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ON THE MAP

The remarkable impact of renewable energy generation in Sicily onto electricity price formation in Italy

Francesco Meneguzzo[1], Rosaria Ciriminna[2], Lorenzo Albanese[1] & Mario Pagliaro[2]

[1]Institute of Biometeorology, CNR, via Caproni 8, 50145 Firenze, Italy
[2]Institute for the Study of Nanostructured Materials, CNR, via U. La Malfa 153, 90146 Palermo, Italy

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Correspondence
Francesco Meneguzzo, Institute of Biometerology, CNR, via Caproni 8, 50145 Firenze FI, Italy. E-mail: f.meneguzzo@ibimet.cnr.it
and
Mario Pagliaro, Institute for the Study of Nanostructured Materials, CNR, via U. La Malfa 153, 90146 Palermo PA, Italy. E-mail: mario.pagliaro@cnr.it

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Abstract

During the first half of 2015, for the first time, the zonal electricity price in Sicily decreased below than the national wholesale price in Italy. Showing the unique pattern of electricity consumption in Italy's largest region at different time scales, we identify the effectiveness of the impact of renewable power generation on utility-scale in Sicily upon the whole of Italy's electricity market. Increasing the electrification of the energy end uses, as it is happening despite prolonged reduction in electricity demand, will lead to further benefits for power consumers throughout the whole country.

Introduction

Sicily is the largest and the most solar irradiated among Italy's regions. For comparison, the global horizontal irradiation yearly total of the second largest region (Lombardia) is 1100 kWh/m^2 whereas Sicily has an average value of 1800 kWh/m^2 [1].

While photovoltaic (PV) power generation was negligible till 2008–2009, the deployment of the Feed-In-Tariff (FiT) incentive scheme in Italy between 2006 and 2013 caused an impressive surge in the PV installed power nationwide as well as in Sicily, jumping from few tenths of MW to 1270 MW during 3 years (2011–2013) [2].

Even without the FiT subsidies (practically terminated on June 2013), in 2014 Sicily saw the installation of another 130 MW bringing the overall power to 1400 MW [3], with owners of the new PV systems benefiting of net metering, namely self-consuming the energy produced by their PV installations. This accelerated deployment of solar electricity took place almost concomitantly to massive adoption of wind energy as Sicily is also the most ventilated region of Italy, so that the installed wind power rose from zero in 2005 to about 2000 MW at the end of 2014 [3].

A preliminary estimate suggests that the PV power deployed in Sicily rose further up to more than 1400 MW during 2015, while the combined PV and wind power generation exceeded 2 TWh [4].

This rapid change, along with significant economic interests behind the incentives that reward only the electricity produced and actually fed into the grid, pushed the State owner of the Italian grid to deploy massive investments to widen and improve Sicily's high voltage grid [5]. The new "Sorgente-Rizziconi" connection between Sicily and the Italian peninsula [6], now almost completed, is a 380 kV line that by the end of 2016 will bring the interconnection capacity from the existing 1000–3000 MW, relieving the bottleneck that historically caused higher electricity prices in Sicily compared to the rest of the country.

From the viewpoint of electric interconnection, indeed, Sicily is an isolated island. For example, in 2014 the existing 1000 MW line was congested for 90% of the year's time [3], limiting, for example, the possibility to export the surplus of renewable energy during holydays and weekends.

We have recently shown why and how the growing penetration of PV renewable power generation in Italy (18 GW as of late 2014) has caused a substantial fall in the price of electricity in the Italian wholesale electricity market (IPEX) [7]. Now we show how the significant PV and wind power generation has changed the electricity price formation in Sicily affecting the national price (PUN) to such an extent to cause a significant decrease in the national electricity price.

In other words, the Sicily zone is substantially a one-way feeder into the Italian electricity market, not only on the side of locally generated power but also as a price steering element, since the zonal price affects the PUN in the weighted average leading to its formation. We also develop a model linking the daily zonal power price in Sicily to the demand not met by PV and wind energy.

The study is concluded suggesting a few practical ways to achieve further economic (and environmental) benefits for electricity consumers not only in Sicily, but also throughout the whole country.

Italy's and Sicily's Electricity Markets

As mentioned above, until recently wholesale electricity prices in Sicily have been constantly higher than in the rest of the country. The monthly average was more than 40% higher than the average national prices in Italy in 2008 and 2009, exceeding the PUN by more than €20/MWh for more than 50% of the months between January 2008 and December 2014 (Fig. 1). Following the spikes in 2008–2009, the Italian energy regulator (AEEG) launched an investigation into Sicilian prices whose outcomes, on August 2009, were transferred to the antitrust regulator (ICA) [8].

According to two following ICA investigations into Sicily wholesale electricity prices launched on January 2010, capacity withholding (mainly economically) was used to raise Sicily's zonal price, in turn affecting the national wholesale purchasing price. Eventually, the two major utilities agreed, the first, to limit the price of power produced in Sicily (a bid cap) to €190 per MWh in 2011, and the other to set prices based on market [9].

Nevertheless, it was only in February 2015 that the Sicily's zonal price fell below €10/MWh over the PUN, never exceeding that threshold again during the subsequent 13-months (until February 2016), even falling *below* the PUN by €1.51/MWh on July 2015 (Fig. 1).

The trends of absolute monthly power prices, PUN and Sicily's zonal price share few key features, such as the spikes in 2008 and the sustained downward trend after 2012 (Fig. 2). Again, the closing gap between Sicily's and Italy's prices becomes apparent since early 2015.

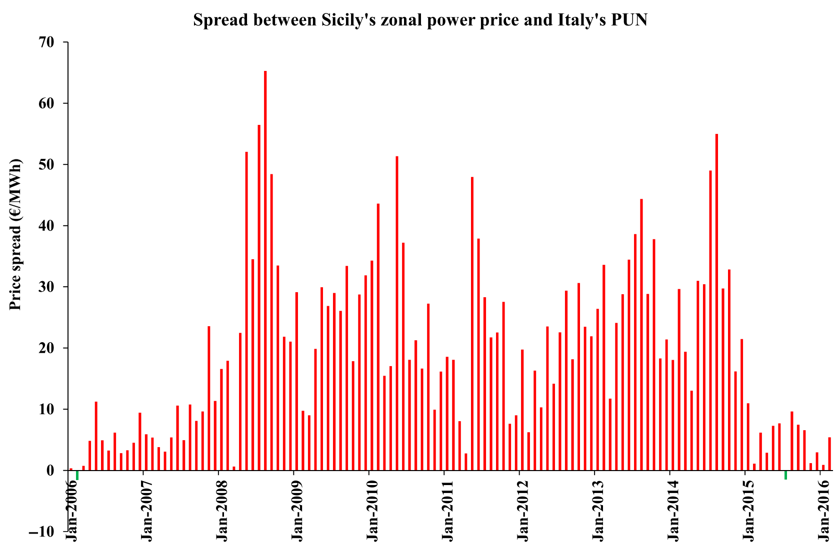


Figure 1. Spread between monthly average Sicily's zonal power price and Italy's PUN. Positive spread in red, negative in green. Source: Energy Markets Authority (GME).

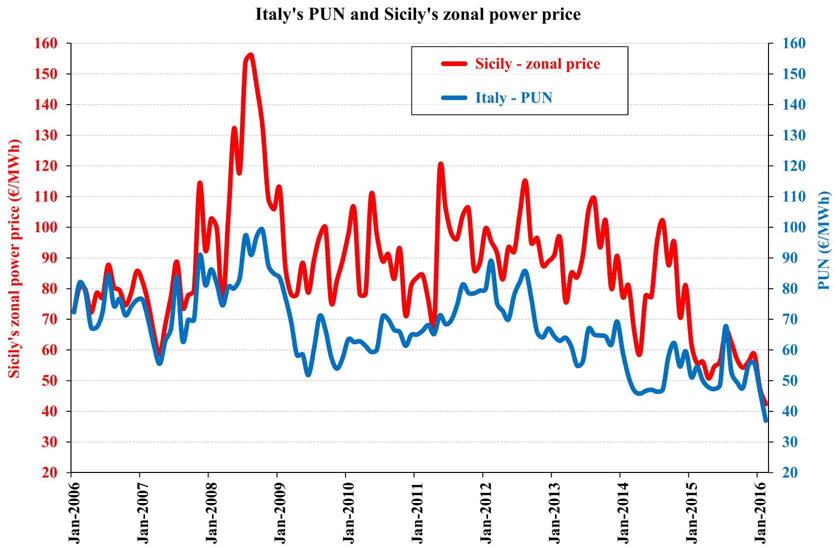


Figure 2. Yearly average prices on the day ahead market in Italy (PUN) and in the Sicily's zone. Source: Energy Markets Authority (GME).

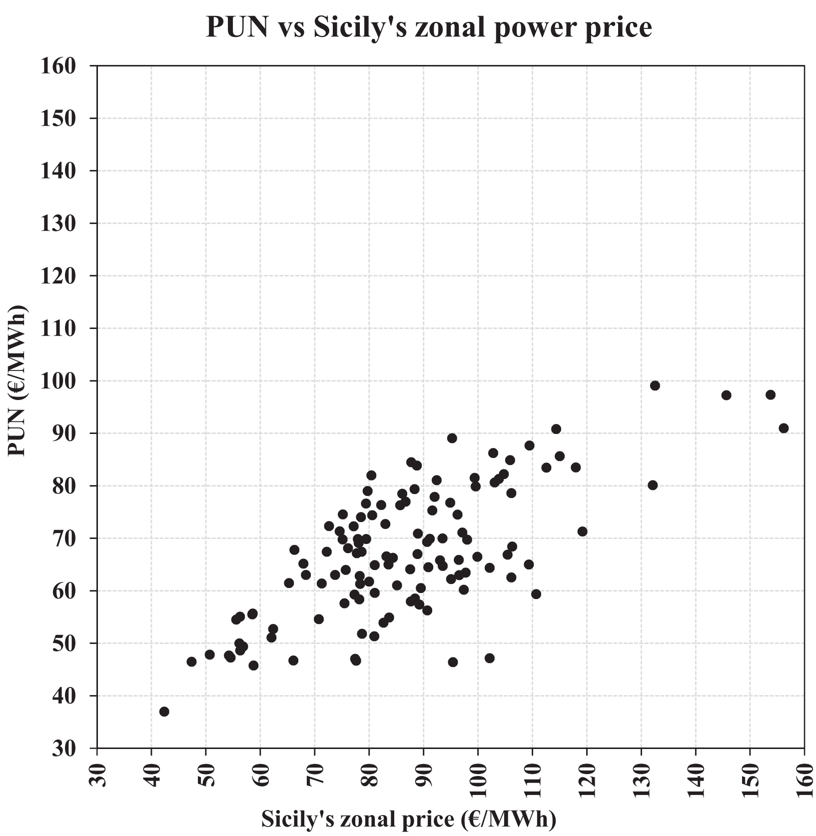


Figure 3. Sicily's zonal power price explains 50% of the variance of the national wholesale price (PUN).

The linear correlation between the PUN and the Sicily's zonal price is especially noticeable, since as much as 50% of the variance of the former is explained by the latter, as shown in Figure 3, a value which is not so distant from the correlation figure found for the peak PUN (wholesale power price during peak hours) model using an autoregressive term, without which the correlation strength fell below 60% [7].

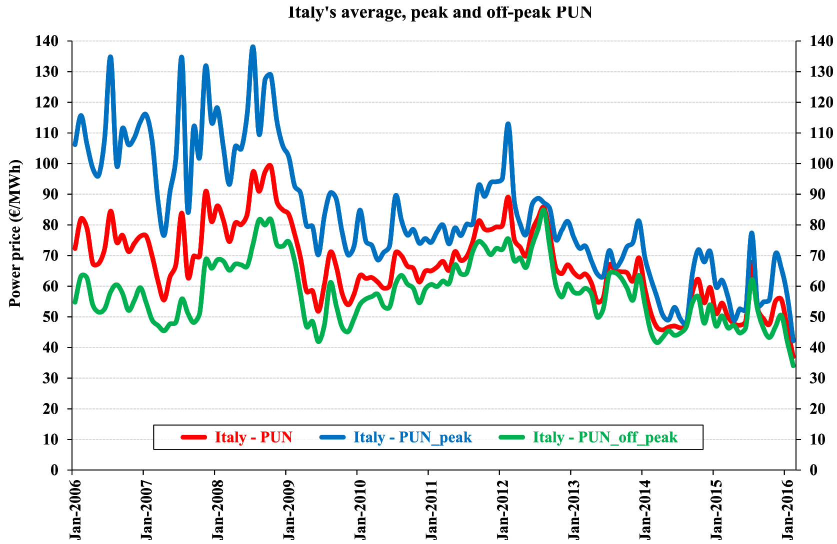


Figure 4. Italy's average, peak and off-peak wholesale power price (PUN). Source: GME.

Power prices formed in the Sicily's zone obviously reflect the impact of the changing prices in raw fuels such as oil and natural gas needed to feed conventional generation plants, and changes in the regional power demand. The closing gap between peak PUN (when most of the demand occurs) and off-peak national prices shown in Figure 4 may be attributed to the growing national generation from renewable sources, mainly PV due to its straightforward impact upon the peak diurnal demand in the merit-order price formation scheme [7].

In the year 2015, while the overall contribution of the renewable energy sources (hydroelectric, wind and PV) to the domestic power generation fell to 33.2% from 37.9% in 2014, mainly due mainly to significantly lower (−24.9%) hydropower generation, the PV production increased by as much as 13%, totaling almost 25 TWh, that is more than 55% of the hydropower and exceeding 9% of the domestic generation (8% in 2014) [10].

It was previously shown that the PV generation affects the peak PUN more than the other renewable sources [7], therefore contributing to close the gap between peak and off-peak PUN. Figure 5 shows the yearly series of PV and wind power generation in Italy where, after the sharp increase from 2010 to 2013, a slower yet sustained upward trend persisted until early 2016.

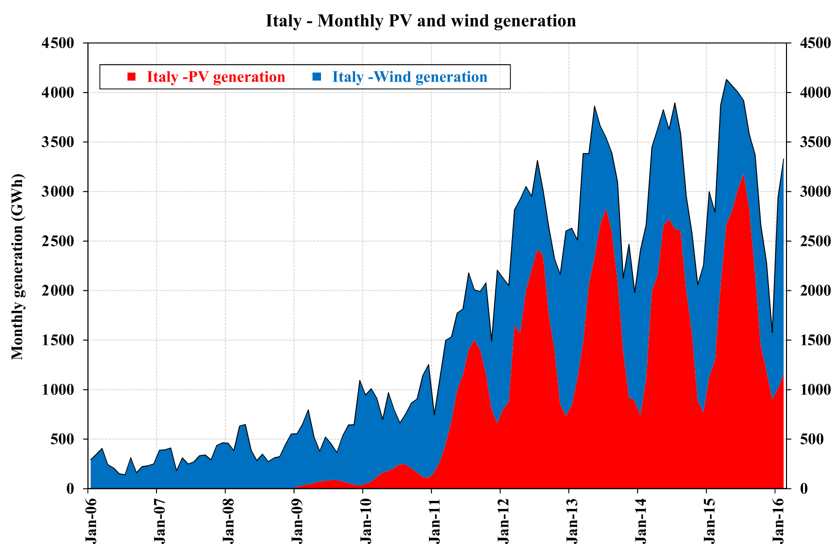


Figure 5. PV and wind power generation in Italy. Source: Terna.

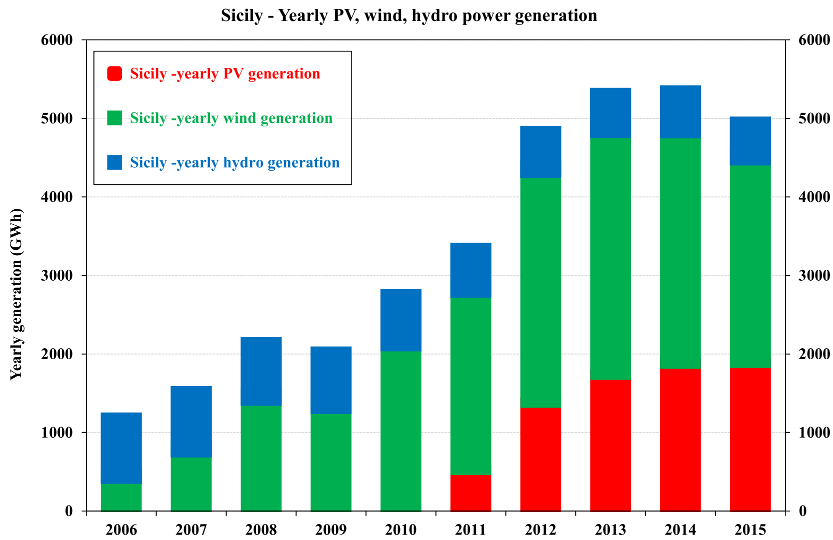


Figure 6. PV, wind, and hydro power generation in Sicily. Source: Terna.

A reputed market research company concluded that, thanks to the renewable energy boom, Italy's electricity market now faces a dramatic overcapacity, with the largest utility having announced closures of several plants for at least 11 GW of capacity, and the fifth largest producer exiting the market with sale of its thermo-electric assets [11].

In this context, in 2013 – following a sharp increase the year before – the amount of renewable energy produced in Sicily exceeded for the first time the threshold of 5 TWh, namely almost 25% of the about 23 TWh produced and fed into the grid [2]. Such a threshold was exceeded in each of the subsequent 2 years, despite a noticeable climatically-forced drop of wind and hydro contributions in 2015, which were partially offset by the slowly increasing PV generation (Fig. 6) [3, 4].

Following the early drop occurring as a consequence of the economic crisis during 2008–2009, both Italy's and Sicily's power demands underwent sustained fall starting in 2012. Yet, while the former halted in 2015, demand of electricity in Sicily nosedived, hitting the 11-years lowest point in February 2016 (Fig. 7). No wonder, therefore, that the historically lowest price was observed in the same month, in its turn helping to explain the partly unexpected record low PUN as a result of the steering effect of Sicily's zonal power price (Fig. 2).

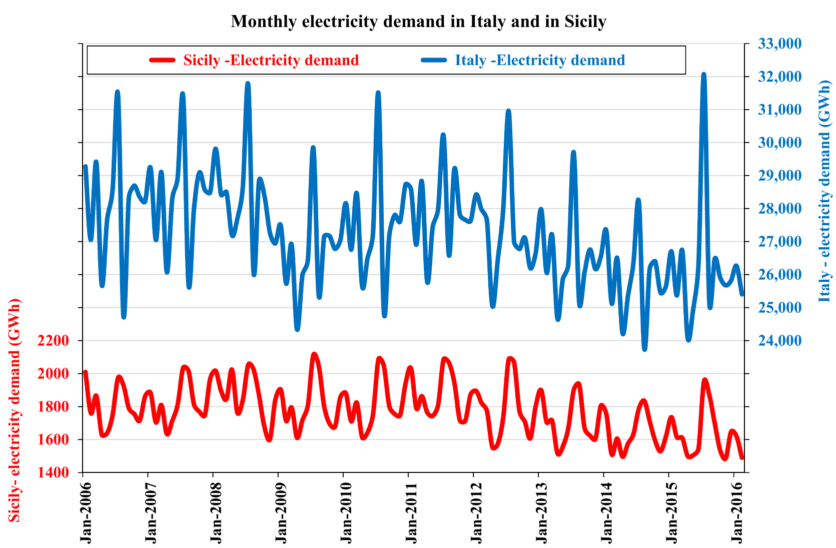


Figure 7. Monthly power demand in Italy and in Sicily. Source: Terna.

In view of the above-mentioned drastic regulatory intervention upon the formation of the zonal power price in Sicily, defining a statistical model linking the monthly Sicily's regional power price with local demand, renewable generation and conventional fuel price, as was done for the Italian market as a whole [7], de facto is impracticable. Nevertheless, there is room for a modeling effort on a daily basis over periods encompassing different seasons, that is, different compositions of the power generation mix, with particular reference to the PV share of the overall generation mix. This is the subject of the next Section.

Impact of Solar and Wind Power Generation

Aiming to show the remarkable impact of solar and wind electric generation in Sicily (and in Italy), we focus on the zonal and national prices of power in the course of the first 6 months of 2015. Prices on the day-ahead market for both Sicily and Italy were collected from GME [12], the manager of the Italian energy markets.

As expected, during the first half of 2015, different climatic conditions affected Sicily, leading to strong changes of solar PV and wind power generation superimposed to

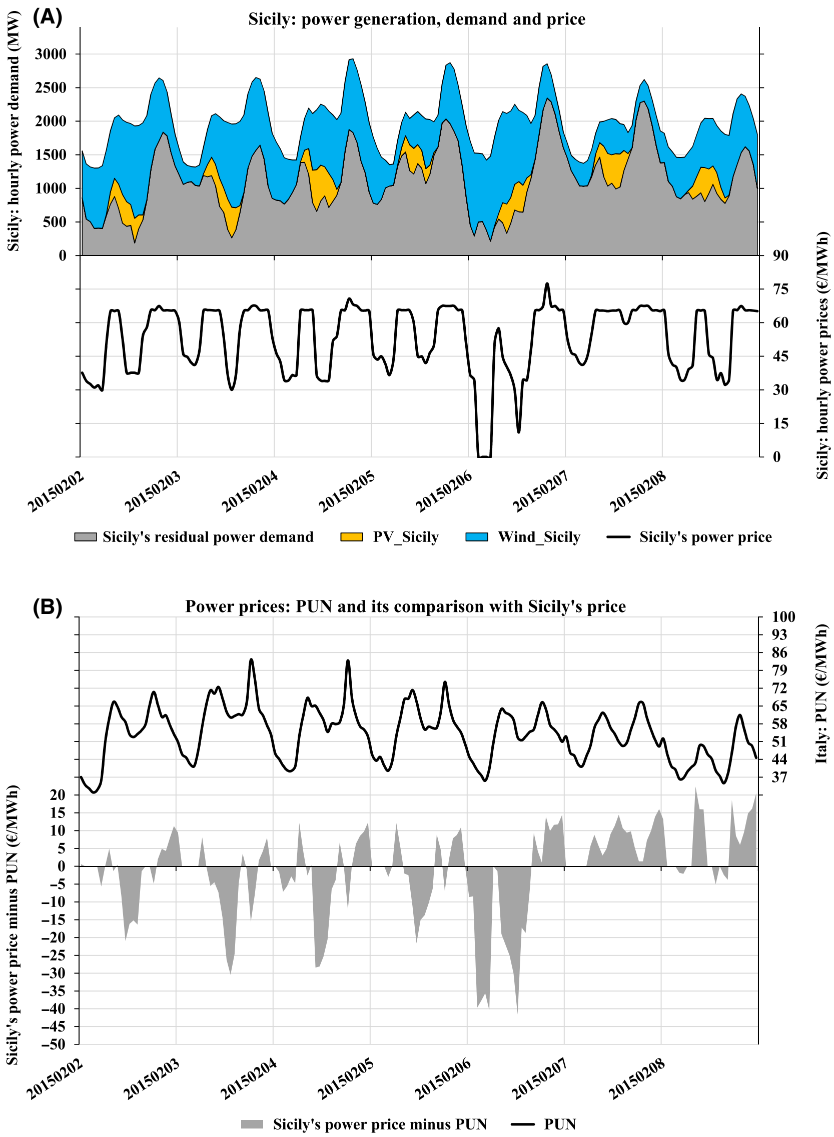


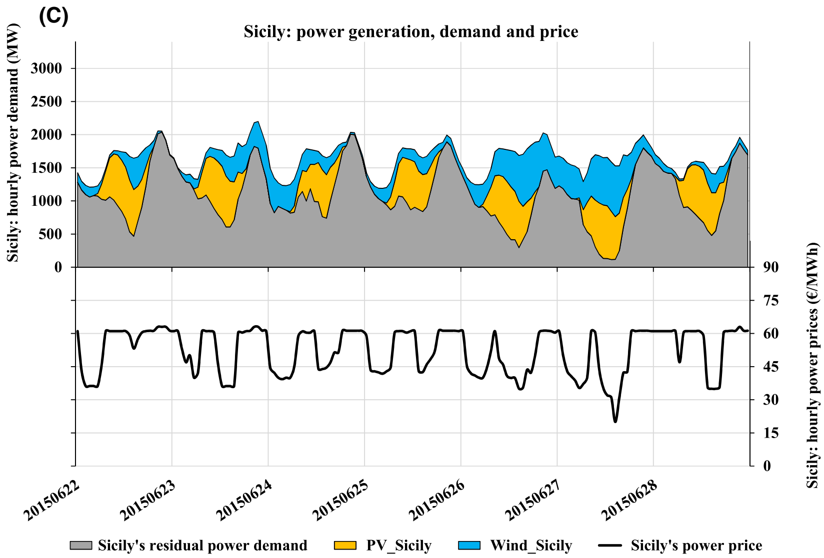
Figure 8. (A) Solar PV and wind hourly power generation superimposed to the residual power demand in Sicily, along with the respective power zonal price in the first week of February 2015; (B) national wholesale power price (PUN) along with the difference between Sicily's power price and PUN in the first week of February 2015. (C) Same as (A) but for the last week of June 2015; (D) same as (B) but for the last week of June 2015.

the daily cycle. Looking at the first week of February (Monday to Sunday) when wind generation was far higher than solar PV generation, Figure 8A shows that the residual electricity demand, that is, demand resulting after subtracting from the total the renewable (solar PV and wind) power generation, is correlated with the zonal power prices on an hourly basis. In other words, price grows along with residual demand, both during day and night, not only during working days but also during the weekend.

A further comparison between the values of Sicily's zonal power price and the national wholesale price during the same week (Fig. 8B) shows that low residual demand in Sicily leads to zonal prices lower than PUN, thereby lowering the national electricity bill.

In Italy, the national power price is formed in the day-ahead market, which works as a periodic multi-unit price auction [13]. The GME uses a merit-order principle to construct and aggregate the supply and demand curves. If electricity flows through the grid violate the transmission constraints (as it happens every day), the market is split into zonal areas: North, Center North, Center South, South, Sardinia and Sicily. Power-generating companies receive the zonal prices, whereas buyers pay the *Prezzo Unico Nazionale* (PUN) which is the average of the zonal prices, weighted by the zonal electricity consumption levels.

Similar results concerning residual electricity demand and zonal hourly power prices were observed during the



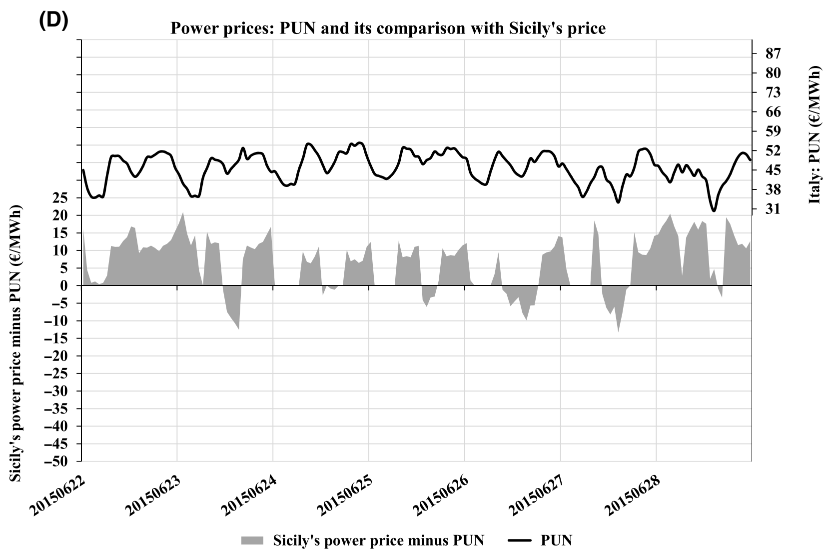


Figure 8. (*Continued*)

last week of June 2015 (Monday to Sunday), when solar PV generation was generally higher than wind-derived generation (Fig. 8C).

However, the substantially lower PUN values due to widespread solar PV generation across Italy, led to negative values of the difference between Sicily's zonal price and PUN only when the zonal residual demand fell below about 500 MW (Fig. 8D).

With reference to the same 2 weeks of 2015 in February and June, comparison between the hourly overall electricity demand in Sicily and Italy shows striking differences (Fig. 9). While the morning and evening peak demands are indeed comparable at the national level, in Sicily the evening peak is much larger both in February (Fig. 9A) and in June (Fig. 9B).

Moreover, the decrease in the electricity demand in Sicily during the weekend is much smaller than in Italy. Both these outcomes show evidence of the general lack of widespread significant industrial activities in Sicily, where three large, energy-intensive oil refineries and two petrochemical parks are installed in northern (Milazzo) and southern Sicily (Gela, Augusta and Priolo Gargallo), working in the continuous mode, independently of regular or weekend days of the week.

Widening the analysis to the whole period 1 January 2015 through 30 June 2015, the relationship between the

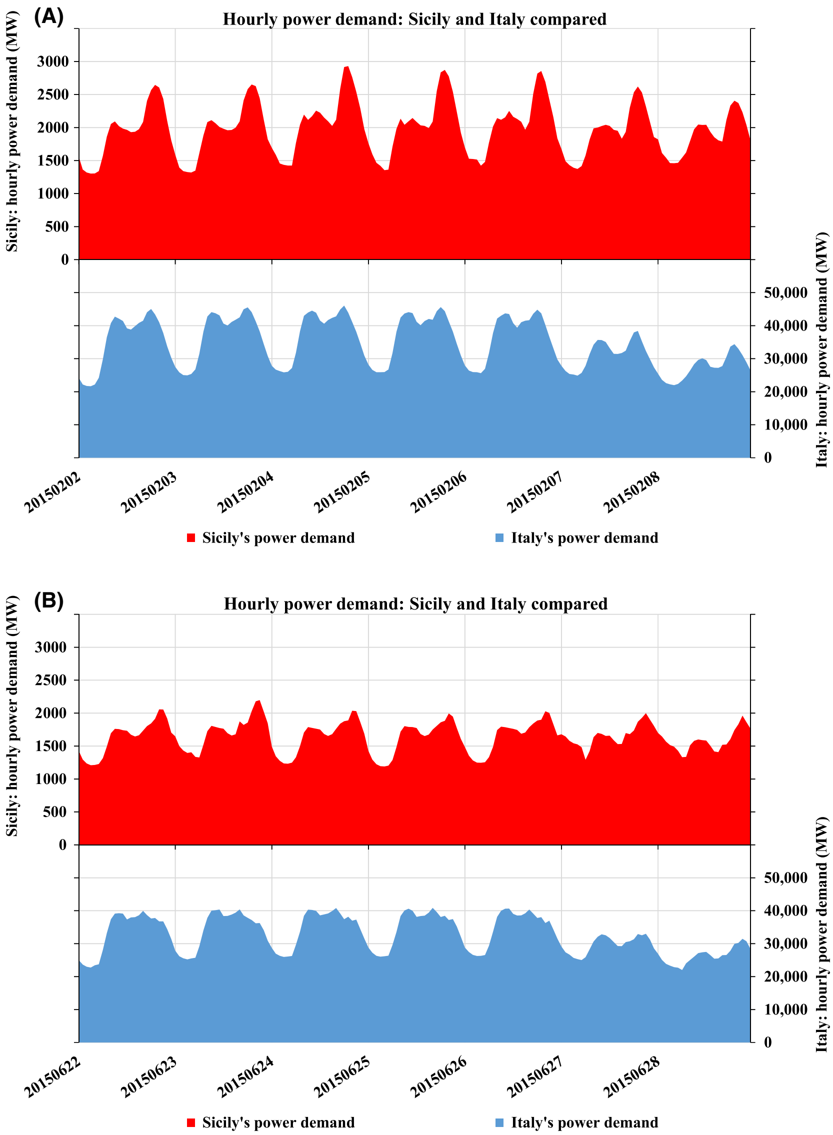


Figure 9. (A) Hourly series of power demand in Sicily and Italy in the first week of February, 2015. (B) Same as (A) but for the last week of June, 2015.

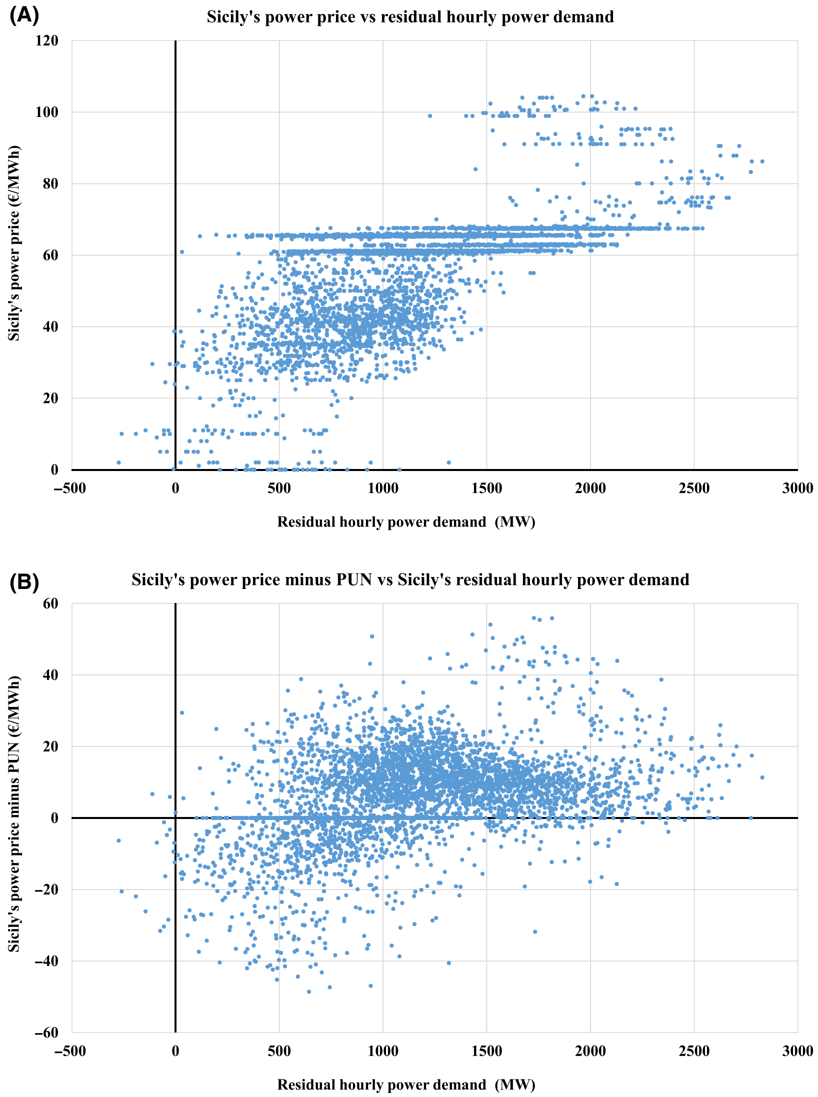


Figure 10. (A) Power price in the Sicily's zone against zonal residual electricity demand; (B) difference between Sicily's zone power price and national wholesale power price (PUN) against zonal residual electricity demand.

Sicily's zonal price and the zonal residual electricity demand, that is the remaining demand after subtraction of solar PV and wind generation, becomes apparent from the plots shown in Figure 10.

Most Sicily's zonal prices fall below the €40/MWh threshold when the residual demand lies below 500 MW (Fig. 10a). Similarly, during the hours in which the residual demand of electricity in Sicily is not generated by renewable sources lies below the same 500 MW threshold, the zonal prices lie below the PUN (Fig. 10B).

In order to outline a more homogeneous statistics, the power prices in the Sicily's zone were averaged across the values observed in six classes of the residual demand.

Figure 11 shows the results along with the standard deviation associated to the average price in each class. Best fit to this curve is a monotonic, logarithmic increase in the zonal price with the residual demand (eq. 1, where price is in €/MWh and the residual hourly demand is in units of MWh) explaining about 98.7% of the sample variance:

$$\text{Sicily's hourly zonal price} = 21.6\ \ln(\text{Residual hourly demand}) - 93.1. \tag{1}$$

Electrification of Energy End Uses

It is now well understood that the beneficial effects of PV generation onto wholesale electricity price formation rapidly increase with electricity demand [7]. Hence, to allow further reduction in the cost of electricity in both

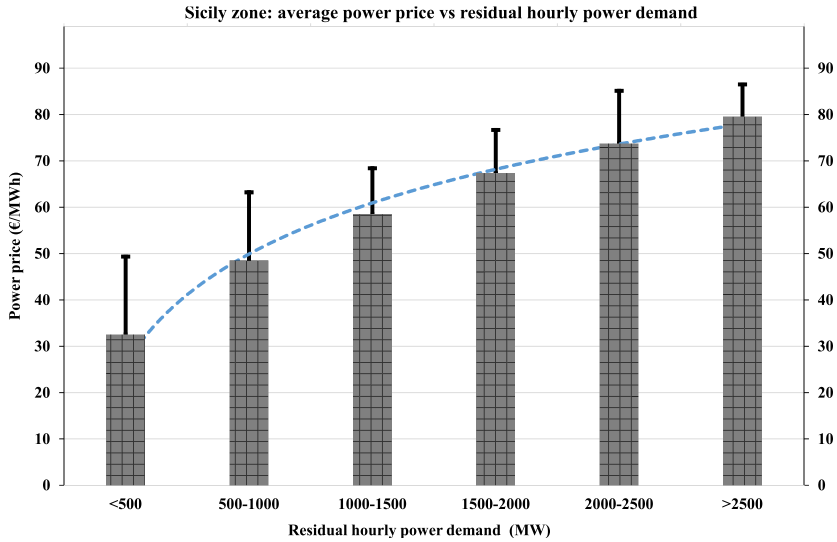


Figure 11. Average power price in the Sicily's zone in classes of the residual electricity demand.

Sicily and in Italy, it is important that the power demand in Sicily returns to grow.

Nevertheless, the contrary occurred both in Sicily and in Italy since 2007, as shown in Figure 7, down to unprecedented low consumption, which weakens the efficiency of solar PV generation concerning its ability to lower the power prices according to the merit-order price formation scheme.

In brief, policy makers in Sicily should boost the electrification of the energy end uses [14], as it happened recently with the new train connection linking the two main cities of the island (Palermo and Catania), as well as replacing obsolete heating systems based on burning natural gas, with much more efficient heat pumps in both residential, commercial, industrial, and public buildings.

Furthermore, new legislation should be passed and aimed to promote the use of pumping storage as an ideally suited option to store the excess of renewable PV and wind energy, using the associated significant (600 MW) hydroelectric capacity installed in Sicily [15].

Of course, electrification means also the adoption of storage systems on a large scale: because of its poor interconnection with Italy's grid, Sicily cannot rely on neighboring regions to balance short-term fluctuations in its grid.

For that reason, the owner of Italy's grid (Terna) has built the new "Sorgente-Rizziconi" and Sicily–Malta cable connection lines, and is adding new storage capacity in Sicily (using lithium-ion batteries) to make the existing grid more flexible, and thus more stable [5].

Conclusions and Perspectives

The analysis of the wholesale electricity prices in Sicily and in Italy reported in this study shows large, positive changes in Sicily's and Italy's electricity markets, due to significant penetration of new renewable energy sources, namely solar PV and wind energy. In 2015, the historical spread between Sicily's electricity zonal price and the national price (the PUN) eventually vanished, occasionally assuming negative values.

Furthermore, the zonal price has been shown to increase with the electric demand not met by renewable energy, according, as we find out, to a log-normal equation.

The forthcoming inauguration of the new 3000 MW high voltage connection between Sicily and the rest of Italy will only enhance such impact that so far has been restricted by the easily saturated 1000 MW existing connection.

Consistently lower values of the electricity national price (the PUN) will be achieved, especially during the sunniest months of the year when the electricity peak demand that has recently surpassed winter's demand (56,883 MW as of 8 July 2015) is met in large part by concomitant PV generation (40% of the above-mentioned peak of July 2015) [16].

Electrification of energy uses is slowly, but inevitably, taking place along with the global solar energy revolution [17].

Railway transportation in Italy, including Sicily, is knowing a renaissance with new high speed trains, new tram and new underground lines. The use of heat pumps in place of conventional heaters to produce low temperature heat is similarly undergoing a slow yet sustained growth [18], starting from large commercial buildings. The ongoing boom of electric bikes and motorbikes is prodromal to the forthcoming diffusion of electric cars [19].

Under these conditions, the reshaping of Sicily's and Italy's electricity market will continue. Investing in the electrification of energy user needs will translate into further economic (and environmental) benefits not only for Sicily's but also for all Italy's electricity consumers.

Acknowledgments

This article is dedicated to Daniele Tringali, eminent engineer at AMG Energia, whose daily engineering and management work does citizen's good in the city of Palermo.

Conflict of Interest

None declared.

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