PV SYSTEM PERFORMANCE AND COST ANALYSIS, A REPORT BY IEA PVPS TASK 2

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ABSTRACT: The scope of this paper is to give an overview of the operational performance and system costs of PV systems from the data collected over a 18-month-period as part of the IEA PVPS Task 2 Economic Survey. The 657 datasets analysed are mainly from small residential grid-connected PV systems and also from some larger grid-connected PV systems from 17 countries, they include freestanding, roof top and façade integrated systems. The PV plants investigated were built between 1983 and 2006. The monitoring period for these plants ranges from 1 to 15 years. Analysis of the data available shows a trend towards lower system cost and a higher performance ratio (PR) over time.

Keywords: Analysis, System performance, Cost reduction.

1 COST OVER TIME SURVEY

From June 2005 until December 2006 the interactive database was active for the PV community to enter system economic and operational data of PV systems. The data were entered mainly by PV plant owners/operators. Some data were also supplied in bulk by Task 2 members. In total data from 774 PV systems was collected over an eighteen month period. Of the 774 datasets collected, 657 sets from PV systems from 17 countries contained useful data for this evaluation. The remaining 117 were either incomplete or double entries and had to be deleted. The data from the 657 sets contain 549 sets with valid economical data. Table 1 shows a list of the data used for the evaluation.

Table 1: Overview of data used for the analysis.

	Systems	Years
Plant information	657	
Nominal module efficiency	232	
System cost	549	
Yield data	340	1 100
Performance data	174	519

In Figure 1 all the 657 systems are grouped by country. The dominant entry is from the USA with 300 systems. In Table 2 the number of entries and total and average nominal power per country is shown. The number of systems per country ranges from 1 for Turkey to 300 for the United States. The total nominal power of all the 657 systems is 16 156 kW.

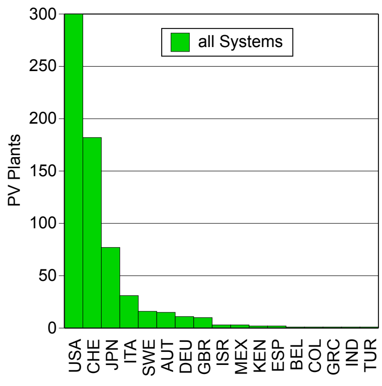

Figure 1: Datasets by country.

Table 2: Overview of all the system data used in this paper.

Country	ISO country code	Total systems	Total nominal power [kW]	Average nominal power [kW]
United States	USA	300	1 582.5	5.3
Switzerland	CHE	182	7 046.5	38.7
Japan	JPN	77	1 517.4	19.7
Italy	ITA	31	5 117.0	165.1
Sweden	SWE	16	345.3	21.6
Austria	AUT	15	126.1	8.4
Germany	DEU	11	135.6	12.3
United Kingdom	GBR	10	256.5	25.6
Israel	ISR	3	1.1	0.4
Mexico	MEX	3	5.2	1.7
Kenya	KEN	2	0.1	0.0
Spain	ESP	2	10.8	5.4
Belgium	BEL	1	5.2	5.2
Colombia	COL	1	0.8	0.8
Greece	GRC	1	3.0	3.0
India	IND	1	1.0	1.0
Turkey	TUR	1	2.0	2.0
	17	**657**	**16 156**	**24.6**

295 PV systems in the USA were built in the years 2003 to 2005 and 229 PV systems have a nominal power ranging from 1 to 10 kW.

As shown in Table 3, 645 of the 657 systems are grid-connected PV plants and 267 of the 657 are domestic systems. The type of mounting was not reported in 340 cases. 119 sloped-roof mounted systems are on top of the list.

Table 3: List for the type of plant, typical use and mounting with number of systems for each section.

Type of plant		Typical use		Mounting	
Grid-connected	645	Domestic	267	NA	340
Grid-connected hybrid	4	Power station	194	Sloped roof	119
Stand-alone	7	Other	73	Flat roof	100
Stand-alone hybrid	1	Office	43	Free-standing	40
		Appartments	28	Sloped roof, integrated	25
		Housing-other	22	Facade, integrated	13
		NA	10	Other	9
		Factory	9	Facade	8
		Other professional	5	Sound barrier	2
		Cath. protection	3	Flat roof, integrated	1
		Other rural	1		
		Vacation house	1		
		Water pumping	1		

About 400 systems of the 657 systems are smaller than 10 kW (Figure 2).

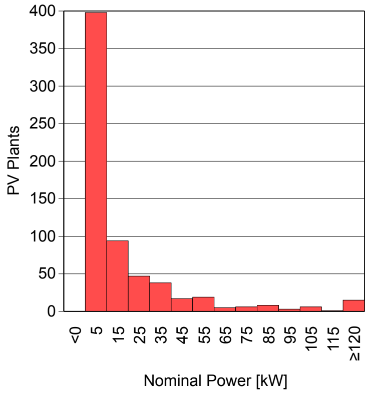

Figure 2: Datasets by nominal power.

A comprehensive analysis of all the data collected in this economic survey will be published in an IEA PVPS Task 2 report in September 2007 [2]. The report also contains case studies from eight Task 2 member countries on system cost, yield over time, performance over time and PV plant failure.

2 ECONOMIC DATA

All the cost data were converted into 2005 prices and into USD. The tables used for this conversion were the OECD consumer price index (CPI), 2007 and the historical exchange rates (HExR), 2007.

In total 549 datasets containing valid economical data from 12 countries were used for this section. The year of construction of the PV plants ranges from 1983 to 2006. A large part, 293 systems, are systems from the United States. Figure 3 shows a histogram of the plant cost. 55% of the plants are in the 8 to 10 USD/W range.

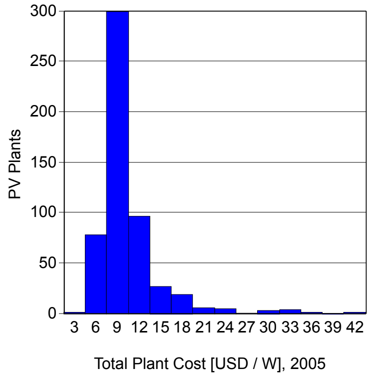

Figure 3: Plant costs.

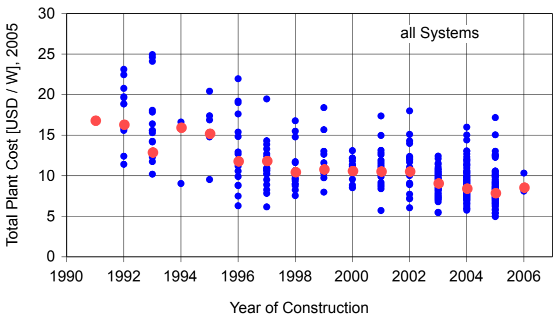

Figure 4: System costs over time, all data.

In Figure 4 the plant costs over time are shown, including all the values and the mean value for each year from 1989 to 2006. In Figure 5 the values for the United States were omitted. Both figures show a clear trend of a decrease in plant cost over time, from 16 USD/W in 1994 to 8 USD/W in 2004.

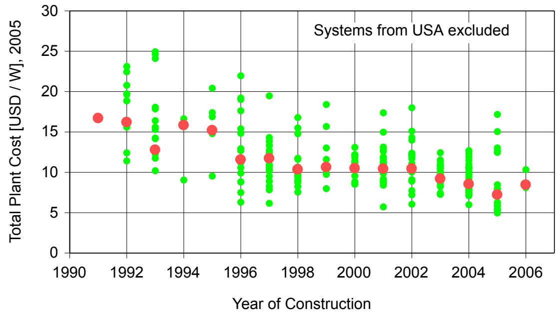

Figure 5: Cost over time, excluding data from USA.

3 YIELD DATA

In this section the yield data from 340 grid-connected PV systems with a total of 1 100 operational years are shown in the Figures 6 and 7. The final yield (Y_f) is the ratio of the energy produced by the PV plant to the nominal power (P_0). The final yield is a representative figure to compare similar PV systems in a specific geographic region.

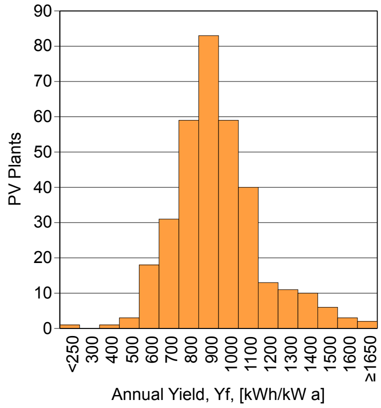

Figure 6: Annual yield.

The annual yield is dependent on the type of mounting, vertical on a façade or inclined on a roof and also on the location as shown in Figure 7.

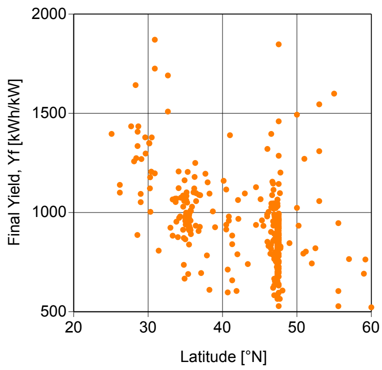

Figure 7: Annual final yield (Y_f) vs. northern latitude.

In Figure 7 the final yield is shown relative to the geographical latitude of the northern hemisphere, ranging from locations in the south of Japan, the south of the United States, central Europe to Sweden. About half of the PV plants are located in Switzerland with a total 680 operational years.

4 NOMINAL MODULE EFFICIENCY

The efficiency value of about 35% of the systems is around 12.5% to 13.5%. In Figure 8 the nominal module efficiency is shown relative to year of construction for 222 of the systems built from 1991 to 2006. The mean value for each year is also shown. The overall trend is an increase from about 11.5% to 12.5% of the installed nominal module efficiency for the 11 year period from 1994 to 2004. Seven systems from the USA with a module efficiency of around 10% account for the lower mean value in 2005. The year 1998 contains five plants with amorphous modules with lower efficiencies mainly from Japan.

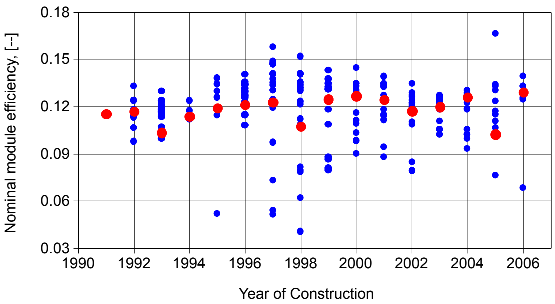

Figure 8: Nominal efficiency over time.

5 PERFORMANCE DATA

The performance ratio (PR) is the ratio of the final yield (Y_f) to the reference yield (Y_r) for a given period. The value of the reference yield is identical to that of the irradiation on the PV array plane (H_i).

The performance ratio can be used to compare PV systems, independent of size, mounting and location. It expresses how much of the available solar energy is converted into electrical energy actually used.

Table 4 shows all 174 PV systems with performance data grouped by country.

Country	PR data-sets Plants	Operational years	years / plant
JPN	70	226	3.23
CHE	32	158	4.94
ITA	24	57	2.38
USA	22	26	1.18
AUT	12	19	1.58
SWE	5	15	3.00
DEU	3	5	1.67
ESP	2	4	2.00
BEL	1	4	4.00
MEX	2	3	1.50
GBR	1	2	2.00
11	**174**	**519**	**2.98**

Table 4: Performance data.

From the survey performance data from 1983 to 2005 from 174 grid-connected PV systems with a total of 519 operational years are available. Most systems with performance data are from Japan, 70 PV plants with 226 operational years from 1996 to 2004 (Table 4).

The values used in the Figures 9 and 10 are the mean values for the whole monitoring period of the system. The monitoring period for each system varies from 1 to 14 years.

Of the 174 PV systems represented in figure 9 about 35% are in the PR range from 0.725 to 0.775.

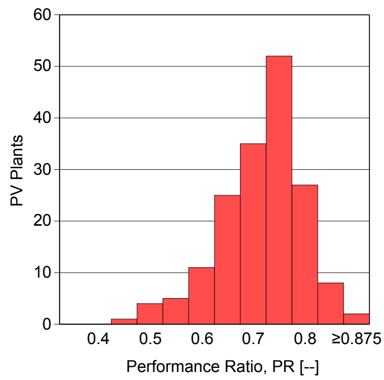

Figure 9: Distribution of performance ratio.

Figure 10 shows the performance over time for more than 170 PV systems built between 1991 and 2005. The performance over time shows a trend of the mean annual PR from 0.68 in 1994 to 0.72 in 2004.

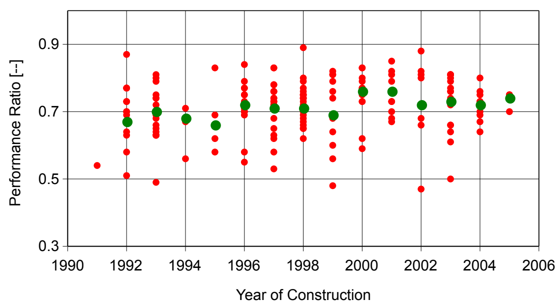

Figure 10: Performance ratio over time.

6 PLANT FAILURE AND MAINTENANCE

The values collected on non-availability of the system and on maintenance and maintenance costs do not represent a representative sample.

For instance, only 28 of 340 systems with yield have reports on failure. From 1 100 operational years, only for 66 years there is a record of no failure and for 76 years failure is reported. That leaves 958 operational years without a report on failure, that does not mean no failure, it means no data.

From Japan comes a valuable contribution on system failure in the form of a survey carried out in Japan by JET-AIST in 2002 to 2004 [2]. From 725 replies of the survey on failures on residential PV systems, 639 reported no significant failure and in 86 cases a first time failure was reported (Figure 11).

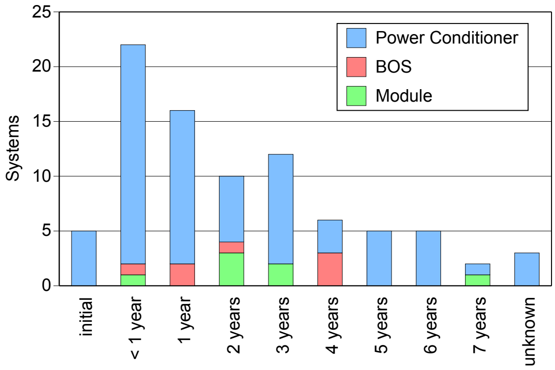

Figure 11: Distribution of operational year of the first failure after installation.

As shown in Figure 11 the most common failure is a failure of the power conditioner and the failure is most likely to occur before the second year of operation. The most common failures are failures of the power conditioner (inverter). Module failures and failures of the BOS (balance of system, cables or switches) have a lower probability.

7 CONCLUSIONS

All the 657 datasets selected for this paper have a data entry for the nominal power (P_0) plus at least one entry for: the total system cost, one full year of yield data (Y_f) or one full year of performance data (PR). 60% of the systems are smaller than 10 kW.

In total, 84% of the data contain cost data. The year of construction varies from 1983 to 2006. A significant finding of this paper is a clear trend towards lower system cost over time from 16 USD/W in 1994 to 8 USD/W in 2004.

52% of the datasets contain yield data (Y_f) with a total of 1 100 operational years. As the annual yield is dependent on the location and on the type of mounting, only similar PV systems in the same geographical location can be compared. There are three main groups of locations for the systems analysed: Israel and southern Japan with a Y_f of about 1 400 kWh/kW, Florida, USA, with a Y_f of 1 000 kWh/kW and central Europe with a Y_f of 900 kWh/kW.

26% of the datasets contain performance data (PR) with a total of 519 operational years. The year of construction ranges from 1991 to 2005. The average plant performance of annual PR increases over time from 0.68 in 1994 to 0.72 in 2004.

An important finding of this survey is that the performance ratio has increased over time, partly because of an increase in the nominal module efficiency. In the survey carried out, however, the reporting on outages and the type of failure is minimal. Accurate reporting on failures of PV systems as part of the monitoring would greatly contribute to the understanding of long-term behaviour of PV systems. Without such reporting one can only guess that the performance ratio has also increased because of an increased reliability of PV systems over time.

Performance, reliability and cost data of PV systems are most important for a broad PV implementation and dissemination strategy in future. While the number of installed PV systems grows very rapidly in several countries (e.g. in Germany due to the feed-in tariff), the number of available PV systems, which are well monitored, seems to decrease at the same time. It is due to this lack of sufficient sample size that the results given in this paper may not always be representative for the relevant country. There is an essential need of reliable and long-term information on the economic and technical performance of PV systems.

The authors wish to thank the colleagues of IEA PVPS Task 2 for providing operational data of PV systems of their countries for this paper.

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ACKKNOWLEDGMENTS

This work is supported by the members of the IEA PVPS Pool Switzerland:
Energy Consultancy, Canton Basel City,
Municipal Utility of Zurich (EWZ),
ScanE, Canton Geneva,
Mont Soleil Association,
Swiss Federal Office of Energy (BFE),
SWISSOLAR.

This work is also supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) [contract no. 0329640D].