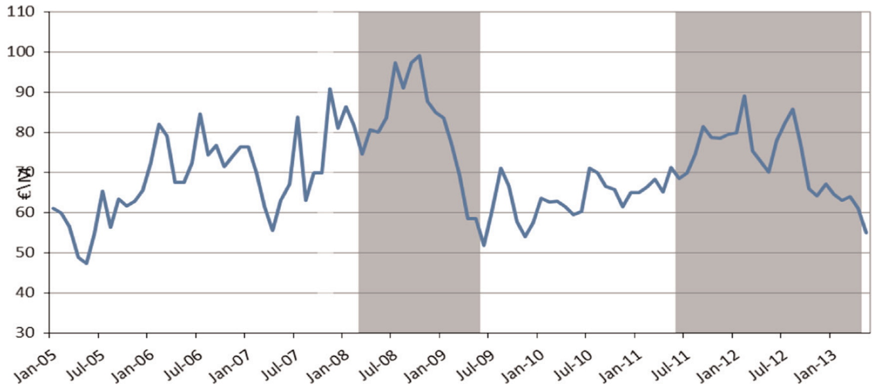

Fig. 2. Italian wholesale electricity prices during 2005–2013 and decreases in GDP (gray areas correspond to periods of GDP decline). *Source*: own elaboration on GME (price) and ISTAT (gdp).

intermittent RES on electricity prices level has varied over time. For this purpose, we re-estimate the impact of RES on the wholesale price year by year.

The paper is structured in the following way. Section 2 introduces the dataset and the empirical approach adopted to assess the impact of solar and wind sources on the level of Italian day-ahead wholesale electricity prices, while Section 3 presents the results of the empirical analysis-the impact of solar and wind penetration on price level and volatility and tests their robustness. Section 4 develops the consumer welfare analysis and discusses the role that the shape of the supply curve and the degree of competition play in the merit-order effect. Section 5 concludes the paper.

2. Methods

This section describes the data and the empirical model. Our approach loosely builds on a consolidated methodology adopted by Woo et al. (2011). We use hourly data for the Italian day-ahead wholesale electricity market provided by the Italian power exchange, Gestore dei Mercati Energetici (GME). Data cover the period from January 1st, 2005 up to October 31st, 2013 and include electricity prices, consumption, imports, exports and supply. Power generation is subdivided according to energy source of production.[9] All the data (both prices and quantities) refer to the day-ahead wholesale electricity market where producers bid according to the forecasted power generation. We convert hourly data into daily-basis averaged hourly data.[10] In this way we reduce excessive and unwanted noise that may arise from using hourly data (Gelabert et al., 2011) and we reduce the intra-day price volatility that arises from intermittent RES power generation.[11]

While the PUN represents the dependent variable in our analysis, national electricity demand (DEM) and non-programmable power generation by sources (SOLAR and WIND) represent our main explanatory variables. As known, daily consumption of electricity is largely price insensitive and inelastic, making it an exogenous variable. Also non-programmable RES are clearly exogenous, as their production depends on weather conditions and they cannot bid strategically according to price dynamics.

We omit from the model traditional and dispatchable sources (hydro, gas, coal and other fossil fuels) because their inclusion in the regression might generate a problem of endogeneity as a result of the GME's least-cost dispatching rule (on this point see also Woo et al., 2011). The positive coefficients reported in the correlation matrix between electricity prices and these sources point to their dispatchability and potential endogeneity. Moreover, gas is highly correlated with national consumption (see Table 6 in Appendix A), thus including both of them might create problem of collinearity, as shown by the related tests (see Table 7 in Appendix A). Therefore, we opt to control for domestic consumption instead of power generation from gas-fired plants. Nevertheless, we control for the gas price, which is an exogenous variable and represents a proxy for its market-based heat rate.[12] Table 8 in Appendix A reports the summary statistics for the key variables of our analysis.

The first step of our analysis consists in testing for unit roots in the above-mentioned series (see Table 9 in Appendix A). We first use the augmented Dickey–Fuller test (Dickey and Fuller, 1979) which tests the null hypothesis H0 that the series have a unit root against hypothesis H1 that the series are stationary.[13] The results are not straightforward as they show that some series are not stationary or are stationary at a 5% critical value. Thus we run again these tests including a trend term. Results show that wind and solar sources are stationary over a (positive) trend, while PUN is stationary at a 5% critical value (but not 1%). To clarify this point, we follow Woo et al. (2011) and Ketterer (2012) and we run the Phillips-Perron test, which is robust with respect to autocorrelation and heteroskedasticity in the disturbance process of the test equation. After including a trend term, results clearly show that all the variables are stationary at a 1% critical value. Thus we can reject the null hypothesis that the series have a unit root and we can specify the multivariate regression model by using the variables in level.

In the first version of the model (Eq. (1)) we include as explanatory variables the daily mean of the hourly national electricity demand (DEM). We control for seasonal effects by introducing a vector of time dummies (*D*) which includes six dummies indicating the days of the week; eleven dummies indicating the month and eight annual dummies indicating the year (Wooldridge, 2003 p. 340).

[9] Coal, gas, other traditional sources (sources other than coal and gas, for example oil), hydro, hydro pumped-storage, geothermic, wind and solar.

[10] Daily-basis averaged hourly price is calculated as follows: $(\sum_{h=1}^{24} \mathrm{PUN}_h)/24$ where h is one of the hours of the day.

[11] Other papers point out that an increase in wind or solar power generation increases price volatility (Ketterer, 2012), but this fact does not have a direct implication for the assessment of the impact of intermittent RES penetration on consumer surplus, which is the core of our analysis.

[12] We use the price traded in the Dutch Title Transfer Facility (TTF) trading point. We also control for the spot price of natural gas traded in the Zeebrugge trading point, but we omit it from the paper as results are comparable with the proposed approach (source: Thomson Reuters).

[13] In order to define the number of lags to be included in the test, we use the Akaike's information criterion (AIC). Several versions of the test have been run to incorporate the different lags and the presence of a trend. The same procedure is useb by Gelabert et al. (2011) and by Würzburg et al. (2013).

These dummies control for year, month and daily effects that can affect wholesale electricity prices dynamics.

$$PUN_t = \beta_0 + \beta_1 DEM_t + \gamma D_t + \varepsilon_t \quad (1)$$

Being interested in understanding to what extent a change in the PUN is driven by different factors on both the demand and supply side, in the second version of the model (Eq. (2)) we add as explanatory variables the production from non-programmable renewable sources (RESNP), which include wind and solar. In this way we get the first assessment of the merit-order effect: the effect of switching between fossil fuels and renewable sources on prices.[14]

$$PUN_t = \beta_0 + \beta_1 DEM_t + \beta_3 RESNP_t + \gamma D_t + \varepsilon_t \quad (2)$$

Model 3 disentangles the RES effect distinguishing between SOLAR and WIND power generation and estimates the variation in wholesale day-ahead electricity prices stemming from a 1 GWh marginal increase in the electricity produced by wind and solar sources, while controlling for national electricity demand.

$$PUN_t = \beta_0 + \beta_1 DEM_t + \beta_2 WIND_t + \beta_3 SOLAR_t + \gamma D_t + \varepsilon_t \quad (3)$$

Finally, we add the daily spot price of natural gas as explanatory variable (GAS_PRICE).

$$PUN_t = \beta_0 + \beta_1 DEM_t + \beta_2 WIND_t + \beta_3 SOLAR_t + \beta_4 GAS\_PRICE_t + \gamma D_t + \varepsilon_t \quad (4)$$

Then we run some tests on the residuals to check the correct specification of our model. We apply the Breusch–Pagan test for heteroskedasticity that verifies the null hypothesis that the error variances are all equal. Then, we test for serial correlation in the OLS residuals using both the Durbin Watson test and applying the Durbin's alternative test that verifies the null hypothesis that there is not serial correlation. Results of the tests indicate that both heteroskedasticity and serial correlation are found in the residuals of the four regressions. Therefore, following Woo et al. (2011) we model the residuals and we assume that they follow a first-order autoregressive process AR(1), $\varepsilon t = \rho \varepsilon t - 1 + \omega t$ with $|\rho| < 1$ and ω being white-noise.

Then we run the regressions using the Prais–Winsten estimation which uses the generalized least-squares method to estimate the parameters in a linear regression model in which the errors are serially correlated and follow a first-order autoregressive process. Moreover, by using the Prais–Winsten estimator, estimates are robust to heteroskedasticity. As results of the regressions will show, the AR(1) assumption is validated for all the regressions.

3. Results

We first describe the results of the regressions run over the entire period 2005–2013 (Table 1). By controlling only for the daily national demand (DEM) and for seasonal dummies, model 1 explains about 53% of daily electricity prices. The coefficient of the DEM variable is significant and positive, as expected, showing that a marginal positive variation in national demand positively affects wholesale daily electricity prices. This result is confirmed also in subsequent models where other explanatory variables are added in our regression.

[14] Due to their high collinearity (see Appendix A) fossil fuels and electricity consumption cannot be jointly added as explanatory variables. Nevertheless, variations in RES production and electricity consumption jointly determine a variation of the residual electricity demand which is covered by traditional thermal capacity. Therefore, by controlling for electricity consumption, we can assess the impact that a switch between fossil fuels and RES has on price.

Table 1
Estimation of daily changes in wholesale electricity price, 2005–2013.

Dependent Variable: PUN_t	(1)	(2)	(3)	(4)
DEM	2.26***	2.26***	2.26***	2.23***
	(0.09)	(0.09)	(0.09)	(0.09)
RESNP		−3.73***		
		(0.29)		
SOLAR			−2.58***	−2.34***
			(0.51)	(0.50)
WIND			−4.19***	−4.20***
			(0.33)	(0.33)
GAS_PRICE				0.44***
				(0.09)
Constant	−17.97***	−18.25***	−17.82***	−24.43***
	(3.18)	(3.15)	(3.15)	(3.25)
DMY dummy	YES	YES	YES	YES
Observations	3.226	3.226	3.226	3.226
r2	0.541	0.557	0.558	0.567
r2_a	0.538	0.553	0.554	0.563
rho	0.660	0.679	0.673	0.643
F	111.0	114.4	111.2	116.6
dw	2.116	2.131	2.125	2.107
dw_0	0.695	0.679	0.688	0.770
Pperron on ε	−27.228	−26.168	−26.507	−28.130
vce	Robust	Robust	Robust	Robust

*$p < 0.05$, **$p < 0.01$ Notes: Standard errors are reported in parenthesis and are robust to heteroskedasticity and serial correlation,
dw_0 indicates the results of the Durbin Watson test before correcting for serial correlation in the residuals.
dw indicates the results of the Durbin Watson test after correcting for serial correlation in the residuals.
*** $p < 0.001$.

Model 2 adds non-programmable RES (RESNP) among the explanatory variables, slightly increasing explanatory power to about 55%. The coefficient of RESNP is negative and significant, indicating that a marginal increase in the supply of non-programmable renewable sources reduces wholesale daily electricity prices. This result is evidence of the merit-order effect in the Italian day-ahead power market. In model 3 we split non-programmable RES between solar and wind power generation. We find that both coefficients of these variables are negative and significant, the latter being slightly greater in absolute value than the former. The result is confirmed in model 4, where we add the spot price of natural gas. Results of model 4 shows that a marginal increase of 1 GWh in the hourly average of daily production from solar and wind sources reduces the daily wholesale electricity price respectively by 2.3 €/MWh and 4.2€/MWh. Moreover, as expected, the positive and significant coefficient of the spot price of natural gas indicates that a marginal increase in gas price increases wholesale electricity prices.

Table 1 reports the results of the original Durbin Watson test (dw_0) indicating serial correlation in the residuals, and shows that, after using the Prais-Winsted estimator, the results of the (transformed) Durbin Watson test (dw) reject the null hypothesis of serial correlation in the residuals. Moreover, the Phillips-Perron test run on the residuals confirms that they are stationary in all the versions of model and the same result holds when using the ADF test. Finally, we highlight that the coefficient $\rho < 1$ confirms that the AR(1) assumption is validated for all the regressions.

Next, we run a second set of regressions (Table 2). Solar and wind production was negligible in 2005 and quite considerable in 2013. Since RES production has increased significantly year by year over the considered period (2005–2013), we run the fourth model on a yearly base. In this way, we take into account that the impact of solar and wind generation on the electricity price may differ

Table 2
OLS estimation of daily changes in wholesale electricity price, 2005–2013.

VARIABLES	(1) 2005	(2) 2006	(3) 2007	(4) 2008	(5) 2009	(6) 2010	(7) 2011	(8) 2012	(9) 2013
DEM	2.32***	2.46***	2.67***	1.94***	1.65***	1.60***	0.95***	1.97***	1.04***
	(0.16)	(0.10)	(0.15)	(0.26)	(0.25)	(0.21)	(0.16)	(0.22)	(0.23)
SOLAR	−12.32	−52.34*	−16.35	0.60	−9.61**	−1.78	−4.64***	−3.47***	−3.45***
	(8.57)	(28.40)	(21.56)	(3.65)	(4.32)	(3.44)	(1.60)	(1.16)	(0.78)
WIND	1.85	−2.35	−3.53	−9.59***	−7.25***	−5.07**	−5.77***	−4.38***	−2.86***
	(7.51)	(5.13)	(8.65)	(2.66)	(1.56)	(2.18)	(1.04)	(0.59)	(0.33)
GAS _PRICE	−0.01	0.19**	1.42***	−0.05	0.42	0.51	0.65**	−0.16	0.54**
	(0.04)	(0.08)	(0.40)	(0.32)	(0.31)	(0.68)	(0.31)	(0.73)	(0.22)
Constant	−24.41***	−10.71	−35.92***	17.45	27.31**	8.19	24.71***	29.11*	24.14***
	(5.82)	(8.83)	(8.20)	(11.49)	(11.08)	(9.58)	(8.58)	(16.18)	(8.62)
DM dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	365	365	365	366	365	365	365	366	304
R−squared	0.883	0.875	0.817	0.560	0.526	0.321	0.562	0.546	0.619
r2_a	0.875	0.868	0.805	0.533	0.497	0.279	0.535	0.519	0.593
rho	0.557	0.389	0.520	0.467	0.411	0.360	0.316	0.550	0.353
F	130.5	161.4	72.49	22.57	20.67	9.898	23.42	17.92	20.70
dw	1.951	2.099	1.944	2.025	2.072	2.009	2.032	1.982	2.063
dw_0	0.916	1.277	1.093	1.096	1.204	1.331	1.426	1.143	1.375
Pperron on ε	−9.612	−3.185	−7.634	−13.632	−9.446	−20.710	−16.789	−11.422	−19.167
vce	Robust	Robust	Robust	Robust	Robust	Robust	Robust	Robust	Robust

Standard errors in parentheses.
dw_0 indicates the results of the Durbin Watson test before correcting for serial correlation in the residuals.
dw indicates the results of the Durbin Watson test after correcting for serial correlation in the residuals.

*** $p < 0.01$
** $p < 0.05$
* $p < 0.1$

Table 3
Impact of solar and wind increase on price volatility.
Source: own elaboration

	Wind	Solar
Beta (coefficient)	−4.2 (0.33)	−2.33 (0.50)
Price mean	70.08	70.08
Price standard deviation	14.31	14.31
Price variance	204.75	204.75
Price change	−0.25	−0.24
Price change as percentage of price mean	−0.36	−0.34
Price variance change	1.37	1.55
Price variance change as percent of price variance	0.67	0.76

Table 4
Annual cost of conto energia and estimated annual savings from PV power generation (mln €).
Source: costs from GSE annual reports; savings from own elaboration.

	Costs	Saving	Savings-Costs
2009	291.790	2.023.347	1.731.557
2010	772.613	–	–
2011	3.855.411	1.485.653	−2.369.758
2012	6.000.000	2.708.949	−3.291.051
2013	6.700.000	3.219.501	−3.480.499
Total 2009–2013	17.619.814	9.437.450	−8.182.364

over time as the accumulated level of RES electricity production increases. Solar and wind production was quite negligible in the period 2005–2007 and, consistently with our expectations, their coefficients are not significant in those years. The only exception is that of the coefficient of solar in 2006, being negative and significant at a 10% critical value.

In subsequent years, the coefficient of wind is always negative and significant, while the solar coefficient is not significant in 2008 and 2010 and it is negative and significant in 2009, 2011, 2012 and 2013. Notably, the magnitude of both wind and solar coefficients shows a declining trend over time. We also find that $\rho < 1$ in all regressions, confirming the initial assumption that residuals follow a first-order autoregressive process.

We add two more observations: (1) in each year of the period 2005–2013, the coefficient of national demand is positive and significant, and it is higher in the period 2005–2007 which precedes the financial crisis; (2) the explanatory power of the model is particularly high in pre-crisis years 2005, 2006 and 2007, while it drops from 2008 and then recovers in 2012 and 2013, without reaching the pre-crisis level. These facts suggest that market functioning and the impact of individual variables on electricity prices have been altered by the financial crisis.

We also test the robustness of our results by re-estimating the fourth model for the entire period assuming ARCH (1) and GARCH (1 1) effects in the error process parameters. The results are broadly in line with previous results: the wind coefficient is significant at a 1% level and not effectively different from those estimated in the previous section and the solar coefficient is

Table 5
Annual costs of wind support schemes[a] and estimated annual savings from wind power generation (mln €).
Source: costs from GSE annual reports; savings from own elaboration.

	Costs	Savings	Savings-costs
2009	745.426	1.562.677	817.251
2010	1.066.082	1.027.215	−38.867
2011	1.185.438	1.464.343	278.905
2012	1.290.000	1.514.847	224.847
2013	1.256.300	1.300.673	44.373
Total 2009–2013	5.543.246	6.869.755	1.326.509

[a] The reported value includes the cost of the Green Certificates Scheme, the national subsides CIP6, Tariffa Omnicomprensiva and Ritiro Dedicato related to wind power generation.

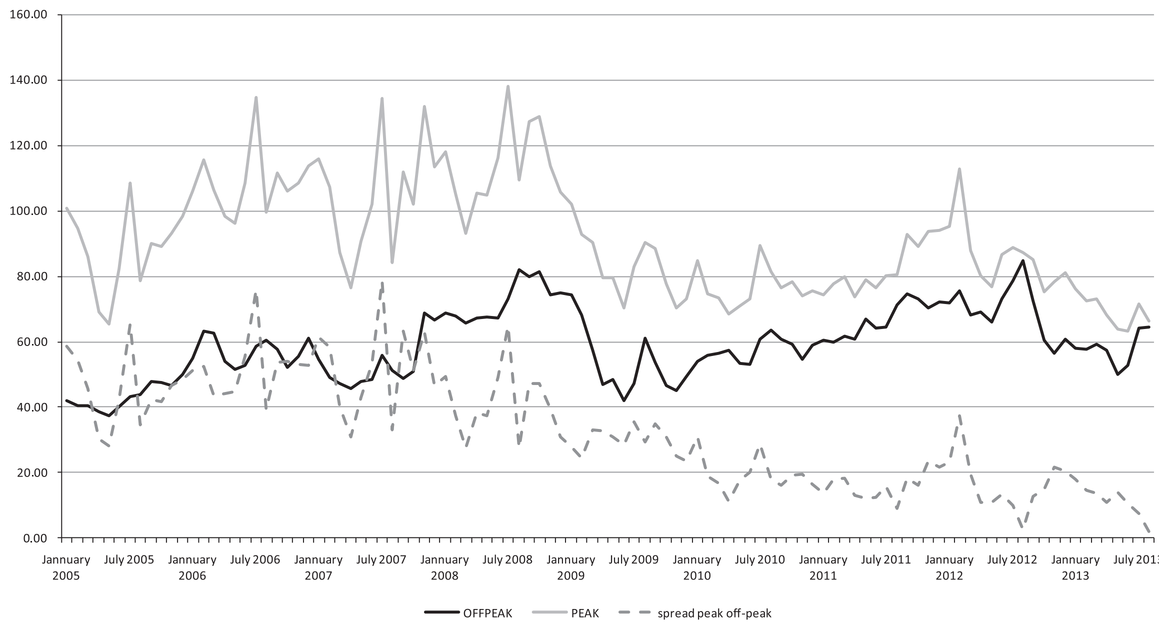

Fig. 3. Trend of peak and off-peak prices (€/MWh).
Source: own elaboration on Gestore Mercato Elettrico (GME).

significant at 5% and still negative even if smaller in absolute value. ARCH(1) and GARCH(1 1) models run on yearly bases show minor differences that consist in the non-significance of the solar coefficient in 2009 and of the wind coefficient in 2005 and 2010. Hence, we conclude that our results are robust to different specifications.

3.1. Impact on price volatility

An increase in solar and wind generation does not only impact on the level of prices, but also on its volatility. Following the procedure adopted by Woo et al. (2011), we predict how the increase in solar and wind generation impacts on price and its variance.

Table 3 reports: the estimated coefficients of wind and solar (standard errors in parenthesis); the mean value of hourly electricity prices; its standard deviation and variance. The daily average of solar and wind productions are respectively 1.01 GWh and 0.60 GWh, with a variance equal to 1.31 GWh and 0.37 GWh respectively. If we assume a 10% increase in solar and wind daily generation (+0.10 GWh and 0.06 GWh respectively), variance increases to the levels of 1.59 GWh for solar and 0.44 GWh for wind. Then, we multiply the 10% variation in daily average production for solar and wind by their respective coefficients (β) to estimate the related price change. The change in price variance is predicted using the forecast variance formula in Feldstein (1971, p. 56).

As seen, an increase in non-programmable RES electricity production reduces the electricity price. Specifically, in our example, a 10% increase in solar and wind generation lowers prices respectively by 0.34% and 0.36%. Moreover, the increase in wind and solar amplifies price volatility, causing a change in price variance equal to 1.4 and 1.5 (0.67% and 0.76%) respectively. We recall that, by using daily averaged data instead of hourly data, we smooth intra-day price volatility. Indeed, we do not observe how price varies within a given day due to fluctuations in intermittent RES power generation over the course of 24 h.

4. Discussion

The previous section shows that the increase in solar and wind generation has reduced wholesale electricity prices. However, the cost of the RES support schemes has been directly passed through into the final electricity bill, implying an increase in the retail electricity price and an economic transfer from final energy consumers to renewable energy producers. This has generated a wide concern on the redistributive effect related to RES support schemes. In this section we disentangle the effect of solar and wind power generation on final consumers of electricity in strictly monetary terms. We compare the total monetary savings stemming from the reduction in wholesale prices due to non-programmable RES production with the cost of support schemes charged on final prices. This analysis allows us to determine whether, in a given year, the electricity price paid by final consumers, and thus the consumers' direct monetary surplus, has increased or decreased due to power generation from renewable sources.

To assess the price reduction and related monetary savings promoted by solar and wind penetration we consider only the statistically significant coefficients estimated on a yearly basis using model 4. Since the GSE provides public data on the costs of wind and solar supporting schemes only from year 2009 on, we develop our consumer welfare analysis only for the period 2009–2013.

The solar and wind coefficients previously estimated indicate the impact of an additional GWh produced by these sources on the daily average of the Italian wholesale electricity price (€/MWh). By multiplying the solar and wind coefficients by daily average hourly data on power generation from the two respective sources, we estimate the total reduction in the electricity price. We make this estimation for each year, thus we implicitly assume linearity in the price and RES quantity effect within the considered yearly period. We find that total solar power generation has lowered the day-ahead wholesale electricity price up to 11.2€/MWh in 2013, while wind power generation has contributed to reduce the day-ahead wholesale electricity price up to 4.5€/MWh in 2013. Finally, we estimate the total annual savings for energy consumers, by multiplying the yearly day-ahead wholesale electricity price reduction induced by RES penetration (€/MWh) by the total annual electricity consumed in the corresponding year (MWh). We estimate that annual savings have increased over time, reaching in 2013 €2.75 bln for solar generation and €1.3 bln for wind generation.

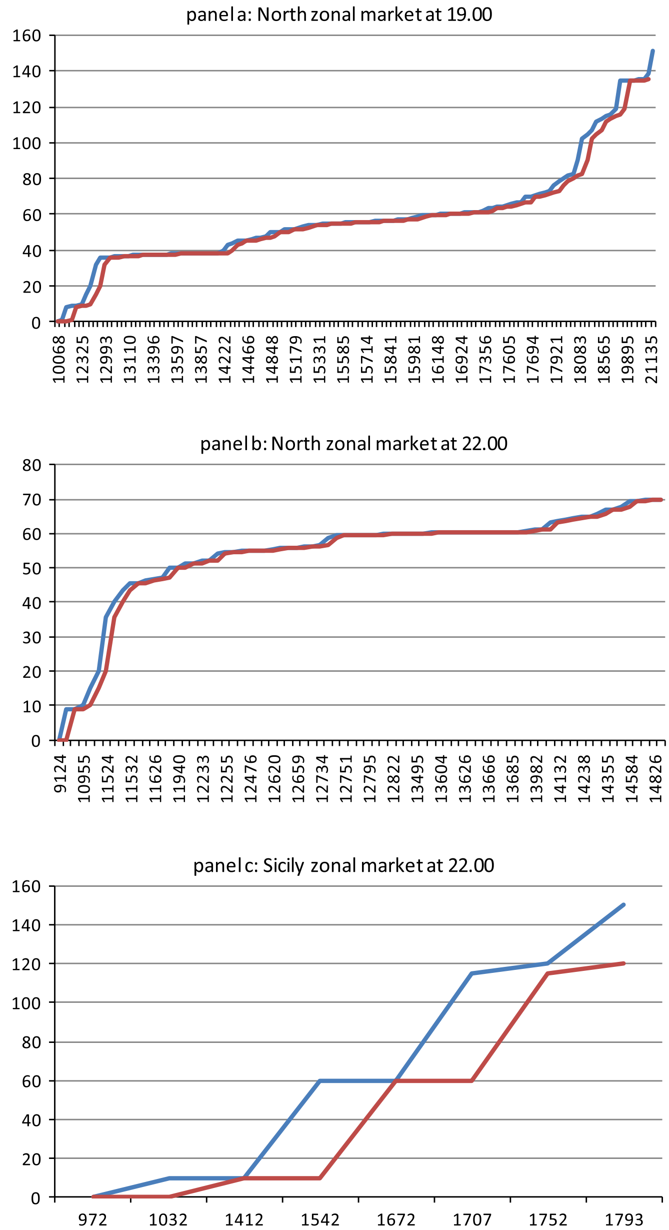

Fig. 4. Real and simulated merit-order function in different zonal markets at different hours, Note: quantities are reported on the *x*-axis (MW) while prices are reported on the *y*-axis (€/MWh), Real merit-order function in blue while the red line simulates a shift on the right after an equal increase of production from RES. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source: own elaboration on GME.

Over the period 2009–2013, solar production generated higher monetary savings than production from wind, mainly because solar production is more prominent than wind production.

We finally compare these estimated savings with the actual costs of the wind and solar supporting schemes that have been implemented in Italy. While solar power generation has been supported by the *Conto Energia*,[15] wind power has been supported by various types of incentives, such as the green certificates scheme and various direct subsidies. Official data on annual costs of the various incentives designed to promote power generation from wind and solar are reported by the GSE in its annual reports, which cover the period 2009–2013.

Table 3 compares savings and costs related to each source. It shows that over the period 2009–2013, solar power generation led to cumulative savings equal to €9.4 bln. These savings are significantly lower than the aggregate cost of the Conto Energia over the same period, which amounts to €17.6 bln. Interestingly, in absolute terms both savings and costs increase over time, but the former less than the latter. As a consequence, their difference decreases over time: while it is positive in 2009, it turns negative from 2011 on.

Since cumulative monetary costs to promote PV are higher than the monetary savings induced by solar power generation, we conclude that the net effect of the PV supporting scheme has been an increase in the final electricity price, to the detriment of consumer surplus. The same result holds if we add the savings estimated using non-statistically significant coefficients (year 2010).

Estimates of savings from wind power generation give opposite results. Table 4 shows that wind power generation has favored a cumulative savings over the period 2009–2013 equal to €6.8 bln. This value is higher than the aggregate costs of the various wind supporting schemes, which equal €5.5 bln. Interestingly, like in the solar case, also for wind we observe that the difference between savings and costs shows a decreasing trend. This result suggests that net monetary benefits have decreased in correspondence with the increase in intermittent RES power generation. As solar production is more prominent than wind production, this intuition might also explain why costs outweigh savings in the solar case, while the opposite results in the case of wind Table 5.

4.1. Some additional considerations

As shown in the previous section, the merit-order effect does not necessarily imply an increase in consumer surplus. Moreover, by distorting private investment choices, RES public supporting schemes might negatively affect producers surplus. Looking at the cost side, RES are characterized by a high fixed to marginal cost ratio while traditional technologies have relatively high marginal costs and a relatively low fixed to marginal cost ratio. Thus it is not clear whether the transition from fossil fuel sources to more renewable sources actually reduces overall production costs. Looking at the revenue side, the reduction in the electricity price induced by RES penetration is likely to lower the revenues of different technologies in a non-uniform way, mainly because electricity prices and power generation by RES and traditional sources are distributed unevenly over the course of a 24 h day. Some studies point out that, by lowering electricity prices, RES penetration reduces the unit revenues of the RES technologies (without considering subsidies) more than revenues of traditional sources. In this respect, Sioshansi (2011) argues that wind technology cannot modulate production and therefore tends to have a lower market

[15] This support scheme has been modified five times. Consequently, five “Conto Energia” have been implemented, differentiated by typology of plants entitled to receive the incentive (size, location etc.); the authorization procedure, the level of monetary support and the maximum amount of subsidies (cap) that can be granted. The total annual cost of the Conto Energia reached more than € 6 billion at the end of 2012 and came to an end in 2013 once the cost reached the cap of € 6.7 billion per year. All the five Conto Energia grant support for a period of twenty years. The latest rules on support for solar photovoltaic power generation (the 5th feed-in scheme) entered into force in 2012. They grant an all-inclusive feed-in tariff to the share of net electricity injected into the grid and a premium tariff to the share of net electricity consumed on site. As to the share of net generation injected into the grid, the tariff depends on the capacity of the plants: plants with a nominal capacity of up to 1 MW benefit from an all-inclusive tariff, while plants with a nominal capacity of above 1 MW benefit from the difference (if positive) between the all-inclusive tariff and the hourly zonal price. If the hourly zonal price is negative, this difference will not exceed the amount of the all-inclusive tariff applicable to the plant.

Table 6
Correlation matrix.

	Pun	Dem	Solar	Wind	Gas	Coal	Hydro	Gas price
Pun	1							
Dem	0.5289	1						
Solar	−0.0243	−0.2805	1					
Wind	−0.094	−0.2125	0.5057	1				
Gas	0.5374	**0.8495**	−0.4043	−0.2528	1			
Coal	0.2835	0.1841	0.3138	0.2823	0.1948	1		
Hydro	−0.0004	0.1152	0.4563	0.1976	−0.0916	−0.1508	1	
Gas Price	0.3532	−0.0831	0.4808	0.4125	−0.101	0.3207	0.0852	1

Note: Correlation refers to the hourly average value of the variables expressed in level.
Coefficients of explanatory variables used within the same regression higher than 0.8 in absolute terms may indicate that a multicollinearity problem exists (Verbeek 2008).

Table 7
Test for multicollinearity.

	Variable	VIF	1/VIF
1° regression[a]	Dem	9.64	0.103748
	Solar	8.09	0.123669
	Wind	2.51	0.398381
	Gas	8.33	0.120090
2° regression[b]	Dem	4.25	0.235531
	Solar	7.83	0.127788
	Wind	2.46	0.406691
	Gas Price	3.12	0.320456

Note: VIF values higher than the threshold of 5 (which corresponds to a tolerance of 0.20) can signal a problem of collinearity or multicollinearity among the independent variables (Smart and Tierney, 2003). Also a higher threshold equal to 10 has been proposed as a cut off value (Kutner et al., 2004).

[a] $PUN_t = \beta_0 + \beta_1 DEM_t + \beta_2 WIND_t + \beta_3 SOLAR_t + \beta_4 GAS_t + \gamma D_t + \varepsilon_t$.
[b] $PUN_t = \beta_0 + \beta_1 DEM_t + \beta_2 WIND_t + \beta_3 SOLAR_t + \beta_4 PRICE\_GAS_t + \gamma D_t + \varepsilon_t$.

value with respect to other technologies that can store production, bid strategically and increase market price when wind is out from the market. Similarly, Haas et al. (2013) show that an increase of PV directly reduces the electricity price in the hours when solar power is available, but conversely conventional power marginal plants tend to increase the market price in the hours when RES are scarce. In this way, traditional sources can partly mitigate the loss of revenues in those hours when market price decreases due to RES penetration. Conversely, RES producers cannot adopt a similar strategic behavior.

Our paper treats daily average prices and we do not observe how power generation by source and price vary across different hours. Moreover, testing the impact of RES on the profits of various sources goes beyond the scope of this paper, which focuses on the welfare impact of RES penetration on consumers. Nevertheless, the trend of peak and off-peak prices (Fig. 3) in the Italian wholesale day-ahead market shows a bearish trend of the peak price, when solar power generation is highly concentrated, and a bullish trend of the off-peak price, in those hours when PV is absent from the market.

This evidence seems to be consistent with Sioshansi (2011) and Haas et al. (2013). These considerations bring us to highlight a crucial point: the impact of RES penetration on price depends on the degree of market competition and on the shape of the merit-order function-in particular on the elasticity of supply. While this topic deserves further empirical analysis of hourly data in various zonal power markets, we briefly sketch the intuition behind this point by looking at the real merit-order function in two Italian zonal markets which are characterized by a different degree of market concentration (North and Sicily). As known, the Sicilian zonal market faces serious interconnection constraints with the rest of Italy (Gianfreda and Grossi, 2012, AEEG, 2014). Therefore, market concentration measured by the HHI index is higher in Sicily than in the North zonal market (AEEG, 2013, p. 86–87).

In detail, we chose randomly two different hours in a randomly chosen day (8th January 2010) and we order the accepted bids in ascending order of price. In this way we build the real merit-order function registered in the specific hourly zonal markets (see blue line of Fig. 4). Next, for each case we assume that 60 MWh[16] produced by RES and offered at a zero price enters the market and shifts the merit-order function to the right (red line of Fig. 4). In this way we simulate how the market clearing price is likely to change after an equal increase of RES power depending on the different shape of the supply curve when it intersects the demand curve.

Panel a of Fig. 4 shows that on the 8th of January 2010 at 19.00 the North zonal market cleared at a 151€/MWh price. At that hour, demand was quite high and equal to 21,271 MWh. When we assume that 60 MWh generated by a RES sources (0,28% of total consumption) enters at the base of the merit-order function, the most expensive marginal plants are driven out from the market and the electricity price decreases by 16€/MWh down to 135 €/MWh. Such a reduction can be explained by the fact that the supply function was very steep at the intercept with the demand function.

In the same zonal market, at 22.00 of the same day (Fig. 4, panel b), the market cleared at a lower price (70€/MWh) in correspondence with a lower level of consumption (15,058 MWh). After assuming a 60 MWh increase of RES production (0,4% of total consumption), the electricity price does not vary at all (−0,2 €/MWh). We observe that, at the intercept with the demand function, the merit-order function is quite flat. Therefore, the amount of RES which entered the market was not sufficient to favor a change in the marginal plant which sets the price.

Finally, Panel c of Fig. 4 shows the wholesale electricity market at 22.00 of the same day in the Sicily zonal market. Here, consumption equals 1,793 MWh and is significantly lower than consumption in the North zone in the same hour. Nevertheless, the supply function is quite steep and the Sicilian price equals 150 €/MWh. In this case we see that when 60 MWh from RES sources (3% of total consumption) enters at the base of the merit-order function, the price declines by 30€/MWh, down to 120€/MWh.

These examples illustrate the idea that the impact of RES on price is conditional to the level of consumption and it depends on the shape of the merit-order function. Moreover, it is also likely to depend on the degree of market competition. When operators exert their market power by setting the price above marginal costs, the merit-order effect induced by RES penetration is likely to be amplified by the cancellation of the mark up that takes place when marginal plants are driven out from the market. As

[16] This amount of electricity is randomly chosen but is quite negligible (less than 3% of total consumption).

Table 8
Descriptive statistics: prices (€/MWh) and quantities (GWh).
Source: own elaboration on GME data and Thomson Reuters (Gas price).

	2005(365)			2006 (365)			2007 (365)			2008 (366)			2009 (365)			2010 (365)			2011 (365)			2012 (366)			2013 (304)		
	Mean*	%	sd	Mean*	%	sd	Mean*	%	sd	Mean*	%	sd	Mean*	%	sd	Mean*	%	sd	Mean*	%	sd	Mean*	%	sd	Mean*	%	sd
PUN	58.6	–	12.7	74.8		12.6	71.0	–	15.4	87.0	–	13.1	63.7	–	13.0	64.1	–	8.3	72.2	–	7.9	75.5	–	11.5	62.5	-	7.9
DEM	36.5	–	4.6	37.1		4.9	37.2	–	5.0	37.5	–	4.8	35.3	–	4.4	35.9	–	4.1	35.2	–	4.1	33.6	–	4.2	32.7	-	3.8
RESNP	0.4	1	0.1	0.5	1	0.1	0.4	1	0.1	1.1	3	0.3	1.4	4	0.4	1.4	4	0.3	1.9	5	0.4	3.8	11	1.0	4.9	15	1.1
SOLAR	0.2	0	0.1	0.2	1	0.0	0.1	0	0.0	0.6	2	0.2	0.7	2	0.2	0.8	2	0.3	1.0	3	0.3	2.7	8	1.0	3.3	10	1.1
WIND	0.2	0	0.1	0.2	1	0.1	0.3	1	0.1	0.6	2	0.2	0.7	2	0.4	0.6	2	0.2	0.8	2	0.3	1.2	3	0.7	1.6	5	1.0
GAS PRICE	16.3	–	4.3	19.9		4.2	14.7	–	4.9	24.9	–	2.8	12.1	–	4.4	17.4	–	3.5	22.6	–	1.3	24.9	–	1.9	27.0	–	2.5

Note: the percentage value refers to the share of solar and wind sources in the electricity mix, calculated as their production over domestic consumption; RESNP stands for non-programmable RES, which include wind and solar.

* mean refers to the hourly average value

Table 9
Tests for unit root.

Variable	ADF in levels	ADF in levels with trend	PPERRON in levels	PPERRON in levels with trend
PUN	−3.168	−3.159	−22.585	−22.583
DEM	−3.879	−6.038	−29.258	−30.351
RESNP	−1.410	−2.648	−4.353	−10.714
SOLAR	−2.472	−4.165	−2.577	−4.952
WIND	−1.976	−3.345	−15.005	−22.866
GAS PRICE	−4.158	−4.681	−4.506	−5.144

Note: MacKinnon (1996) critical values for rejection of hypothesis of unit root are −2.570 for 10% confidence level, −2.860 for 5% confidence level, and −3.430 for 1% confidence level for the model with constant and no trend. With trend they respectively are −3.120 (10% confidence level), −3.410 (5% confidence level) and −3.960 (1% confidence level).

mentioned, though these examples offer a quite clear idea about the influence of the shape of the supply function on the merit-order effect, a more formal analysis is required to reach more robust conclusions. This will be the focus of further research.

5. Conclusions and policy implications

The Italian electricity market has undergone several important changes in recent years. In particular the contraction in electricity consumption as well as the significant growth in solar and wind power generation have deeply changed the electricity production mix, with a sharp increase in the non-programmable RES share and a decrease in the share of traditional electricity sources. The EU 2020 RES target, defined by the Directive 2009/28/EC of the EU 2020 Climate-Energy Package, spurred this change, leading various EU Member States to design different RES support schemes. These public policies have been widely justified on the basis of the direct and indirect benefits of RES development. From an environmental point of view, RES production reduces GHG emissions, with a positive impact also on health due to better air quality. Moreover, greater RES production reduces energy dependence (IPCC, 2011; IEA, 2012), lowering the energy deficit (European Commission, 2014) and the impact on economic activity of rapid and unexpected variations in international fossil fuel prices. Finally, RES production can promote green growth and green employment (OECD, 2011). However, against these benefits, rapid RES development entails direct and indirect costs, such as subsidies, costs related to further grid development and reserve capacity congestion costs, inefficiencies deriving from overlapping with the ETS. They may also worsen producer surplus by increasing overall production costs with respect to revenues. Developing a comprehensive cost-benefit analysis for RES support schemes goes beyond the scope of this paper, as this would entail an in-depth analysis of many direct and indirect factors that we have not taken into consideration in our analysis. Our paper contributes to the debate by assessing the impact of RES penetration in the Italian wholesale day-ahead market on electricity prices and consumers' surplus. We find evidence of the merit-order effect for both wind and solar sources. Next, we compare the estimated monetary savings stemming from the reduction in the level of wholesale prices with the cost of support schemes charged on final electricity prices. In this way we assess the effect of RES production on final consumers of electricity. When looking at solar energy production we find that the related savings have been lower than the cost of the supporting schemes, resulting in a decrease in consumer surplus. The opposite result holds for the wind case, where the cost of the related supporting schemes is entirely outweighed by the monetary savings. Analysis on a year to year basis shows that the impact of RES on prices and the net monetary benefits (savings minus costs of the supporting schemes) decrease over time, in correspondence with the increasing degree of penetration of solar and wind sources.

Summarizing, our analysis suggests that careful, step by step monitoring is highly desirable and even necessary in the case of RES support schemes, so as to regularly fine-tune the level of support given to non-programmable RES. Among other aspects, future research could focus on how the impact of non-programmable RES on wholesale electricity prices varies among different zonal markets depending on specific market characteristics, such as the shape of the supply curve and the degree of market concentration.

Appendix A. Summary statistics and diagnostic tests

See appendix Table 6–9.

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