Analysis of Photovoltaic Systems
ANALYSIS OF PHOTOVOLTAIC SYSTEMS

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IEA-PVPS Task 2
Operational Performance of PV Systems and Subsystems

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FOREWORD

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its 23 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D agreements established within the IEA. Since 1993, the 20 countries participating in the programme and the European Commission have been conducting a variety of joint projects in the applications of photovoltaic conversion of solar energy into electricity.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. The programme is divided into nine Tasks.

The member countries participating in Task 2 are Austria (AUT), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), The Netherlands (NLD), Switzerland (CHE) and the European Commission.

The objective of Task 2 is to provide the other Tasks of PVPS and PV experts with information on the operational performance, reliability and costs of PV systems and subsystems, to present data on the operational reliability of PV systems to research laboratories, utilities and manufacturers, to provide information on PV system design to installers, system designers and vocational schools, and to provide information on the state-of-the-art monitoring and normalized presentation of results of grid-connected and stand-alone PV systems.

This report contains a summary of the work on the analysis of PV systems which was executed within Task 2, Subtask 1 (International Database and Analysis of PV Systems).

This international technical report has been prepared under the supervision of PVPS Task 2 by:

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in co-operation with the experts of the following countries: Austria, European Union, France, Israel, Japan, the Netherlands and Switzerland.

The report expresses, as nearly as possible, the international consensus of opinion of the Task 2 experts on the subjects dealt with.
ABSTRACT AND KEYWORDS

In recent years, national and international demonstration programmes in the field of photovoltaics have been initiated to develop typical market segments and to enhance technology progress. Gathering direct experiences of the feasibility, reliability and operating costs of PV systems is an important aspect of various implementation programmes. Evaluation programmes create a great deal of collected information on technical and non-technical issues, but only a portion is published and available. The International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS) represents an attempt to highlight common achievements and problems, and to promote recommended practices.

As part of the IEA-PVPS programme, Task 2 is collecting and analysing operational data of PV plants in various types of systems (grid-connected, stand-alone systems, hybrid systems) spread all over the world. The objective of this Task is to provide PV experts and other target groups as well as other Tasks with suitable information on the operational performance, reliability and costs of PV system and subsystems. The IEA-PVPS Task 2 database is designed for the normalized analysis and representation of the operational data from different PV applications.

This report summarizes the analysis of more than 260 PV systems integrated in the IEA-PVPS database, illustrates the operational behaviour of the systems by suitable graphs and presents the detailed results in a normalized form. The analysis allows comparisons between typical PV systems in different countries under different climatic conditions and systems of different load pattern.

Keywords: database, evaluation, grid-connected systems, indices of performance, maintenance, monitoring, mounting, national programmes, normalized presentation, power stations, PV components, sizing, stand-alone PV systems

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Our thanks also goes to the Operating Agent of Task 2, Reinhard Dahl, for his supervision and his support for this work. In particular we esteem the Task 2 participants and Operating Agent of Task 1, Greg Watt, for their valuable comments and for their contribution in the proof reading process.

This work has been executed within the framework of the Implementing Agreement of the International Energy Agency’s Photovoltaic Power Systems Programme.

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1 EXECUTIVE SUMMARY

1.1 IEA-PVPS Task 2 database

This work has been carried out by the participants of Task 2 of the International Energy Agency (IEA), Photovoltaic Power Systems Programme (PVPS). Task 2 addresses the operational performance of photovoltaic power systems and subsystems, and is divided into three subtasks. This report deals with Subtask 1 “International Database and Analysis of PV Systems” with emphasis on the evaluation of PV systems (activity 13). The main objective is to provide information on the operational performance, reliability and costs of PV systems and subsystems. In addition reported experiences and results of technical and economical performance are considered as being essential and of great value for the promotion of PV systems and components. The target groups are other Tasks of PVPS and PV experts, research laboratories, utilities, manufacturers, system designers, installers, standardization organizations and vocational schools.

For the IEA-PVPS Task 2 database, monitoring data of 266 PV systems from the IEA member countries (AUT, EU, FRA, DEU, ISR, ITA, JPN, NLD and CHE) were collected. The database contains complete datasets of 266 PV systems with an installed capacity of 11 MWp ranging from 0.1 kWp up to 3 MWp. Grid-connected PV systems including grid-connected hybrid systems are in majority with 80 %, while stand-alone systems and SAS hybrid systems total 20 %.

Most of the monitoring data have been gathered under various national demonstration programmes in the IEA member countries: e. g. Austrian Rooftop Programme, French Rural Electrification Programme, EU Thermie Programme, German 1 000-Roofs-Photovoltaic-Programme, Japanese Sunshine and Japanese Field Test Programme. There has been an increasing trend for demonstration programmes to focus on, or include, grid-connected PV systems. For the purpose of analysing the operational performance three primary applications of on-grid PV systems were identified: decentralized systems ranging from 1 kWp to 10 kWp (PV roofs), dispersed systems ranging from 10 kWp to 100 kWp (BIPV, sound barrier), and centralized systems greater than 100 kWp (PV power plants).

With respect to the operational performance of stand-alone systems including hybrid systems two main categories were defined: off-grid domestic systems for rural electrification (isolated houses and Alpine huts) and off-grid professional systems (remote communications, control and protection devices).

The IEA-PVPS database is designed to accommodate the technical and operational data of different types of systems. For PV systems with more than one PV array, DC/DC converter or inverter, it is possible to enter multiple sets of technical information for the same type of subsystem. The operational data are monthly values of monitored data and can be entered for multiple years of operation. All or parts of the technical or monitored data can be entered manually using the PVbase database programme or imported from an ASCII file. It is also possible to export data to an ASCII file. The database comprises 182 fields for each plant or project. All the fields including type, unit and possible range are listed in annex A – 1. To carry out a normalized evaluation and presentation of all the systems in the database using the PVreport programme, 91 minimum fields were defined as absolutely necessary.

The database software (PVbase and PVreport programmes) allows the user to process the collected data of the systems and to present the results in tables and graphs. Meteorology
and energy production data, for example, may be displayed on a monthly basis for an individual system and on a yearly basis for multiple systems. The same feature applies as well for energy yield, performance ratio, and system and components efficiency figures of selected plants. The database programmes are described in chapter 4.

1.2 Evaluation of data and presentation of results

This report focuses on the detailed analysis of the monitored and collected data. All system and subsystem performance data have been evaluated in terms of operational performance and reliability. To a great extent the evaluation procedures are based on the European Guidelines and the IEC Standard 61724. In addition there are additional recommendations for existing guidelines on national levels. Complementary developments which are relevant for the monitoring data in the IEA-PVPS database are carried out in Austria, France, Germany, Italy, Netherlands and Switzerland.

For the presentation of results in this report, the derived parameters from the IEA-PVPS database were exported into spread sheet programmes to produce a variety of graphical presentations (chapter 6). Table 1.1 shows an overview of the derived performance data and the graphical presentations for grid-connected and for stand-alone PV systems. Due to the available data in the database, the scope of the presented results varies considerably from country to country.

Table 1.1: Overview of performance indicators and their graphical presentation for grid-connected systems (GCS) and for stand-alone systems (SAS)

<table>
<thead>
<tr>
<th>Derived parameter</th>
<th>Symbol</th>
<th>Graphical presentation</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal power</td>
<td>$P_0$</td>
<td>Distribution of $P_0$</td>
<td>GCS &amp; SAS</td>
</tr>
<tr>
<td>Final yield</td>
<td>$Y_f$</td>
<td>Distribution of annual $Y_f$</td>
<td>GCS</td>
</tr>
<tr>
<td>Performance ratio</td>
<td>PR</td>
<td>Distribution of monthly and annual PR</td>
<td>GCS &amp; SAS</td>
</tr>
<tr>
<td>Reference yield</td>
<td>$Y_r$</td>
<td>$Y_r$ and PR as a function of $Y_f$</td>
<td>GCS</td>
</tr>
<tr>
<td>Array capture losses</td>
<td>$L_C$</td>
<td>Bar graph of monthly $Y_f + L_S + L_C$</td>
<td>GCS &amp; SAS</td>
</tr>
<tr>
<td>System losses</td>
<td>$L_S$</td>
<td>Bar graph of monthly $Y_f + L_S + L_C$</td>
<td>GCS &amp; SAS</td>
</tr>
<tr>
<td>Array efficiency</td>
<td>$\eta_{A,\text{mean}}$</td>
<td>$\eta_{A,\text{mean}}$ as a function of $\eta_{A0}$</td>
<td>GCS &amp; SAS</td>
</tr>
<tr>
<td>Module temperature</td>
<td>$T_m$</td>
<td>$\eta_{A,\text{mean}}$ as a function of $T_m$</td>
<td>GCS &amp; SAS</td>
</tr>
<tr>
<td>Overall plant efficiency</td>
<td>$\eta_{\text{tot}}$</td>
<td>Distribution of $\eta_{\text{tot}}$</td>
<td>GCS</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>$E_{\text{CONS}}$</td>
<td>Distribution of $E_{\text{CONS}} = E_{\text{RO}} + E_{\text{FU}} + E_{\text{TU}}$</td>
<td>GCS</td>
</tr>
<tr>
<td>Solar fraction</td>
<td>$F_S$</td>
<td>Distribution of $F_S$; $F_S$ versus $E_{\text{CONS}}$</td>
<td>GCS</td>
</tr>
<tr>
<td>Direct use fraction</td>
<td>$F_d$</td>
<td>Distribution of $F_d$; $F_d$ versus $F_S$</td>
<td>GCS</td>
</tr>
<tr>
<td>Potential energy</td>
<td>$E_{\text{pot}}$</td>
<td>Distribution of monthly $E_{\text{pot}}$</td>
<td>SAS</td>
</tr>
<tr>
<td>Useful energy</td>
<td>$E_{\text{use}}$</td>
<td>Comparison of monthly $E_{\text{use}}$ to $E_{\text{pot}}$</td>
<td>SAS</td>
</tr>
<tr>
<td>Matching factor</td>
<td>MF</td>
<td>Distribution of annual $MF = PR \cdot F_A$</td>
<td>SAS</td>
</tr>
<tr>
<td>Usage factor</td>
<td>UF</td>
<td>$UF = E_A/E_{\text{pot}}$ as a function of PR</td>
<td>SAS</td>
</tr>
<tr>
<td>Outage fraction</td>
<td>O</td>
<td>Distribution of O</td>
<td>GCS &amp; SAS</td>
</tr>
</tbody>
</table>

A summary of the performance results is presented and illustrated in annex D, where 38 representative PV systems (three to seven selected systems from each country) are
documented in the form of a standard performance report. This standard report for individual (and multiple) systems and for one or more operational years may be produced by using the PVreport programme. It contains general information on the PV plant and annual results of meteorology, system energies, performance indices and utility grid energies as listed in Table 1.2. One selected graph (e.g. indices of performance) for each of the 40 PV systems is included in the standard PV database report.

### Table 1.2: Available parameters in the standard PV database report

<table>
<thead>
<tr>
<th>General information</th>
<th>Meteorology</th>
<th>System energies</th>
<th>Performance indices</th>
<th>Utility grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant name</td>
<td>Irradiation, horizontal</td>
<td>Inverter energy output</td>
<td>Reference yield</td>
<td>Energy to utility grid</td>
</tr>
<tr>
<td>Country</td>
<td>Irradiation, in array plane</td>
<td>Useful energy</td>
<td>Final yield</td>
<td></td>
</tr>
<tr>
<td>Nominal power</td>
<td>Ambient air temperature</td>
<td>PV array fraction</td>
<td>Array capture losses</td>
<td></td>
</tr>
<tr>
<td>Type of plant</td>
<td></td>
<td>Energy consumption</td>
<td>System losses</td>
<td></td>
</tr>
<tr>
<td>Mounting structure</td>
<td></td>
<td></td>
<td>Performance ratio</td>
<td></td>
</tr>
<tr>
<td>Array area</td>
<td></td>
<td></td>
<td>Array efficiency</td>
<td></td>
</tr>
<tr>
<td>Availability of data</td>
<td></td>
<td></td>
<td>Inverter efficiency</td>
<td></td>
</tr>
<tr>
<td>Calculated month</td>
<td></td>
<td></td>
<td>Overall plant efficiency</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 1.3 Results of performance analysis

From the analysis of grid-connected PV systems in the IEA-PVPS database, it was learnt that the average annual yield ($Y_f$) only slightly fluctuates from one year to another and has typical annual values of $Y_f = 700 \text{ h/y}$ for Germany and the Netherlands, $Y_f = 830 \text{ h/y}$ for Switzerland and up to $Y_f = 1 600 \text{ h/y}$ for Israel. However, there is considerable scattering around these average values for the individual systems ranging from 400 h/y to 950 h/y (Germany) and from 500 h/y to 1 400 h/y (Switzerland).

The performance ratio (PR) is used to indicate the overall effect of losses on the array’s rated output due to array temperature, incomplete utilization of the irradiation, and system component inefficiencies or failures. The performance ratio ($PR = Y_f / Y_r$) is defined as the ratio of the final yield to the reference yield, given by a dimensionless number.

Figure 1.1 shows the distribution of annual performance ratios (PR) calculated from 387 annual datasets of 170 grid-connected PV systems. The annual performance ratio (PR) significantly differs from plant to plant and ranges between 0.25 and 0.9 with an average PR value of 0.66 for 170 PV systems. It was found that well maintained PV systems operating well show an average PR value of typically 0.72 at an availability of 98% (e.g. Switzerland). A tendency of increasing annual PR values during the past years has been observed.
One unexpected loss factor is clearly identified among high and very high array capture losses ($L_c$ in the order of 1.5 h/d). There is a systematic deviation of minus 5 points to minus 15 points of the measured PV nominal power from the rated power specified in the data sheets by the manufacturer. As a consequence of these results, the manufacturers of PV modules have improved the accuracy of their module quoting with respect to STC performance during the last years.

Another major loss factor is detected for PV plants having partial shading of the PV array, which leads to a significant reduction of the energy yield of that system. In order to avoid unnecessary energy losses, a position with as little shading as possible should be chosen for the PV array during the planning phase.

The susceptibility of grid-connected PV systems to failures, particularly regarding DC/AC inverters, has clearly decreased. The PV array has continued to be the most reliable component. The inverters of grid-connected systems achieve mean annual efficiency figures of higher than 88 % and a mean availability of better than 97 % (e. g. Germany).

Despite good results, which have been obtained in many of the grid-connected systems, the investigation of the operational behaviour of the reported PV systems has identified further potential for optimization:
• improving efficiencies of components by the selection of high efficiency modules and inverters
• avoiding diode, wiring and mismatch losses
• avoiding MPP inverter losses by optimum components matching
• avoiding high module temperatures by suitable measures of module integration into the building during installation
• avoiding array coverage due to dirt and snow on the PV array surface
• reducing array shading as much as possible during the planning phase

The performance analysis of data from stand-alone and stand-alone hybrid systems has revealed that the operational performance not only depends on the component efficiency, but also on system design and load pattern. Figure 1.2 shows the distribution of annual performance ratios (PR) for 27 domestic stand-alone and stand-alone hybrid systems. Annual performance ratios range from 0.2 to 0.6 for off-grid domestic applications depending whether they have a back-up system and from 0.05 to 0.25 for off-grid professional systems, which are often oversized for reliability reasons. The analysis of stand-alone systems in terms of performance ratio shows that the PR does not reflect the proper technical operation of a system as is the case for grid-connected systems.

Using the matching factor (MF), which is the product of the performance ratio (PR) and the array fraction ($F_A$), allows a better illustration of the performance of hybrid systems. A high value of the matching factor indicates that the solar component properly matches the electrical load and limits the back-up contribution. For the reported stand-alone systems, annual MF values between 0.2 and 0.6 were achieved highlighting better performance of hybrid systems in general in comparison to SAS without back-up. Nevertheless, the considered hybrid systems have not been designed as such but rather as a juxtaposition of two energy sources (solar PV and conventional). The wide MF range demonstrates that an optimization in the design phase is needed.
Figure 1.2: Distribution of annual performance ratios (PR) for typical domestic stand-alone PV systems
8 CONCLUSIONS

As part of the IEA-PVPS Programme, Task 2 is collecting and analysing operational data from PV plants in various types of systems (grid-connected, stand-alone, hybrid systems) spread all over the world. Within the first phase of Task 2 work an international database on operational performance of PV systems and subsystems was developed and updated. The IEA-PVPS Task 2 database is designed for the normalized analysis and representation of the operational data from different PV applications. Providing relevant information on the long-term performance and reliability of PV plants, on sizing and performance prediction for stand-alone systems and on performance improvements of PV systems is considered to be the clear benefit of the Task 2 database.

This report has laid particular emphasis on the analysis of operational performance of PV components and systems. It illustrates the operational behaviour of the systems by suitable graphs and presents the detailed results in a normalized form. Data from more than 260 PV systems integrated in the IEA-PVPS database have been evaluated, which allows comparisons between typical PV systems in different countries under different climatic conditions and systems of different load pattern.

Making use of the national monitoring activities within PV promotion programmes in Task 2 countries was the most common approach for collecting PV system data for the IEA-PVPS Task 2 database. Most of the systems in the database can be associated with national programmes under which data were originally monitored and evaluated. These national demonstration programmes in the countries participating in IEA-PVPS Task 2 largely reflect the priorities of each country.

There is an increasing emphasis on grid-connected PV systems, particular on the integration of PV into existing structures. Japan, Germany, the Netherlands, Switzerland and Austria have programmes to promote residential PV installations. Due to the emphasis in those countries, grid-connected PV systems including grid-connected hybrid systems are dominant in the IEA-PVPS database with a share of 80%. Israel is focusing on adapting PV to its specific climate. France considers PV power systems as a potential source of electricity in remote rural areas where it has been demonstrated that PV is cheaper than extending the grid. Thus France is focusing on stand-alone systems in rural electrification programmes and contributes a major part of the stand-alone data in the IEA-PVPS database.

A problem encountered in the data collection was the access to the available monitored data by the country representative of Task 2. In the case of direct access due to an involvement of the participant in the national monitoring initiatives or campaigns at the same time, transfer and checking of data was easier and faster. In other cases, where the monitored data had to be processed by third parties not directly involved in IEA activities, data collection took considerably more effort and was time consuming. Additionally, any inconsistency detected in the monthly datasets was more difficult to solve without having direct access to the monitored data and to the background information on the system monitoring.

PV systems of different configurations and at different locations can be readily compared by evaluating their normalized system performance indices such as yields, losses and efficiencies. Yields are energy quantities normalized to nominal array power. Component and overall PV plant efficiencies are normalized to array area. Losses are the differences between yields and the performance ratio is the ratio of two yields. For the evaluation of
operational data and for the presentation of results, normalized performance indicators are being used. This feature simplifies the performance assessment of the different PV systems in the IEA-PVPS database.

From the analysis of data in the IEA-PVPS database of 260 PV plants the following annual performance ratios can be expected for the different types of systems:

- grid-connected PV systems \( PR = 0.6 \ldots 0.8 \)
- stand-alone systems without back-up \( PR = 0.1 \ldots 0.6 \)
- stand-alone systems with back-up \( PR = 0.3 \ldots 0.6 \)

The distribution of annual performance ratio (PR) calculated of 170 grid-connected PV systems shows that the PR significantly differs from plant to plant and ranges between 0.25 and 0.9 with an average PR value of 0.66 for 170 PV systems. It was found that well maintained PV systems operating well show an average PR value of typically 0.72 at an availability of 98 %. A tendency for increasing annual PR values during the past years has been observed.

In the early nineties (1992-1997), large grid-connected power plants showed annual PR values between 0.4 and 0.7 due to partial and total failures and a high non-availability of the PV plants as described in section 6.6. From recent large, grid-connected PV power installations with excellent inverter efficiencies, the annual PR may achieve values greater than \( PR = 0.8 \). As a result, grid-connected systems have generally improved in efficiency due to further improvements in component efficiency and optimized system design. The module efficiency is clearly improving and the manufacturers’ rating of PV module nominal power is closer to the monitored and realistic value. As high efficiency inverters have been developed for grid-connected systems during the last years, the inverter efficiency is also tending to increase.

A major loss factor was detected for PV plants having partial shading of the PV array, which leads to a significant reduction of the energy yield of that system. In order to avoid unnecessary energy losses, a position with as little shading as possible should be chosen for the PV array during the planning phase.

In the years 1992 to 1996, maintenance efforts had been recorded for four large grid-connected PV systems in Italy. Experimental data showed that plant non-availability ranges from 15 % to 30 % in terms of working hours, because of the time spent for detecting and locating the failure, for diagnosis and for supplying the parts to be replaced. The main causes of total failures were identified to be inverter unreliability in the order of 50 % and other critical components such as medium voltage equipment, power factor and filtering components. For all the four plants taken into consideration, it was found that the cost of the replaced components were nearly always similar to the cost related to manpower.

During the last years, the susceptibility of grid-connected PV systems to failures, particularly regarding DC/AC inverters, has clearly decreased. The PV array has continued to be the most reliable component. The inverters of grid-connected systems achieve mean annual efficiency figures of higher than 88 % and a mean availability of better than 97 %.
Despite good results, which have been obtained in many of the grid-connected systems, the investigation of the operational behaviour of the reported PV systems has identified further potential for optimization:

- improving efficiencies of components by the selection of high efficiency modules and inverters
- avoiding diode, wiring and mismatch losses
- avoiding MPP inverter losses by optimum components matching
- avoiding high module temperatures by suitable measures of module integration into the building during installation
- avoiding array coverage due to dirt and snow on the PV array surface
- reducing array shading as much as possible during the planning phase

The performance analysis of data from stand-alone and stand-alone hybrid systems has revealed that the operational performance not only depends on the component efficiency, but also on system design and load pattern. Annual performance ratios range from 0.2 to 0.6 for off-grid domestic applications depending whether they have a back-up system and from 0.05 to 0.25 for off-grid professional systems, which are often oversized for reliability reasons. The performance analysis of stand-alone systems in terms of performance ratio (PR) has shown that in contrast to grid-connected systems, the PR alone cannot be used to describe the proper operation of stand-alone systems from a technical point of view.

Using the matching factor (MF), which is the product of the performance ratio (PR) and the array fraction ($F_A$), gives a better illustration of the performance of hybrid systems. A high value of the matching factor indicates that the solar part properly matches the electrical load and limits the back-up contribution. For the reported stand-alone systems, annual MF values between 0.2 and 0.6 were achieved highlighting better performance of hybrid systems in general in comparison to stand-alone systems without back-up. Nevertheless, the considered hybrid systems have not been designed as such but as a juxtaposition of two energy sources (solar PV and conventional). The wide MF range demonstrates that an optimization in the design phase is needed. A more detailed analysis concerning the operation of stand-alone systems will necessitate:

- more detailed and more reliable monitoring campaigns, which are at present feasible even for small remote systems with the development of integrated data loggers
- several years of measurement to better appreciate the evolution of user behaviour over time
- the use of simulation tools to evaluate the influence of new component sizes or new regulation strategies to increase the system performance

Experiences from one-axis and two-axis tracking systems were gained from Israeli installations in an arid desert (latitude 30.80° North; altitude above sea-level 475 m; annual global horizontal irradiation 2 000 kWh/(m²·y); annual rainfall 90 mm). With respect to the electrical performance of trackers, the results of single, horizontal axis sun-tracking systems were disappointing. In general the system output was found to be lower than the designers had expected. On the other hand, the two-axis tracking system performed more or less according to expectations.

Analysis of mirror enhancement showed that V-trough mirrors enhance system performance during days with clear skies but not on cloudy days. As a result, mirrors must be positioned with great care in order to prevent non-uniform illumination of the modules at all times of the year. This is not difficult to achieve with two-axis trackers, but requires some detailed calculations in the case of one-axis trackers.
New national PV promotion programmes are being launched in various IEA-PVPS countries, which will lead to a rapid growth of installations and, possibly, to an increased amount of monitoring data. This will give benefits to PV system performance evaluation and enable the preparation of guidelines for supervision and maintenance aspects. Good maintenance is important, particular for rate based financed PV systems and Green Power schemes in order to promote the use of photovoltaics.
This annex contains three examples of database reports on operational performance of PV systems. Further results of selected PV systems in nine different countries are given in Annex D of the full document.

The full report can be downloaded from the same web site.

Paper copies may be obtained at the following address:

Forschungszentrum Juelich GmbH
Mr. R. Dahl
PT BEO 21
D-52425 Juelich
Germany
Phone: +49 (0) 2461 61 3254
Fax: +49 (0) 2461 61 2880
E-Mail: r.dahl@fz-juelich.de

The full report (230 pages) will be available at the cost of 75 USD.
### Photovoltaic Database Report

<table>
<thead>
<tr>
<th>Plant Name:</th>
<th>Reinheimer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country:</td>
<td>France</td>
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<tr>
<td>Type of plant:</td>
<td>Stand-alone hybrid</td>
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<tr>
<td>Nominal Power:</td>
<td>1.08 kW_p</td>
</tr>
<tr>
<td>Battery storage:</td>
<td>750 Ah / 24 V</td>
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<tr>
<td>Mounting:</td>
<td>Freestanding</td>
</tr>
<tr>
<td>Array area:</td>
<td>11.52 m²</td>
</tr>
</tbody>
</table>

![Image of Reinheimer plant]
IEA-PVPS Task 2
Annex D - 3 France

Photovoltaic Database Report

Plant Name: Reinheimer
Country: France
Type of plant: Stand-alone hybrid
Nominal Power: 1.08 kWp
Array area: 11.52 m²

Indices of Performance, Plant: Reinheimer, 1995

<table>
<thead>
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<th>Month</th>
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<tbody>
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<tr>
<td>MAR</td>
<td>2.60</td>
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<tr>
<td>APR</td>
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<td>3.50</td>
</tr>
<tr>
<td>AUG</td>
<td>2.50</td>
</tr>
<tr>
<td>SEP</td>
<td>2.00</td>
</tr>
<tr>
<td>OCT</td>
<td>1.50</td>
</tr>
<tr>
<td>NOV</td>
<td>1.00</td>
</tr>
<tr>
<td>DEC</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Year: 1994 1995 1996
Availab. of monitored data: 0.75 1 0.25 AMD []
Calculated Month: 9 12 3

Meteorology:
Glob. Irradiation, horizontal: H sum [kWh/m²]
Irradiation, in array plane: 931 1268 385 Hl sum [kWh/m²]
Ambient air temperature: 0 0 0 Tam avr [°C]

System Energies:
Energy output from inverter: 0 0 0 EIO sum [kWh]
Useful energy: 670 931 206 Euse sum [kWh]
PV array fraction: 0.83 0.85 0.66 FA []
Energy consumption: 670 931 206 Econ sum [kWh]

System Performance Indices:
Reference yield: 3.39 3.48 4.29 Yr avr [h/d]
Final yield: 1.86 1.97 1.39 Yf avr [h/d]
Array capture losses: 1.27 1.29 2.04 Lc avr [h/d]
System losses: 0.26 0.21 0.85 Ls avr [h/d]
Performance Ratio: 0.55 0.57 0.33 PR []
Array efficiency: 5.9 5.9 5.0 eta A [%]
Inverter efficiency: 5.9 5.9 5.0 eta inv [%]
Overall plant efficiency: 5.2 5.4 4.0 eta tot [%]

Utility Grid:
Energy to utility grid: 0 0 0 ETU sum [kWh]
Energy from utility grid: 0 0 0 EFU sum [kWh]
### Photovoltaic Database Report

**Plant Name:** Reinheimer  
**Country:** France  
**Type of plant:** Stand-alone hybrid  
**Nominal Power:** 1.08 kWp  
**Mounting:** Freestanding  
**Array area:** 11.52 m²

#### System Energies:

- **Energy output from inverter:**
  - 1994: 0 kWh  
  - 1995: 931 kWh  
  - 1996: 385 kWh  

- **Useful energy:**
  - 1994: 670 kWh  
  - 1995: 931 kWh  
  - 1996: 206 kWh  

- **PV array fraction:**
  - January: 0.83  
  - February: 0.85  
  - March: 0.66  

- **Energy consumption:**
  - January: 0 kWh  
  - February: 931 kWh  
  - March: 206 kWh

#### System Performance Indices:

- **Reference yield:**
  - 1994: 3.39 [h/d]  
  - 1995: 3.48 [h/d]  
  - 1996: 4.29 [h/d]  

- **Final yield:**
  - 1994: 1.86 [h/d]  
  - 1995: 1.97 [h/d]  
  - 1996: 1.39 [h/d]  

- **Array capture losses:**
  - 1994: 1.27 [h/d]  
  - 1995: 1.29 [h/d]  
  - 1996: 2.04 [h/d]  

- **System losses:**
  - 1994: 0.26 [h/d]  
  - 1995: 0.21 [h/d]  
  - 1996: 0.85 [h/d]  

- **Performance Ratio:**
  - 1994: 0.55  
  - 1995: 0.57  
  - 1996: 0.33  

- **Array efficiency:**
  - 1994: 5.9 %  
  - 1995: 5.9 %  
  - 1996: 5.0 %  

- **Inverter efficiency:**
  - 1994: 5.2 %  
  - 1995: 5.4 %  
  - 1996: 4.0 %  

- **Overall plant efficiency:**
  - 1994: 5.2 %  
  - 1995: 5.4 %  
  - 1996: 4.0 %

#### Utility Grid:

- **Energy to utility grid:**
  - 1994: 0 kWh  
  - 1995: 0 kWh  
  - 1996: 0 kWh  

- **Energy from utility grid:**
  - 1994: 0 kWh  
  - 1995: 0 kWh  
  - 1996: 0 kWh

---

**Potential PV Energy and Energy Consumption, Plant: Reinheimer, 1995**

<table>
<thead>
<tr>
<th>Month</th>
<th>kWh/d</th>
</tr>
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<tbody>
<tr>
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<tr>
<td>FEB</td>
<td>0.45</td>
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<tr>
<td>MAR</td>
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</tr>
<tr>
<td>MAY</td>
<td>0.50</td>
</tr>
<tr>
<td>JUN</td>
<td>0.50</td>
</tr>
<tr>
<td>JUL</td>
<td>0.50</td>
</tr>
<tr>
<td>AUG</td>
<td>0.50</td>
</tr>
<tr>
<td>SEP</td>
<td>0.50</td>
</tr>
<tr>
<td>OCT</td>
<td>0.50</td>
</tr>
<tr>
<td>NOV</td>
<td>0.50</td>
</tr>
<tr>
<td>DEC</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Potential PV Energy, yearly tot.: 1369.82 kWh/a**

**Energy Cons., yearly tot.: 929.3 kWh/a**

**Ebuacdc, yearly tot.: 151.4 kWh/a**

---

**Year:** | **1994** | **1995** | **1996** | **AMD** | **[]**
---|---------|---------|---------|-------|------
**Availab. of monitored data:** | 0.75 | 1 | 0.25 | AMD | []
**Calculated Month:** | 9 | 12 | 3 | | 
**Metorology:**

- **Glob. Irradiation, horizontal:**
  - H sum [kWh/m²]

- **Irradiation, in array plane:**
  - January: 931 kWh/m²  
  - February: 1268 kWh/m²  
  - March: 385 kWh/m²

- **Ambient air temperature:**
  - January: 0 °C  
  - February: 0 °C  
  - March: 0 °C

**System Energies:**

- **Energy output from inverter:**
  - January: 0 kWh  
  - February: 931 kWh  
  - March: 206 kWh

- **Useful energy:**
  - January: 670 kWh  
  - February: 931 kWh  
  - March: 206 kWh

- **PV array fraction:**
  - January: 0.83  
  - February: 0.85  
  - March: 0.66

- **Energy consumption:**
  - January: 0 kWh  
  - February: 931 kWh  
  - March: 206 kWh

**System Performance Indices:**

- **Reference yield:**
  - January: 3.39 [h/d]  
  - February: 3.48 [h/d]  
  - March: 4.29 [h/d]

- **Final yield:**
  - January: 1.86 [h/d]  
  - February: 1.97 [h/d]  
  - March: 1.39 [h/d]

- **Array capture losses:**
  - January: 1.27 [h/d]  
  - February: 1.29 [h/d]  
  - March: 2.04 [h/d]

- **System losses:**
  - January: 0.26 [h/d]  
  - February: 0.21 [h/d]  
  - March: 0.85 [h/d]

- **Performance Ratio:**
  - January: 0.55  
  - February: 0.57  
  - March: 0.33

- **Array efficiency:**
  - January: 5.9 %  
  - February: 5.9 %  
  - March: 5.0 %

- **Inverter efficiency:**
  - January: 5.2 %  
  - February: 5.4 %  
  - March: 4.0 %

- **Overall plant efficiency:**
  - January: 5.2 %  
  - February: 5.4 %  
  - March: 4.0 %

**Utility Grid:**

- **Energy to utility grid:**
  - January: 0 kWh  
  - February: 0 kWh  
  - March: 0 kWh

- **Energy from utility grid:**
  - January: 0 kWh  
  - February: 0 kWh  
  - March: 0 kWh

---

<table>
<thead>
<tr>
<th>Year</th>
<th>Availab. of monitored data</th>
<th>Calculated Month</th>
<th>AMD</th>
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<tbody>
<tr>
<td>1994</td>
<td>0.75</td>
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</tr>
<tr>
<td>1995</td>
<td>1</td>
<td>12</td>
<td>0.25</td>
<td>AMD</td>
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<td>AMD</td>
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### Photovoltaic Database Report

<table>
<thead>
<tr>
<th>Plant Name:</th>
<th>LS-29</th>
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<tbody>
<tr>
<td>Country:</td>
<td>Germany</td>
</tr>
<tr>
<td>Type of plant:</td>
<td>Grid connected</td>
</tr>
<tr>
<td>Nominal Power:</td>
<td>1.48 kW&lt;sub&gt;p&lt;/sub&gt;</td>
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<tr>
<td>Mounting:</td>
<td>Sloped roof</td>
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<tr>
<td>Array area:</td>
<td>10.08 m&lt;sup&gt;2&lt;/sup&gt;</td>
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</table>
Photovoltaic Database Report

Plant Name: **LS-29**
Country: Germany
Type of plant: Grid connected
Nominal Power: 1.48 kWp

Indices of Performance, Plant: **LS-29**, 1994

- **Yf**, yearly tot.: 804.73 kWh/kWp*a
- **Ls + Lc**, yearly tot.: 310.29 kWh/kWp*a

### Yearly Performance

<table>
<thead>
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<th>1993</th>
<th>1994</th>
<th>1995</th>
<th>AMD</th>
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<tbody>
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<td>Availab. of monitored data</td>
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<td>1</td>
<td>[]</td>
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<tr>
<td>Calculated Month</td>
<td>9</td>
<td>12</td>
<td>12</td>
<td>[]</td>
</tr>
</tbody>
</table>

### Meteorology

- **Glob. Irradiation, horizontal**: 904, 1115, 1118 [kWh/m²]
- **Ambient air temperature**: H sum [°C]

### System Energies

- **Energy output from inverter**: 982, 1191, 1156 [kWh]
- **Useful energy**: 1984, 2340, 2304 [kWh]
- **PV array fraction**: 0.50, 0.51, 0.50
- **Energy consumption**: FA [kWh]

### System Performance Indices

- **Reference yield**: 3.29, 3.05, 3.05 [h/d]
- **Final yield**: 2.41, 2.2, 2.13 [h/d]
- **Array capture losses**: 0.73, 0.72, 0.70 [h/d]
- **System losses**: 0.05, 0.05, 0.05 [h/d]
- **Performance Ratio**: PR [h/d]
- **Array efficiency**: 10.8, 10.6, 10.3 [%]
- **Inverter efficiency**: 1002, 1149, 1148 [%]
- **Overall plant efficiency**: 10.8, 10.6, 10.3 [%]

### Utility Grid

- **Energy to utility grid**: 902, 872, 863 [kWh]
- **Energy from utility grid**: 1002, 1149, 1148 [kWh]

---

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### IEA PVPS TASK 2 REPORT PROGRAMME

#### Photovoltaic Database Report

**Plant Name:** LS-29  
**Country:** Germany  
**Type of plant:** Grid connected  
**Nominal Power:** 1.48 kWp  
**Array area:** 10.08 m²  


<table>
<thead>
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<th>Month</th>
<th>kWh</th>
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</thead>
<tbody>
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<td>MAR</td>
<td>100</td>
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<td>MAY</td>
<td>150</td>
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<td>NOV</td>
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</table>

#### Year: 1993  1994  1995

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<th>1994</th>
<th>1995</th>
<th>AMD</th>
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<tr>
<td>Calculated Month:</td>
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<td>12</td>
<td>12</td>
<td>[ ]</td>
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</tbody>
</table>

#### Meteorology:

- **Glob. Irradiation, horizontal:** [kWh/m²]  
- **Irradiation, in array plane:** [kWh/m²]  
- **Ambient air temperature:** [°C]

#### System Energies:

- **Energy output from inverter:** [kWh]  
- **Useful energy:** [kWh]  
- **PV array fraction:** [ ]  
- **Energy consumption:** [kWh]

#### System Performance Indices:

- **Reference yield:** [h/d]  
- **Final yield:** [h/d]  
- **Array capture losses:** [h/d]  
- **System losses:** [h/d]  
- **Performance Ratio:** [ ]  
- **Array efficiency:** [%]  
- **Inverter efficiency:** [%]  
- **Overall plant efficiency:** [%]

#### Utility Grid:

- **Energy to utility grid:** [kWh]  
- **Energy from utility grid:** [kWh]
### Photovoltaic Database Report

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<thead>
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<td>Country:</td>
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<td>Type of plant:</td>
<td>Grid connected</td>
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<td>Nominal Power:</td>
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<td>Mounting:</td>
<td>Flat roof</td>
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<td>Array area:</td>
<td>170.10 m²</td>
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</table>
Photovoltaic Database Report

Plant Name: MARZILI
Country: Switzerland
Type of plant: Grid connected
Mounting: Flat roof
Nominal Power: 22.71 kWp
Array area: 170.10 m²

Indices of Performance, Plant: MARZILI, 1997

Year: 1993 1994 1995
Availab. of monitored data: 1.00 1.00 1.00 AMD [ ]
Calculated Month: 12 12 12

Meteorology:
Glob. Irradiation, horizontal: [H sum [kWh/m²]]
Irradiation, in array plane: [H' sum [kWh/m²]]
Ambient air temperature: [Tam avr [°C]]

System Energies:
Energy output from inverter: [EIO sum [kWh]]
Useful energy: [Euse sum [kWh]]
PV array fraction: [FA [ ]]
Energy consumption: [Econ sum [kWh]]

System Performance Indices:
Reference yield: 3.19 3.04 3.37 Yr avr [h/d]
Final yield: 2.52 2.3 2.41 Yf avr [h/d]
Array capture losses: 0.42 0.49 0.72 Lc avr [h/d]
System losses: 0.25 0.25 0.24 Ls avr [h/d]
Performance Ratio: 0.79 0.76 0.72 PR [ ]
Array efficiency: 11.6 11.2 10.5 eta A [%]
Inverter efficiency: 90.9 90.4 91 eta inv [%]
Overall plant efficiency: 10.5 10.1 9.6 eta tot [%]

Utility Grid:
Energy to utility grid: 20938 19132 20052 ETU sum [kWh]
Energy from utility grid: 0 0 0 EFU sum [kWh]
### Photovoltaic Database Report

#### Plant Name: MARZILI
Country: Switzerland
Type of plant: Grid connected
Nominal Power: 22.71 kW_p

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<td>Availab. of monitored data:</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
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</tr>
<tr>
<td>Calculated Month:</td>
<td>12</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Meteorology:
- Glob. Irradiation, horizontal: H sum [kWh/m²]
- Irradiation, in array plane: 1179 1290 Hz sum [kWh/m²]
- Ambient air temperature: 8.7 9.8 Tam avr [°C]

#### System Energies:
- Energy output from inverter: 19885 21107 EIO sum [kWh]
- Useful energy: 19885 21107 Euse sum [kWh]
- PV array fraction: 1 1 FA [ ]
- Energy consumption: Econ sum [kWh]

#### System Performance Indices:
- Reference yield: 3.23 3.53 Yr avr [h/d]
- Final yield: 2.39 2.54 Yf avr [h/d]
- Array capture losses: 0.61 0.75 Lc avr [h/d]
- System losses: 0.23 0.23 Ls avr [h/d]
- Performance Ratio: 0.74 0.72 PR [ ]
- Inverter efficiency: 91.4 91.6 eta inv [%]
- Overall plant efficiency: 9.9 9.6 eta tot [%]

#### Utility Grid:
- Energy to utility grid: 19885 21107 ETU sum [kWh]
- Energy from utility grid: 0 0 EFU sum [kWh]