Monitoring 30,000 PV systems in Europe: Performance, faults, and state of the art

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Objective: ask questions and get answers from the data

- Energy yield?
- Overall performance? Differences? Key factors?
- Best PV cell technologies?
- Improvement in state of the art?
- PV modules/systems degradation?
- Do we observe faults?
- Effects of the policymaker?
### Data from 31000+ PV systems

**INPUT DATA**

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV systems characteristics</td>
<td>PV system installer or owner</td>
</tr>
<tr>
<td>Energy production</td>
<td>Energy meter or inverter</td>
</tr>
<tr>
<td>Solar irradiation (GTI)</td>
<td>Synermet</td>
</tr>
</tbody>
</table>

**Country** | **Nb PV systems** | **Peak power [MWp]** | **Type**     
---|------------------|----------------------|--------------|
| France         | 17672            | 65                   | Rooftop      |
| Belgium        | 7648             | 50                   | Rooftop      |
| UK             | 5835             | 23                   | Rooftop      |
| Spain          | 29               | 116                  | PV plant     |
| Rest of Europe | 307              | 3                    | Rooftop      |
| **TOTAL**      | **31491**        | **255**              |              |
The peak power of most of the PV systems is < 5 kWp
France: peak power limited to 3 kWp by public incentives

Peak power of PV systems - France

Frequency [%]

Peak power of PV system [kWp]
Belgium: peak power shaped by net-balance incentives

Peak power of PV systems - Belgium

![Histogram of peak power of PV systems in Belgium with a lognormal distribution fit.](image)

- **Lognormal**
  - **Loc**: 1.517
  - **Scale**: 0.4280
  - **N**: 5971

Frequency [%]

Peak power of PV system [kWp]

0.0 2.5 5.0 7.5 10.0 12.5 15.0
The annual energy yield greatly varies geographically.

Annual Energy Yield - Belgium, France, Spain, UK

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean</th>
<th>StDev</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>907.7</td>
<td>108.3</td>
<td>5971</td>
</tr>
<tr>
<td>France</td>
<td>1115</td>
<td>153.9</td>
<td>41578</td>
</tr>
<tr>
<td>Spain</td>
<td>1886</td>
<td>355.3</td>
<td>76</td>
</tr>
<tr>
<td>UK</td>
<td>898.2</td>
<td>100.8</td>
<td>7745</td>
</tr>
</tbody>
</table>
Annual energy yield of PV plants in Spain and tracking

Annual Energy Yield of PV plants in Spain vs static/tracker generator type

- **Normal**
  - PV generator type
    - PV plant - static
    - PV plant - tracker
  - Mean: 1450, 2127
  - StDev: 146.2, 139.1
  - N: 27, 49

Frequency [%]

Annual Energy Yield [kWh/kWp]

- Frequency distribution for PV plants in Spain showing the yield range from 1100 to 2500 kWh/kWp.

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The yearly PR follows a Weibull distribution

Yearly integrated Performance Ratio - Europe

Weibull
Shape 13.25
Scale 0.7871
N 55495

Performance Ratio [-]

Frequency [%]
The data follow a Weibull distribution for $0.6 < PR < 0.9$
The mean yearly PR in Europe lies within 0.75 – 0.8
Mean yearly PR France: 2-3% lower than other countries
The small PV systems have a lower PR

Yearly integrated Performance Ratio vs PV system peak power - Europe
Difference in PR between inverters: 1-5 %

Yearly integrated Performance Ratio vs Inverter manufacturer - PV systems Europe
Difference in PR between modules (no thin-film): 1-6%

Yearly integrated Performance Ratio vs PV module manufacturer - PV systems Europe
PV modules technology greatly affects performance

Yearly integrated Performance Ratio vs PV cell technology - PV systems Europe

Performance Ratio [-]

PV cell technology
HIT bcSi xSi xSi-Sat CdTe UMGSi aSi CIS/CIGS

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PV systems performance has improved over time

Yearly integrated Performance Ratio in 2013 vs year of installation of PV system - Europe

Performance Ratio [-]

Year of installation

2007 2008 2009 2010 2011 2012 2013
PV systems performance degradation over time is low

Yearly integrated Performance Ratio for PV systems installed in 2008 vs production year

![Graph showing yearly integrated Performance Ratio for PV systems installed in 2008 vs production year. The graph indicates that the performance ratio is relatively stable over time, with a slight decrease observed in the later years.]
Some PV systems are clearly subject to faults

Monthly integrated Performance Ratio - All 12 months of the year - Europe
The monthly PR is influenced by several parameters
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