WHERE HAS ALL THE POWER GONE? A HEALTH CHECK OF ITALIAN SOLAR ELECTRICITY IN 2016

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ABSTRACT: In 2015 Italy had a level of PV penetration >8%. However, as reported by professionals and the specialized press with sometimes alarmist tones, solar electricity generation in 2016 has been much lower compared to 2015. With final 2016 data now available, we give a closer look at the aggregate data and calculate some Key Performance Indicators (KPI) for the whole country and for each region to assess the health status of solar PV electricity in Italy twelve years after the start (2005) of the feed-in-tariff subsidy scheme. At country level, the 2016/2015 relative variation in final yield Y_f is - 5.4%. About 80% of this variation can be attributed to a lower insolation in 2016 compared to 2015 (-4.3%). The remaining losses are reflected in the –1.1% PR relative variation (2016/2015) and can be attributed to a mix of factors: degradation in performance (system/components), moderate use of O&M, etc. At country level, the average PR is below 70%. This low value is partly attributed to the fragmentation and small average size of PV systems in Italy (~ 28 kWp in 2016), to their non-optimal orientation/inclination and to presence of shading. Other reasons, linked to the dynamics and features of the national feed-in tariff incentive schemes are briefly recalled. We further note, that the alarmist tones circulated about the pronounced decline in generation of solar electricity in 2016, are not justified. On the contrary, 2015 has been a year with an availability of solar resources considerably higher than 2016 and of the long-term average. Nevertheless, still concerns about the actual (and long-term) performance of the Italian solar park as a whole exist.
Keywords: PV system, operation, performance, reliability

1 INTRODUCTION

With a share of 8.4% of electricity generation covered by solar electricity, in 2015 Italy has become the country with the highest penetration of photovoltaics (PV) into its electricity mix [1]. In 2016, Italy has added ~+370 MWp of capacity totaling an overall installed capacity of 19.3 GWp. During year 2016, however, professionals and the specialized press (see e.g. [2, 3]) has reported with quite alarmist tones a considerable decline in production of PV electricity generation in Italy. Provisional figures from Terna (Italian power transmission company) for 2016 were in fact reporting a strong decrease in the electricity production from PV (-10%, 2016 vs 2015 for the period January-September) [4]. A different analysis from GSE [5] covering the first eleven months of 2016 on a subset of plants (~7 GWp of size >55 kWp, corresponding to ~36% of the total) pointed out an year-on-year decline in PV production of -4.6% (2016 vs 2015 for the period January-November).

Now that the final figures for 2016 are confirmed, we analyze year-on-year variations in solar resources at country and a regional level and compute a set of Key Performance Indicators (KPIs) for the whole country and for each distinguished region using aggregate values. These include the Final Yield Y_f and the Performance Ratio PR. The assessment of solar resource for Italy was carried out using a satellite model developed by *Solargis*.

We finally discuss the factors leading to a potential underperformance of Italian solar PV in its entirety, and how these factors are strongly linked to the dynamics and features of the national feed-in tariff incentive schemes in place from 2005 to 2013.

2 SOURCES AND APPROACH

2.1 Input data

In this paper, we make use of official figures released by *Gestore Servizi Energetici* (GSE, the Italian public company in charge of managing subsidies to renewables) for statistics related to Italian solar PV [6, 7].

Country's electricity generation and consumption data are obtained by *Terna* (Italian transmission system operator TSO [8, 9]), and insolation data for 2015, 2016 and long-time averages (1994-2016) by *Solargis* [10, 11, 12].

The inputs to the Solargis model are multispectral satellite images from Meteosat satellite and atmospheric parameters like aerosols and water vapour. Spatial resolution of Meteosat data considered in the calculation scheme is approximately 3 km at sub-satellite point. Model results are served in 2 arc-minutes (app. 4x4 km) regular grid in WGS84 geographical coordinate system. For the purpose of this study, the spatial resolution of solar data products is enhanced to 15 arc-seconds (nominally 500 m) using digital terrain model comprising a combination of data from the Shuttle Radar Topography Mission. The primary temporal resolution of satellite data is 15 min. The atmospheric parameters are updated daily. The air temperature at 2m data is derived from the NOAA Climate Forecast System, with spatial resolution of approximately 20 km and temporal resolution of 1 hour.

For simplicity, in this work we use, for the whole country and for each region, the yearly sum of Global Tilted Irradiation (GTI) calculated at 25°-tilt. This, rather than using GTI calculated at optimal tilt, introduces a slight underestimation in the effective availability of solar resources (~1.5% and ~0.4%, respectively, for the

Northern and Southern part of the country) and, consequently, a moderate overestimation of the same magnitude in the computation of the PR.

For a south-facing installation, the optimal tilt would be 36°, 34° and 30°, respectively, for Milan, Rome and Palermo.

2.2 Key performance indicators

We make use of two KPIs, which are generally used at the solar plant/array level, and that, utilizing aggregate average values, we use to compute country and regional performance indicators. These are:

(1) the *final yield* Y_f **(**kWh/kWp): i.e. the annual net AC energy output E_a [kWh] of a system divided by the peak DC power P_{STC} [kW] of the installed PV array at standard test conditions (STC: 1000 W/m^2, 25°C, AM1.5):

$$Y_f = E_a / P_{STC} \qquad (1)$$

Y_f is a direct function of the cumulative irradiation (i.e. higher Y_f should correspond to sunnier regions) and, therefore, it generally depends on the latitude as well.

(2) the *performance ratio PR* (%) is an index illustrating the overall effect of losses on the system/array's rated output due to device temperature, incomplete utilization of the irradiance (e.g. due to shading or non-optimal orientation), and system component inefficiencies or failures [13]. It provides an indication of how a system effectively performs under real operating conditions, compared to how it would be operating if it were constantly exposed to standard laboratory (STC) ones.

$$PR = (E_a \times G_{STC}) / (Ha \times P_{STC}) \qquad (2)$$

with G_{STC} [kW/m^2] the irradiance at STC (1000 W/m^2), and H_a [kWh/m^2/y] the yearly cumulative irradiation. In this work, for H_a we use the Global Tilted Insolation at 25° tilt (GTI-25°) for the whole country and for each separate region.

3 RESULTS

3.1 Deployment of solar electricity in Italy

Figure 1 shows the historical deployment of solar PV in Italy since the start of the national feed-in tariffs scheme (*Conto Energia*) in 2005 (see Table I as well). The figure shows cumulative and newly added PV capacity per year and the average size of PV plants, which is larger in Southern Italy (~35 kW), rather than in the central (~28 kW), and northern part of the country (~21 kW). In 2016, in fact 91% of the plants have a size ≤ 20kW, whereas 60% of the PV capacity corresponds to installation with a size > 200 kW. The *Conto Energia* incentive scheme ended in 2013 and has had a boom of new installations in year 2011, with a peak of newly added capacity in this year (~9.5 GWp).

At the end of year 2016, the weighted average age of the Italian solar PV park (considering 0.5 years increments) is of 5.2 years.

3.2 Solar resources in Italy

Figure 2 shows the GTI at 25° tilt calculated by *Solargis* for the whole country and for each region for years 2015 and 2016, together with the long-term average (1994-2016). These data clearly indicate that for nearly all regions (and for the whole country) the annual insolation has been remarkably higher in 2015 rather than in 2016, and that GTI values for 2016 are more aligned to the long-term average.

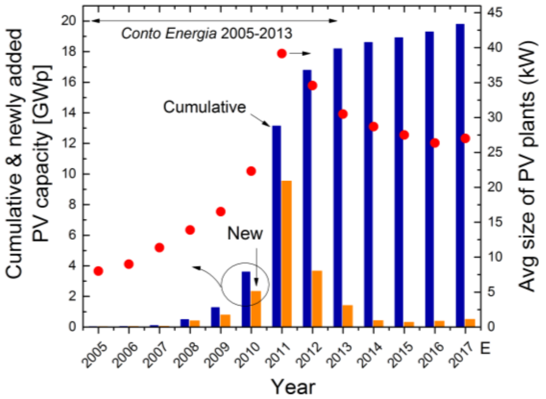

Fig. 1: average size of PV pants, cumulative and newly added PV capacity in Italy since 2005

On average, at country level 2016 has had -4.4% less GTI than 2015. More specifically, as can be observed in inter-annual variability map for Italy showing the relative difference in GTI (2016 vs 2015, see Fig. 3):

- In central and Northeast regions (e.g. Umbria, Abruzzo, Veneto, Friuli-Venezia Giulia) GTI in 2016 was on average -6% lower than in 2015. In some Southern regions and islands (Calabria, Sicilia, Sardegna) it was lower than -3%;
- Locally (particularly along the Apennines and in parts of Veneto) the drop was higher than -8% or even -10%;
- Only very rarely the year-on-year difference was positive (e.g. in Southern Calabria, along the coastal region of Toscana or in Piemonte).

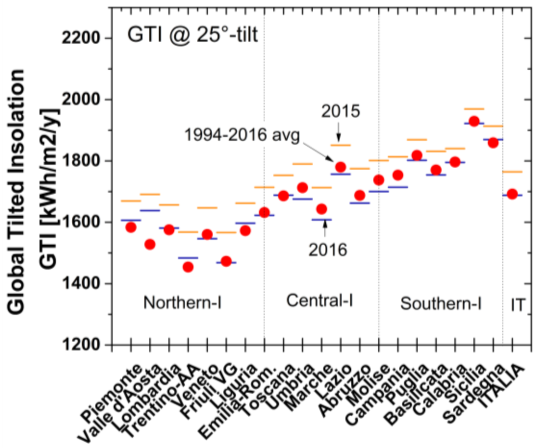

Fig. 2: global tilted irradiation (GTI, kWh/m^2/y) at 25° tilt for all Italy and its regions in 2015 and 2016. The long-term GTI average (1994-2016, dots) is shown as well.

3.3 Key performance indicators

In Fig. 4 we show the calculated final yield Y_f and performance ratio PR for each region and for the whole country in years 2015 and 2016. The PR is calculated using GTI values at 25°-tilt, which, as previously observed in Section 2, leads to a slight overestimation of this indicator. To compute regional and national Y_f and PR we do not use the total PV capacity (GW_p) available at year's end, but we make use of what we call *adjusted PV capacity* (kW_p): i.e. the available PV capacity at the end of the year minus half of the newly added PV capacity in the specific year.

The use of this parameter should promote a smoother match between the newly-added capacity (MW) and the electricity generation (MWh) from the new installation in a given year. This adjustment works well under the assumption that the rate of new installations is constant over the year, which has been the case in years 2015 and 2016 (see [6, 7]), and which has presumably been the case for the years (after 2013) when new installations could not benefit from feed-in-tariff-like incentive schemes (*Conto Energia*). On the contrary, this newly-defined parameter can only partly mitigate this mismatch for the previous years with booming installations, when a rush to connect the new installation to the grid towards the end of the year has frequently been reported, and, therefore, no constant rate of new-added capacity over the year can be assumed.

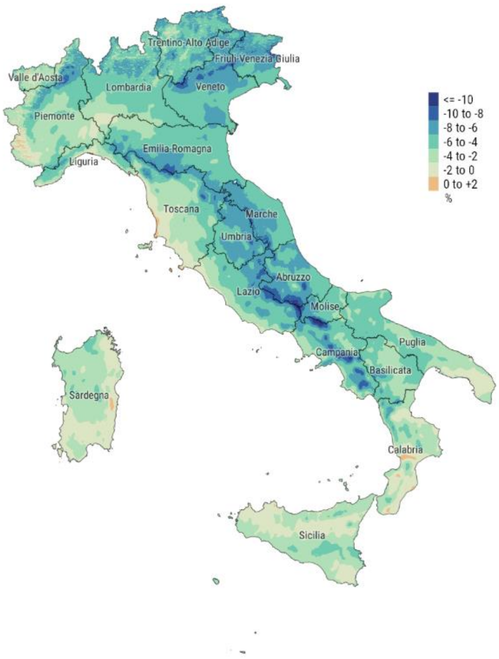

Fig. 3: inter-annual variability map of solar resources for Italy showing the relative difference between GTI ($kWh/m^2/y$) at 25° tilt in 2016 vs 2015 data.

Due to the larger insolation in 2015 compared to 2016, the Y_f has been understandably higher in 2015 for all regions (with the exception of Valle d'Aosta) and for the whole country.

Similarly, for most regions and for Italy the PR has been higher in 2015 rather than 2016. For this parameter, which should be uncorrelated to the annual cumulative irradiation, the trend is, however, less clear with some regions exhibiting a higher PR in 2016.

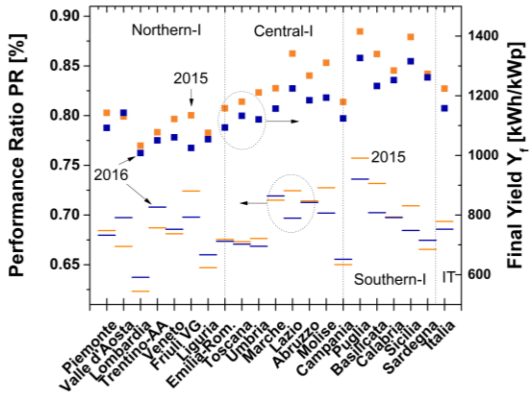

Fig. 4: performance ratio PR (lines) and final yield (squares) for years 2015 and 2016 for Italy and for each region.

4 DISCUSSION

From the long-term average GTI data in Fig. 2 (regions and country), we note that the insolation in 2016 has been more in line with the historical availability of solar resources than 2015, a remarkably sunny year. So that the previously mentioned alarmist tones about the decline in production of PV in Italy in 2016, are not justified.

On the other hand, from Fig. 4 and Table I, we observe that for the whole country between 2015 and 2016 the electricity generation from PV and the average final yield have decreased by -3.7% and -5.4%, respectively. About 80% of the decline in Y_f in 2016 with respect to 2015 can in fact be ascribed to the lower GTI (- 4.3%), but still the decline in GTI does not explain the full discrepancy. This is reflected in the lower country average PR with a -1.1% decline in 2016 compared to the previous year.

We further note that the country average PR is below 70% (68.6% in 2016), a value that is well below the 80-85% value exhibited by well-functioning and properly maintained PV plants. Furthermore, in Fig. 4, we observe that, at regional level, some outliers exist. Regions with the lowest PR are Lombardia, Liguria, and Campania. Puglia, the region with largest average size of solar plants (~58.8 kW in 2016), exhibits the highest PR.

If we consider the country average PR, this is a value reflecting the average performance of the entirety of solar PV installations (>732'000 in 2016) and simultaneous contributions from well and poorly designed/performing/maintained PV plants.

As the average size of PV plants in Italy is relatively small (~27 kW, see Figure 1), these numbers include contributions from a vast majority of small-scale PV plants that, more frequently than larger scale ones, may suffer from non-optimal orientation/inclination, shading, sub-optimal selection of components, poor design practices, malfunctioning, limited use of operation and maintenance (O&M) services.

As previously mentioned, in the booming years of PV in Italy (until 2012) fostered by the *Conto Energia* incentives, a rush in terminating installations by year's end has frequently been reported. This often at the expense of overall system quality.

In addition, there exist anecdotal evidence that the quality of some components (particularly modules and inverters) available in years of high demand in the Italian/European market is sometimes below standard, leading to a severe underperformance of the corresponding installations.

The combination of these reasons could explain most of the relatively low performance of Italian solar electricity when considered in its entirety.

We are not able, however, at this stage to assess the impact of the different contributions and to recognize if a accelerated long-term decrease in performance - beyond a physiological one - is taking place over the years. This would be the subject of a future work.

These evidences from the Italian experience about the correlation of overall PV quality with market dynamics and incentives could hopefully provide a constructive feedback to the several countries (particularly in sun-belt regions) that are about to design feed-in tariffs (or other incentive schemes) to promote a domestic diffusion of solar electricity. Overgenerous feed-in tariffs, combined with non-optimal timing and sharp year-end rate reduction mechanism will in fact generate distortion in the market, cause non-healthy temporal dynamics and considerably increase local market prices for solar PV; and, not ultimately, possibly cause the flow of often below standard components to the domestic markets.

Table I: figures of PV electricity generation, cumulative, newly-added and adjusted PV capacity, solar resources, country average final yield and performance ratio in Italy for years 2015 and 2016 (and relative variation).

Solar PV in Italy – all country	**2015**	**2016**	**2016/2015 relative variation**
PV Elec. Generation (GWh)	22’942	22’104 *	**-3.7%**
Newly added PV capacity (MW/y)	306.4	382.4	+24.8%
Cumulative PV capacity (MWp)	18'900.8	19'283.2	+2 %
Adjusted PV capacity (GWp)*	18'747.6	19'092.0	+1.8
Global Tilted Irradiation GTI at 25°-tilt (kWh/m2/y)	1’764.39	1’688.26	-4.3 %
**Avg Final Yield (kWh/kWp) ** **	**1’223.7**	**1’157.8**	**-5.4%**
**Avg Performance Ratio PR (%) ** **	**69.4**	**68.6**	**-1.1 %**

* The adjusted PV capacity takes into account only half of the newly added capacity per year.
**Rated to the adjusted PV capacity.

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Finally, we conclude with two general remarks:

(1) In 2016, a national average PR of 75% – which is a reasonable target - would have led to a +9.3% increase in solar electricity generation (corresponding to +2’070 GWh);

(2) The GTI figure of Fig. 2 do not include error bars, which are significantly large and that would be reflected in the corresponding uncertainty of the calculated PR figures. This will be the subject of a subsequent work.

5 CONCLUSIONS

At country level, the 2016/2015 relative variation in final yield Y_f is - 5.4%. About 80% of this variation can be attributed to a lower insolation in 2016 compared to 2015 (2016/2015 GTI: -4.3%).

The remaining losses are reflected in the –1.1% PR relative variation (2016/2015) and can be attributed to a mix of factors: degradation in performance (system/components), moderate use of O&M, etc.

At country level, the average PR is below 70%. This low value is partly attributed to the fragmentation and small average size of PV systems in Italy (~ 28 kWp in 2016), to their non-optimal orientation and to presence of shading. Other reasons, linked to the dynamics and features of the national feed-in tariff incentive schemes in place from 2005 to 2013, are briefly recalled.

We further note, that the alarmist tones circulated among professionals and in the specialist press about the pronounced decline in generation of solar electricity in Italy in 2016, are not justified. On the contrary, 2015 has been a year with an availability of solar resources considerably higher than 2016 and of the long-term average. Nevertheless, still concerns about the actual (and long-term) performance of the Italian solar park as a whole exist.

Finally, by having a look at regional PR values, we notice that some outliers are present: regions with the lowest PR are Lombardia, Liguria, and Campania, the region with the highest PR is Puglia, the region with the plant’s largest average size.

6 ACKNOLEDGMENTS

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