Supervision of the energy performance of multi-arrays PV plants by means of bi-monthly violin plots

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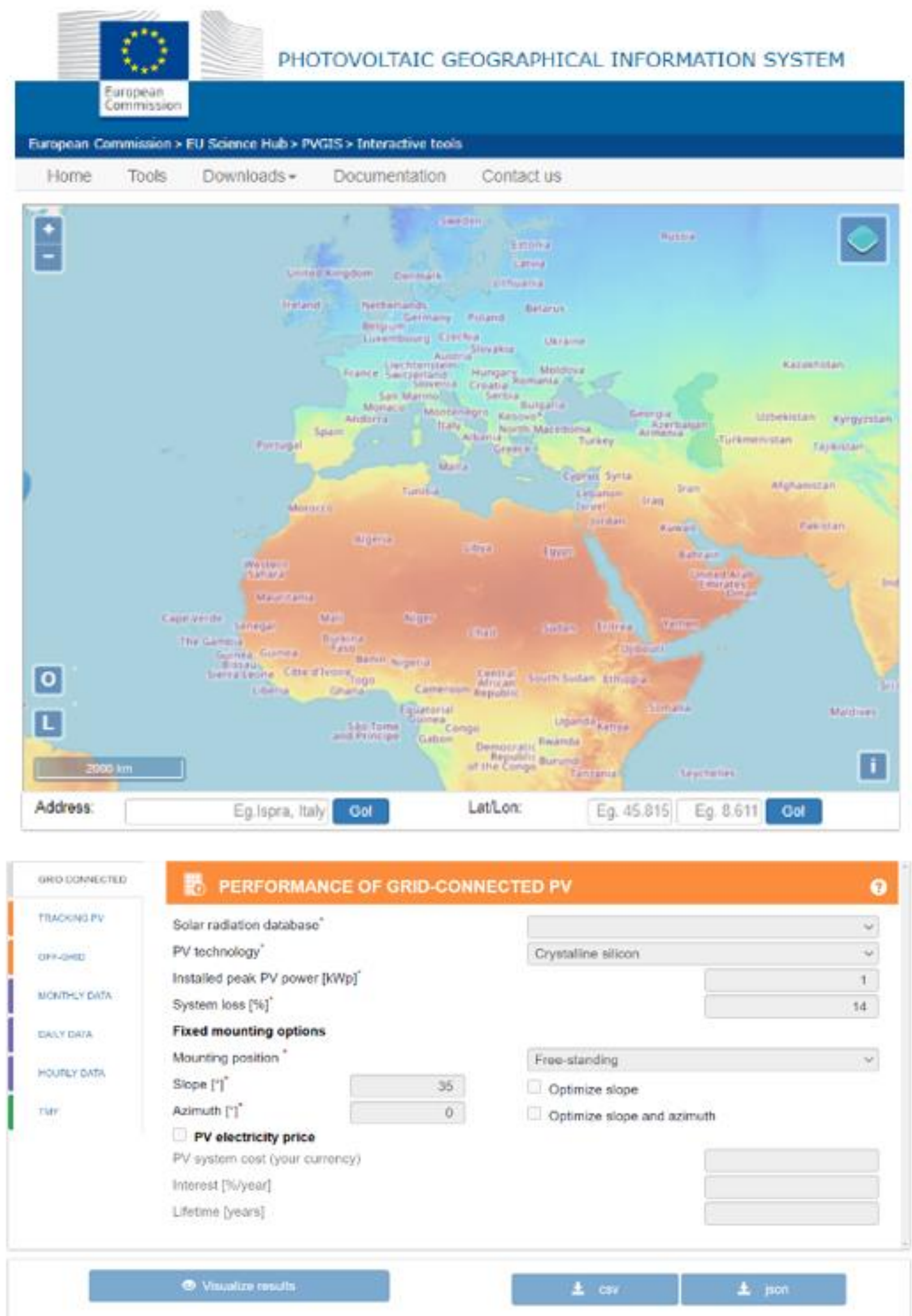

Fig. 1, Photovoltaic Geographical Information System (PVGIS), http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

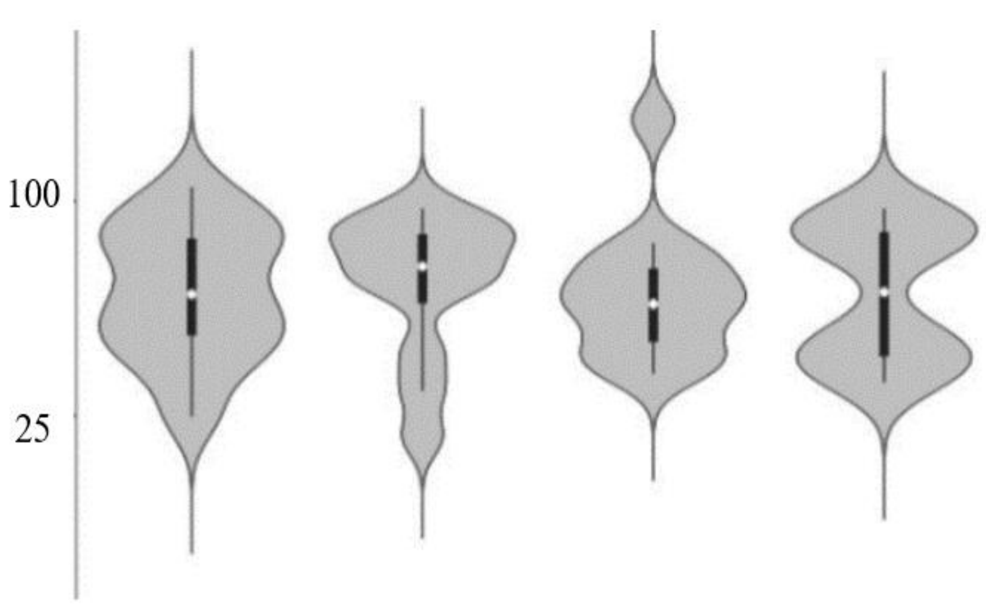

Fig. 2. Examples of violin plot: symmetric, skewed, with outlier, and bimodal.

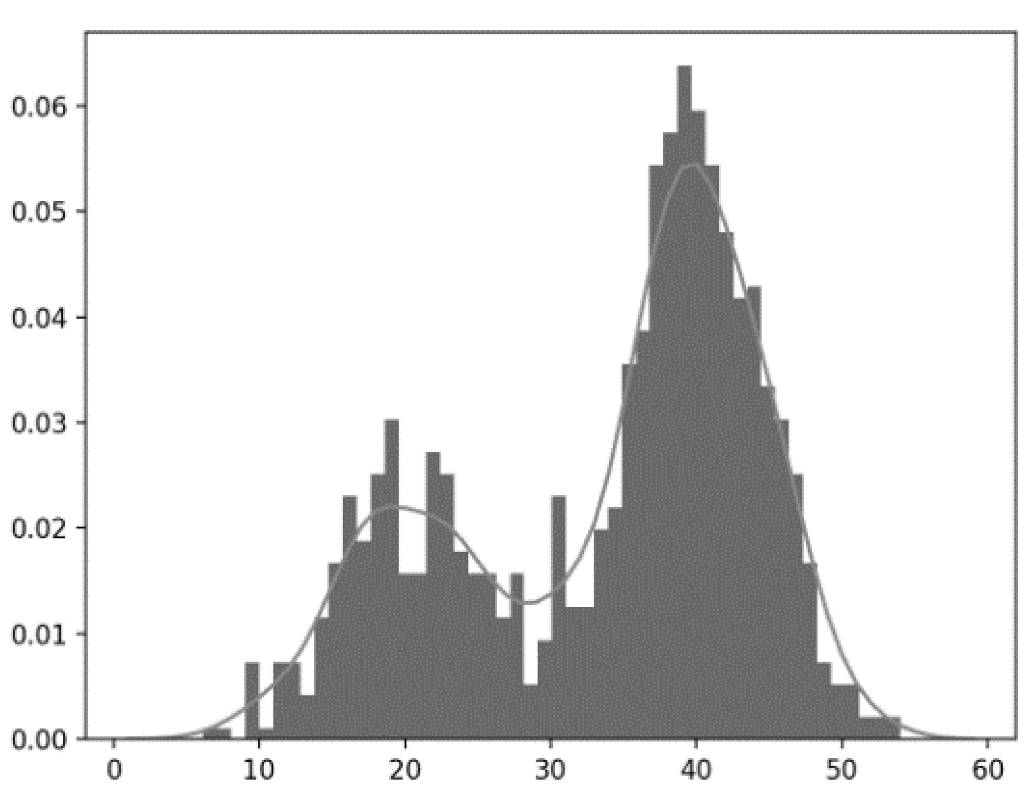

Fig. 3. Histogram with a KDE.

TABLE I. SPECIFICATIONS OF THE PV PLANT

Total number of modules	132
Type and manifacturer	Solterra 150W
Cells	monocrystalline
Max power [W]	150
Min. power [W]	140
Voltage at typical power [V]	34.7
Current at typical power [A]	4.32
Open circuit voltage [V]	43.2
Short circuit current [A]	4.7
NOCT [°C]	48° ± 1
Warranted Module efficiency (%)	11.80
Temperature coefficient voltage β	-153 mV/°C
Temperature coefficient current α	+0.90 mA/°C
Temperature coefficient power γ	-0.40 % /°C

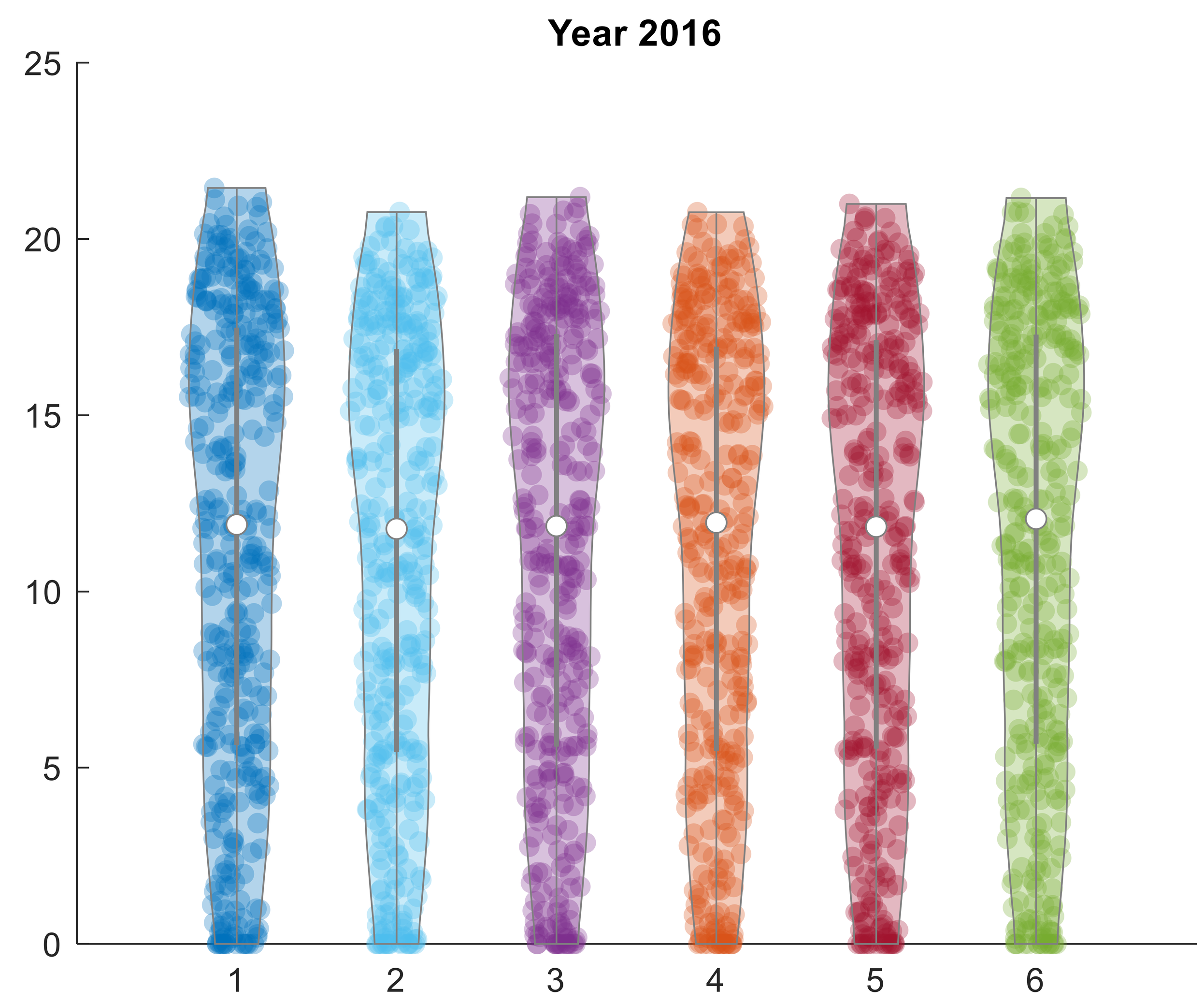

Fig. 4. Yearly violin graphs of the energy produced by the 6 PV arrays

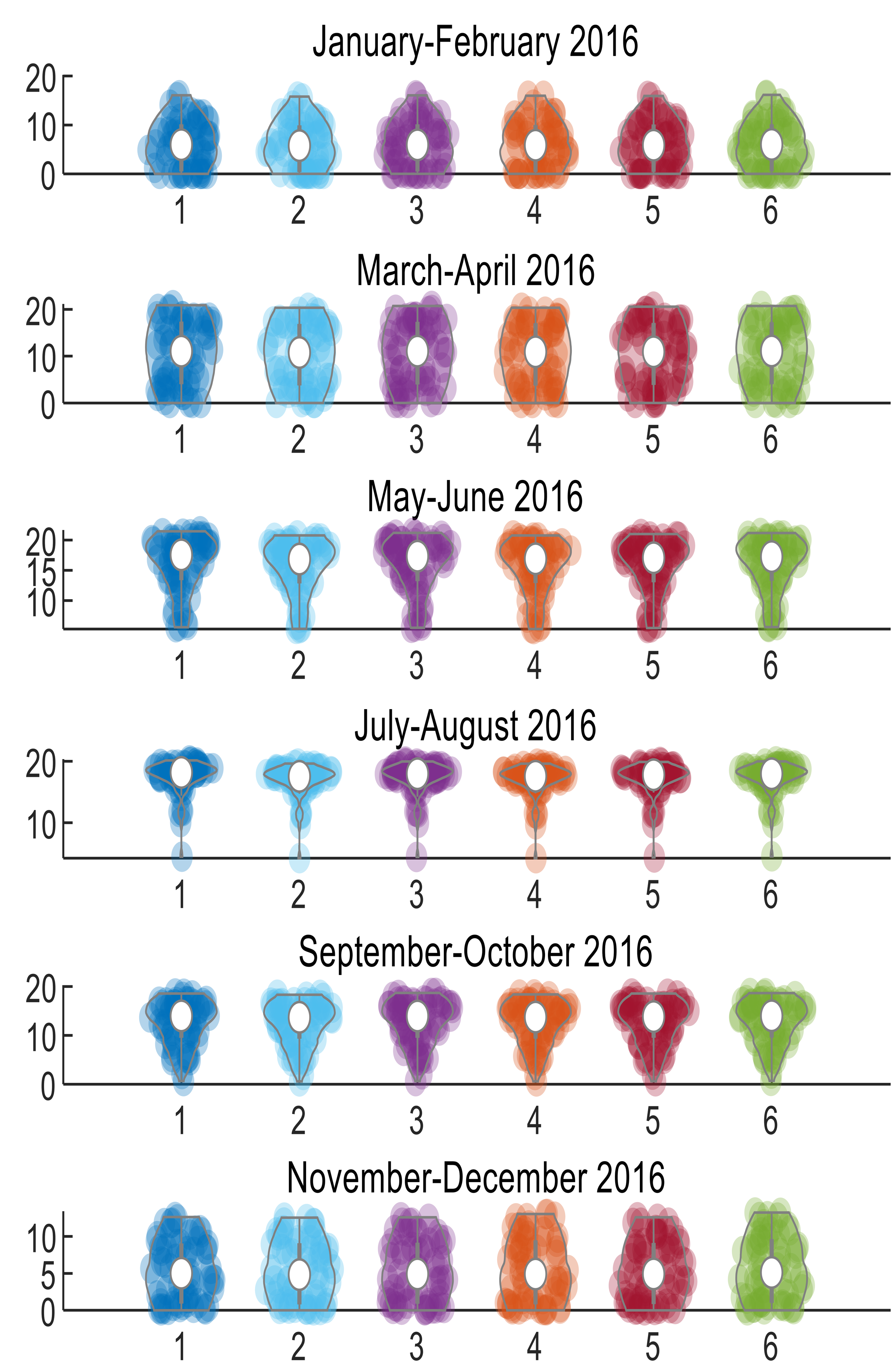

Fig. 5. Bi-monthly violin graphs of the energy produced by the 6 PV arrays.

Case study

The methodology was applied to the energy datasets a real 20kWp PV plant, constituted by 6 strings, Table I and II report the parameters from the manufacturer datasheets of the PV module and inverter. A complete description of the whole PV plant is available in [9].

TABLE II. SPECIFICATIONS OF THE INVERTER

MPP voltage range[V]	268 – 550
Max input voltage [V]	600
PV power [W]	4100
Max input current [A]	12.2
Nominal output power [W]	2600
Max. output power [W]	3000
Maximum efficiency	95%
Nominal mains voltage/frequency	230V / 50Hz
Total harmonic distortion	< 4.0%
Power factor	1

Yearly-based analysis

Preliminary analysis based on the whole yearly energy dataset (Fig. 4) allows to understand if great criticalities are present. It results that the shapes are similar, and the median values (white dots) are almost identical. Therefore, great criticalities are not detected, even if the maximum values are different. Particularly, **arrays #1, #3, and #6** show the maximum values, whereas the other strings have lower values. However, the differences are not excessive, and they are due to singular situations, not structural ones, as evidenced from the similarity between the shapes.

Bi-monthly violin plots

Each line of Fig. 5 reports the violin plots of the six arrays constituting the PV plant under test. These diagrams depend on the bi-monthly energy datasets; then, there are 6 lines, each of them representing the energy behaviors of the six arrays in a specified period.

Each column describes the variable energy behavior of each array during the whole year. By observing the violin plots of each period, they result almost equal, highlighting the PV arrays always produce the same energy. This is a confirmation that no anomaly is present, considering that the strings, equally constituted from the components point of view, are under equal environment conditions.

The periods March-April and November-December show almost uniform distributions, highlighting that the values from zero to the maximum one are equally frequent. The first period January-February is characterized over of all by low values. The periods May-June and, over of all, July-August are characterized by very high values, highlighting that the maximum values of the produced energy are largely more frequent than the others. The shape of the diagrams in May-June remembers exactly the **violin shape**, while the violins in July-August are characterized by a **bimodal** distribution.

The diagrams of a year can be utilized as benchmark for the next year because they show a cyclic behavior, as confirmed for the energy datasets of the successive year of the PV plant under investigation. After this analysis, we can affirm that no difference in energy performance of the PV strings results in any analyzed period and all the PV arrays showed the same electrical behavior.

Conclusions

Violin graph-based strategy to supervise the behavior of multi-array PV plants is useful in absence of environmental data. The procedure is applied to a real 20 kWp six-arrays PV plant for six bi-monthly periods. No anomaly was detected, comparing the diagrams of the six arrays within each period,

References

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[10] I.-S. Kim, "Online fault detection algorithm of a photovoltaic system using wavelet transform", Solar Energy, 2016, 226, 137–145.

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