IEA INTERNATIONAL ENERGY AGENCY

Trends in PV Power Applications in selected IEA countries between 1992 and 1997

Task 1
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PVPS
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

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Trends in PV Power Applications in Selected IEA Countries Between 1992 and 1997

The Third of a Series of Survey Reports

Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation 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 is one of the collaborative R & D agreements established within the IEA, and since 1993, its participants 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. Currently seven Tasks have been established and a further two are in preparation.

The twenty one members participating in Task 1 are Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), European Commission, Finland (FIN), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), The Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), The United Kingdom (GBR) and The United States of America (USA).

The objective of Task 1 is to promote and facilitate the exchange and dissemination of information on the technical, economic and environmental aspects of photovoltaic power systems for utility applications and other users.

This report has been prepared under the supervision of Task 1 by: Donna Munro and Emily Rudkin of Halcrow Gilbert Associates (GBR) and approved by the PVPS Programme Executive Committee.

Executive Summary

This report presents a description of the status of photovoltaic (PV) power systems in the 20 participating countries[1] of the IEA Photovoltaic Power Systems Programme. A survey of the status of PV power systems applications and markets in each country is conducted every two years and a report is then published interpreting the information in these national reports. This third international survey report presents an overview of PV power systems applications and markets at the end of 1997 and analyses the trends in PV power systems implementation since 1992.

Photovoltaic Power Systems

For the purpose of this survey, four primary applications of PV were identified: off-grid domestic, off-grid non-domestic, on-grid distributed and on-grid centralised. The box opposite describes each of these applications.

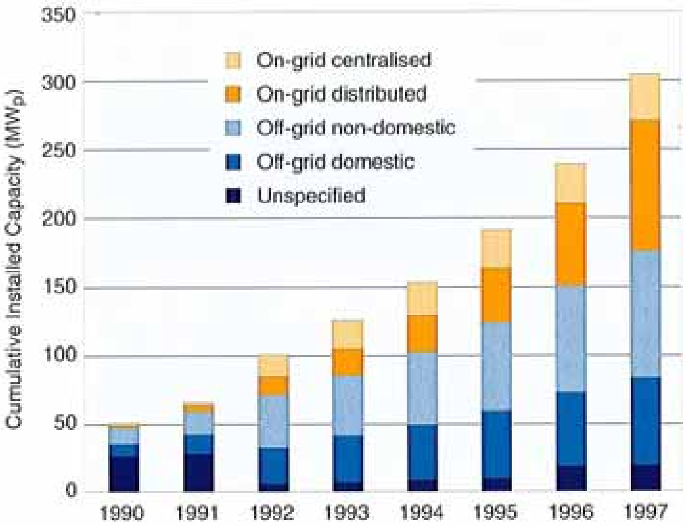


Figure 1 - Cumulative installed PV power by application in the reporting countries

Figure 1 shows the cumulatively installed PV power in the reporting countries between 1990 and 1997. It can be seen that the installed power increased from 51 MW_p in 1990 to 304 MW_p in 1997, an average yearly growth rate of 25 %. Installed power refers to (terrestrial) applications with a peak rating of 40 W or more.

Figure 2 shows the PV power installed annually in the reporting countries for the years 1993 to 1997 divided into the four applications defined above. In 1997,

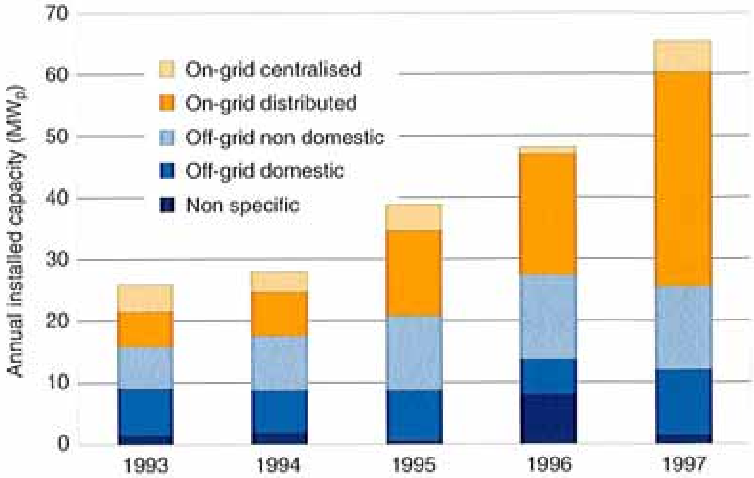


Figure 2 - Annual installed PV power by application in the reporting countries

65 MW_p of PV was installed, and it is clear that there has been a strong trend for increasing quantities of on-grid distributed systems to be installed.

Table 1 *(see page 4)* summarises the quantity of photovoltaic power installed and modules produced in the reporting countries. If the power installed per year in the reporting countries is compared to the module production, it can be seen that only 65 % of modules produced in 1997 are accounted for. The remaining modules are mainly exported to the rest of the world, although some will be used for low power applications below 40 W_p in the reporting countries. The reporting countries account for a large part of the module production world-wide, at a rough estimate around 90 %. However they account for below 60 % of the world market for PV modules.

Demonstration of Applications for PV

The uptake of PV technology has been encouraged by demonstration and field test programmes undertaken in all the reporting countries. There is an increasing trend for demonstration programmes to focus on, or include, on-grid systems. In a few countries, where major demonstration programmes have been conducted in the past, the emphasis is currently moving towards market incentive programmes rather than demonstration programmes. Successful market stimulation programmes are reported to be underway in Germany, Japan and the USA.

Demonstration programmes focusing on on-grid distributed PV systems are underway in Austria,

1 Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), Finland (FIN), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), the Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), the United Kingdom (GBR), the United States of America (USA)

Off-grid domestic

Off-grid domestic systems provide electricity to isolated households in remote areas. They have been installed throughout the world, particularly in developing countries, where they are often the most appropriate technology to meet the energy demands of rural communities. They are primarily installed in remote areas such as isolated villages or islands, where the use of PV may be more economical than extending the utility grid for distances exceeding 1 or 2 kilometres. Off-grid domestic PV systems are common in Australia, France, Germany, Italy, Mexico, the Netherlands, Spain, Switzerland and the USA with each country having over 2 MW_p cumulative installed at the end of 1997

Off-grid non-domestic

Photovoltaic power systems are used to power a variety of off-grid non-domestic applications including water pumping, vaccine refrigeration, remote communications, lighting, safety, control and protection devices. Photovoltaics have been cost effective for a number of years supplying these high value applications. As PV technologies continue to improve and costs decrease, more such applications will become viable and so the size of the market will continue to grow. In many of the reporting countries, including Australia, Canada, Israel, Korea, the United Kingdom and the U.S.A., this is the sector where most PV power systems have been installed. This sector accounted for over 30 % of the PV power capacity installed by the end of 1997.

On-grid distributed

The installation of on-grid distributed PV systems is a relatively recent application where a PV system is installed to supply power to a building, or other load, feeding electricity back into the utility grid at times when the electricity generated exceeds the load. Systems are typically between 1 kW_p and 50 kW_p in size and may be integrated into buildings or other structures. The size of this market has grown substantially with the implementation of national and international demonstration programmes: in 1992 on-grid distributed systems accounted for 14 % of installed power, whereas in 1997 they accounted for over 30 %. This application sector is of particular importance in Germany, Japan and Switzerland where it accounted for 68 %, 64 % and 63 % of installed power respectively.

On-grid centralised

There are two main purposes for installation of on-grid centralised PV systems: they may be used as an alternative to centralised power generation, or for strengthening of the utility distribution-grid. Utilities in a number of countries have been interested in investigating the feasibility of these types of power plants and hence set up a number of demonstration projects ranging in size from hundreds of kilowatts to over 5 MW_p. The total installed on-grid centralised capacity in the countries surveyed was 35 MW_p at the end of 1997.

Table 1 - Cumulative installed PV power and module production in the reporting countries

Year	Off-grid power cumulative installed and percentage increase		On-grid power cumulative installed and percentage increase		Total PV power installed and percentage increase		Power installed per year and percentage increase		Module production
	MW_p	%	MW_p	%	MW_p	%	MW_p	%	MW_p
1992	69		30		99				
1993	85	23	40	34	124	26	25		52
1994	102	21	50	26	152	22	28	8	
1995	123	20	68	36	191	25	39	39	56
1996	148	21	91	31	239	25	48	24	
1997	173	17	131	45	304	27	65	36	100

Denmark, Germany, Italy, Japan, the Netherlands, Switzerland and the UK. Many of these demonstration programmes apply to particular groups of users. Programmes reported include those focusing on housing, schools, commercial buildings and public facilities. Many countries which do not have demonstration programmes have initiated a number of individual on-grid demonstration projects including Canada, Israel, Korea, Mexico, Norway, Portugal and Sweden.

The demonstration or dissemination programmes in Canada, France, Portugal, and Korea concentrate on off-grid systems. These countries all have large areas with rural populations isolated from the grid. The PV for the North demonstration programme in Canada, focuses on adaptation of technologies for performance in cold climates. These countries also report some on-grid systems being demonstrated.

On-grid centralised PV power plants have been demonstrated in some countries where there is a strong utility interest in PV and conditions are suitable in terms of climate and land availability. A number of grid-connected, centralised PV demonstration plants have been set up in Germany, Italy, Japan, Spain, Switzerland and the USA generating reliable power for utility grids and providing experience in the construction, operation and performance of such systems. However utility interest is now tending to focus on distributed PV plants and few centralised plants were started in 1996 or 1997.

Status of the PV Industry

The current trend in the PV industry is towards increased manufacturing capacity and large investments have been made in new manufacturing facilities. Larger and more efficient production plants, which utilise the latest technologies, are crucial in reducing production costs and further developing the market.

The breakdown of PV production and production capacity in 1997 between different regions and different materials is shown in Table 2. The total module production of 100 MW_p in 1997 is an increase of 78 % from 1995 when total production was 56 MW_p. PV module and cell annual manufacturing capacity increased from 115 MW_p in 1995 to over 200 MW_p in 1997.

Table 2: PV Production in MW_p in the reporting IEA countries in 1997

Region	Cell production	Module production	Module production capacity	a-Si production	Crystalline silicon module production	Other module production
USA and Canada	51	36	72	2.5	29	4.4
Japan	29	34	81	2.4	32	0
Europe	15	22	48	0.9	21	0
Rest[1]	8	8	8	0	8	0
Totals	103	100	209	5.8	90	4.4

1. Rest includes production in Korea and Australia

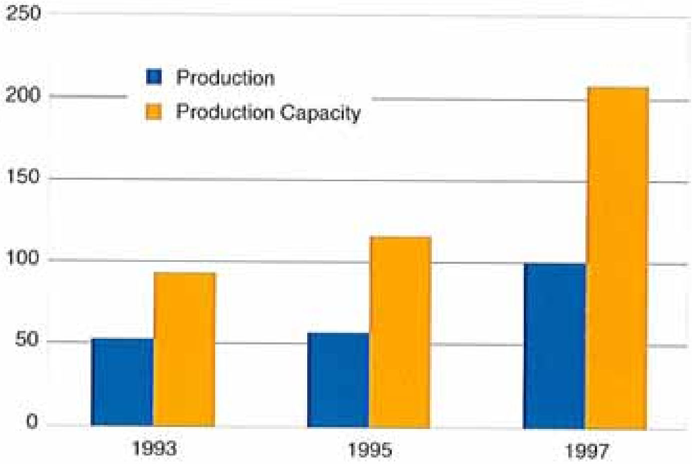


Figure 3 - PV module production and capacity in the reporting IEA countries

Figure 3 shows the total quantity of PV power modules produced in the reporting countries in the years 1993, 1995 and 1997 and compares this to the total production capacity at the time. It can be seen that although production and capacity both increased, the utilisation of capacity for module production remained fairly constant at around the 50 % mark. This does not necessarily mean that PV production facilities were operating this far below capacity. New plants which only came on stream part way through the year, will have produced substantially less than their full annual capacity. Some manufacturers have the capacity to operate continuously with 3 shifts a day, while their current operational procedures only involve working 1 or 2 shifts. In addition some vertically integrated module manufacturers sold a part of their production on as PV cells rather than modules.

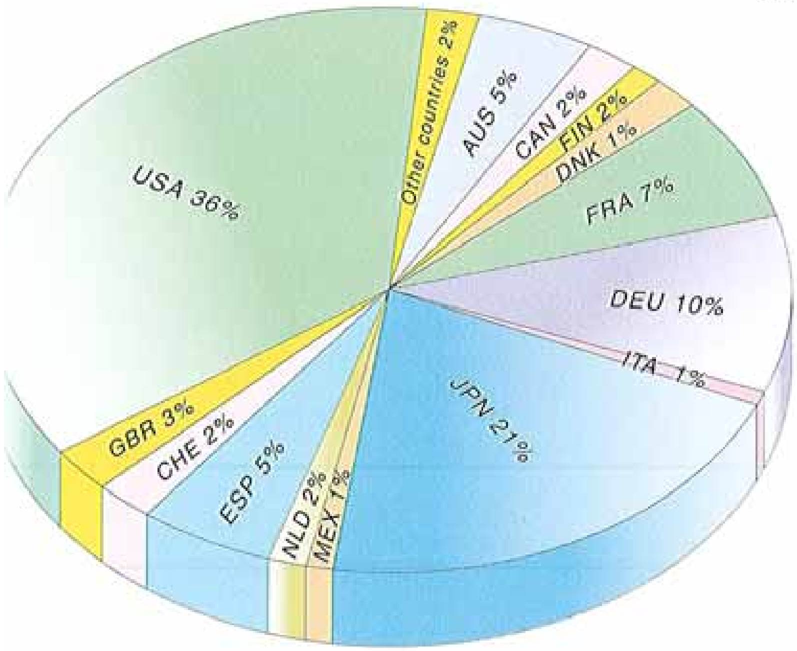


Figure 4 - Distribution of PV industry revenue between the reporting countries in 1997 (Total 1 133 MUSD)

In 1997, crystalline silicon accounted for nearly 90 % of module production and just under 80 % of production capacity. Thin film technologies are continually improving, and in 1997 10 MW_p of thin film modules were produced, a market share of 10 %. They use materials such as amorphous silicon, cadmium telluride, copper indium diselenide and thin film silicon. Additional thin film production facilities are reported to be under construction. These materials offer potentially lower costs due to their reduced requirements for raw materials and suitability for large scale production processes. Research and development into thin film technologies and manufacturing processes is continuing.

The PV industry revenue in the reporting countries was estimated to be in the region of 1 133 MUSD in 1997, and 873 MUSD in 1996, a 29 % annual growth rate. This resulted in over 9 100 full time equivalent labour places associated with the PV industry in 1997. Since 1995 the number of labour places has grown by approximately 16 % with the majority of the growth in manufacturing. Figure 4 shows the value of PV business split between the reporting countries in 1997.

Module and System Prices

Module prices represent a significant proportion of the price of PV power systems and have decreased in the past due to the expanding market and increased production. Future decreases in module prices are expected.

In 1997, the average price for a small order of crystalline silicon modules, weighted according to the module production of each country, was 5.0 USD/W_p. Non-standard modules for building integration tended to have higher prices. For a large order of crystalline silicon modules the average price was 4.1 USD/W_p. These are factory prices to distributors, approximately 20 % should be added for prices to customers. Prices for amorphous silicon modules were only available from a few countries and ranged between 4.5 - 6.6 USD per W_p for a small order, and 3.3 - 6.0 USD per W_p for a large order.

Table 3 *(see next page)* shows average prices for large and small orders of crystalline silicon modules in 1993, 1995 and 1997. The figures in Table 3 show a significant fall in module prices between 1993 and 1997: 41 % for small orders and 27 % for larger orders. Note fluctuating exchange rates may have affected module prices in some countries.

Prices for entire PV systems vary widely and depend on a range of factors including system size, location, customer and the technical specification. For building integrated systems, the cost of the system varies significantly depending on whether the system is part of a

Table 3: Average prices for large and small orders of crystalline silicon modules in 1993, 1995 and 1997

Year	Small module order (USD/W_p)	Large module order (USD/W_p)
1997	5.0	4.1
1995	5.5	4.9
1993	8.5	5.6

retrofit or is integrated into the roof structure of a new building. Typical system prices in 1997 in the reporting countries are shown in Table 4. Prices do not include recurring charges after installation such as battery replacement or operation and maintenance. The prices associated with on-grid systems were generally lower than those for off-grid systems because no storage batteries and associated components are necessary.

increasing number of people are prepared to pay a premium for electricity generated from PV, with 20 000 customers explicitly choosing to buy PV generated power. In a number of countries, including Canada, France, Portugal, Spain and Sweden, concern was expressed as to the high cost of PV systems although perceptions were generally positive. As a result PV was seen as more relevant to remote applications.

The Future

National targets for the proportion of electricity to be supplied by renewable sources have been set for various future dates by a number of countries including Australia, Denmark, the Netherlands and Switzerland. Targets for installed PV capacity have been specified by a number of the reporting countries. Japan plans to install 5 000 MW_p by 2010; Korea has a long term goal of installing 20 MW_p for island off-grid applications; and the Netherlands intends to install 250 MW_p of grid-connected PV by 2010 and 1 250 MW_p by 2020. In Germany a 100 000 Roofs PV Programme is under consideration. These targets indicate that a multi-gigawatt level of installed capacity and sustained growth can be expected over the next years.

Table 4: Turnkey photovoltaic power system prices for different applications in the reporting countries

	Price by Application (USD/W_p)					
	Off-grid 40-1 000 W_p	Off-grid 1-4 kW_p	On-grid 1-4 kW_p	On-grid 10-50 kW_p Ground mounted	On-grid 10-50 kW_p Building integrated	On-grid > 50 kW_p
1997	8-53	8-36	5-20	6-11	6-21	6-36

Policy and Perceptions

A wide variety of initiatives for promoting the use of photovoltaics, or renewable energy in general, exist in the reporting countries. Market deployment initiatives are being undertaken in a number of countries particularly where it is felt that the market for a particular application of PV is ready for stimulation. These initiatives often follow on from successful demonstration programmes where it is felt that the market has matured beyond the point of needing demonstration programmes.

Utilities' perceptions of PV systems were reported to be generally favourable in the reporting countries, with the electricity utilities in several countries actively promoting PV through various dissemination programmes. Some utilities in the reporting countries were concerned about the effect of large numbers of small embedded generators on the electricity distribution systems. Research programmes are currently being undertaken in a number of countries and through Task V of the IEA PV Power Systems Programme to investigate this.

The public perception of PV was generally positive throughout the reporting countries. In Japan, there is a positive public response to PV through ambitious programmes such as the Residential PV System Dissemination programme. In Switzerland, an

Production capacity in 1997 was 210 MW_p and plans to install a further 300 MW_p have been announced. It is clear that substantial investment in new manufacturing facilities is currently on-going and planned for the future.

Improvements in PV technologies are continually being introduced, both in PV cell development and module fabrication processes. It is apparent that the commercial production of new thin film modules is beginning, which offer the promise of low cost and mass production volume, albeit with a lower conversion efficiency than crystalline silicon.

Based on the average historic growth rate of 25 % per year of installed PV power since 1993, it is estimated that by the year 2000 over 590 MW_p of PV power will be installed in the reporting countries.

There are many future opportunities within the field of photovoltaics both for those within the PV industry and for potential users of the technology.

Chapter 1

Introduction

1.1 The Photovoltaic Power Systems Programme

The Photovoltaic Power Systems Programme was established in 1993. Since then it has formed the basis for a co-operative programme of research, development, analysis and information exchange related to the application of photovoltaics between participating countries.

The mission of the Photovoltaic Power Systems Programme is "to enhance the international collaboration efforts through which photovoltaic solar energy becomes a significant renewable energy option in the near future". The underlying assumption is that the market for PV systems will gradually expand from the present niche markets of remote applications and consumer products, to the utility market, through building-integrated and other diffused and centralised PV generation systems. This market expansion requires the availability of, and access to, reliable information on PV systems, applications and markets to be shared with the various actors.

The IEA study "Enhancing the Market Deployment of Energy Technology", published in 1997, affirms that "the timing and manner in which the PV market will develop in the future is not evident, but expansion can be viewed as a certainty. Deployment will increase if technology improvements deliver the cost reductions and performance improvements that are widely believed to be possible".

The PVPS programme aims to realise its mission by adopting the following objectives related to reliable photovoltaic power system applications for utilities, energy service providers and other public and private users.

1. To contribute to the cost reduction of PV power applications.
2. To increase the awareness of the potential and value of PV power systems.
3. To foster the removal of technical and non-technical barriers.
4. To enhance technology co-operation.

The IEA Photovoltaic Power Systems Programme is divided into a number of tasks, as shown in Table 1.1. There are nine tasks in total, two of these are now closed, five are currently on-going and two further tasks are under preparation.

The objective of Task I is to promote and facilitate the exchange and dissemination of information on the technical, economic and environmental characteristics of PV power systems for applications in participating countries. The main activities undertaken to achieve this objective are: the preparation and dissemination of a series of bi-annual International Survey Reports, of which this is the third in the series; the regular production and distribution of the newsletter PV Power; and special information activities which have so far led to the production of three reports entitled "Buy Back Rates and Incentives", "R & D Status and National Strategies" and "Environmental Aspects of PV"; and a book entitled "PV in Cold Climates".

In addition, the IEA has organised two international executive conferences in order to raise utility and government awareness of PV. The first conference, held in Taormina, Italy, in 1990 gathered utility executives, PV manufacturers and government leaders to develop a strategic blueprint for market development of PV applications based on cost

Table 1.1: Tasks in the Photovoltaic Power Systems Programme

Task	Description	Status
I	Exchange and Dissemination of Information on Photovoltaic Power Systems	On-going
II	Operational Performance and Design of Photovoltaic Power Systems and Subsystems	On-going
III	Use of Photovoltaic Systems in Stand Alone and Island Applications	On-going
IV	Modelling of Distributed Photovoltaic Power Generation in Support of the Electric Grid	Closed
V	Grid Interconnection of Building Integrated and Other Dispersed PV Power Systems	On-going
VI	Design and Operation of Modular Photovoltaic Plants for Large Scale Power Generation	Closed
VII	Photovoltaic Power Systems in the Built Environment	On-going
VIII	Very Large Scale PV Power Generation Systems in Remote Areas	In preparation
IX	Deployment of PV Technologies, Co-operation with Developing Countries	In preparation

effectiveness. The second Conference, held in Sun Valley, Idaho, USA in 1995 demonstrated the rapid evolution of utility business strategy in PV, with discussions focusing on the integration of utility and PV business in the Developing World. The third conference in this series will be held in November 1999 in Venice, Italy, and will focus on "PV Power Systems in Evolving Electricity Markets, Key Issues and Strategic Opportunities".

1.2 Survey Report Scope and Objective

This document summarises the results of the third in a series of surveys on the status of PV power systems applications in those countries participating in the Photovoltaic Power Systems Programme. The data gathered in these surveys are analysed and published every two years. The first International Survey Report was distributed in 1995 and covered the years 1992 and 1993; the second International Survey Report was distributed in 1997 and updated the first report for the years 1994 and 1995; this third report updates the previous two reports for the years 1996 and 1997.

The objective of the survey reports is to present and interpret trends in both PV systems and components being used in the PV power systems market, as well as changing applications within that market, in the context of business situations, policies and relevant non-technical factors in the reporting countries. This report therefore presents a description of the PV products and applications in the PV power systems market in the 20 reporting countries as of the end of 1997 and presents trends in PV power applications between 1992 and 1997.

The survey report is not intended to serve as an introduction to PV power systems, nor is it intended to serve as a policy document. Its purpose is to present data in graphical and tabular form, with related analysis that will allow those interested in the use of PV power systems to draw their own conclusions about the state of a particular application, and future prospects.

The survey reports are intended to meet the needs of those responsible for developing the business strategies of the PV companies, and to aid the development of medium term plans for electricity utilities and other providers of energy services. They should also give guidance to government officials responsible for setting energy policy and preparing national energy plans.

1.3 Survey Method

Data for this report were drawn from national reports supplied by each participating country by the respective national representative. A list of the reporting countries and national representatives is given on the inside front cover. The data collected covered the following main topics:

- The Market Today
- Demonstration and Field Test Programmes
- Industry Status and PV Systems Components
- Policy, Initiatives and Trends

Most national data supplied had an estimated accuracy between 80 % and 100 %, with most data being accurate to within ±10 %. Data on national budgets was normally extremely accurate. Data on installed power was less accurate while data on production levels and costs varied in accuracy depending on the willingness on the national PV industry to provide data for the survey.

The data were collated and this report prepared by the technical writers. The report has been reviewed by the national representatives to ensure the accuracy of the data used and approved by the PVPS programme Executive Committee.

For the purposes of this report installed power refers to (terrestrial) PV applications with a peak rating of 40 W or more.

PV demonstration and field test programmes and projects in operation in 1996 and 1997 are included in this report. Projects currently under construction are briefly summarised.

In order to avoid double counting, a module manufacturer has been defined as a company where the encapsulation of PV modules takes place. The company may also partly or entirely produce the ingots or wafers, process the cells, frame the modules, or fit junction boxes.

Information is also presented on R & D, demonstration and market incentive budgets, labour places, existence of specific environmental regulations which favour PV plants, taxes on environmental pollution (e.g. carbon taxes), and utility and public perceptions of PV.

1.4 Definitions, Symbols and Abbreviations

For the purposes of this report, the following definitions apply.

Demonstration Programme: a programme to demonstrate the operation of PV systems to the general public and potential users/owners.

Final yield (Y_f): the energy delivered to the load per kilowatt peak of installed PV per day.

Market deployment initiatives: initiatives to encourage the market deployment of PV through the use of market instruments such as green pricing, rate based incentives etc. They may be implemented by government, the financing industry, utilities etc.

MUSD: Million U.S. Dollars (see USD).

Off-grid domestic: a PV system installed in a household or village which is not connected to the utility grid.

Off-grid non-domestic: includes PV systems used for a variety of applications such as water pumping, remote communications, safety and protection devices etc. which are not connected to the utility grid.

On-grid centralised: a PV system used for support of the utility distribution grid performing the function of a centralised power station.

On-grid distributed: a PV system installed on consumers' premises usually on the demand side of the electricity meter. This includes grid-connected domestic PV systems and other grid-connected PV systems on commercial buildings and motorway sound barriers etc.

Performance Ratio ($PR=Y_f/Y_r$): defined as the ratio of the final yield to the reference yield, given in percent.

PV: photovoltaic.

PV system: a photovoltaic system including photovoltaic modules, inverters, batteries and all associated installation and control components. When calculating installed photovoltaic capacity only systems with a capacity of 40 W_p or more have been included.

Reference yield (Y_r): this represents the solar energy theoretically available per day per kW_p of PV installed.

USD: U.S. Dollars. This is the currency used throughout the report. Exchange rates are given in Annex A. (see MUSD)

Watts Peak (W_p): W_p is the peak power of a PV module or system under standard test conditions of 1 000 $W.m^{-2}$ irradiance, 25 °C junction temperature and solar reference spectrum AM1.5.

Chapter 2

Implementation of Photovoltaic Systems

This chapter identifies four primary applications for photovoltaic power systems, and looks at the market for each application, illustrating each with a case study. The final sections discuss PV demonstration and field test programmes in the reporting countries and the budgets allocated for market stimulation, demonstration and R&D programmes.

2.1 Applications for Photovoltaics

PV systems have traditionally been used as a power source for those off-grid applications, such as telecommunications and navigational aids, where small amounts of power have a high value and PV is cost competitive. However, in the past 20 years PV costs have steadily decreased and niche markets have developed and expanded in remote areas for both domestic and non-domestic applications. More recently, the potential for the connection of PV systems to the utility grid has been recognised, with the installation of demonstration projects in many countries. These systems, which are increasingly being integrated into existing structures, are likely to become commonplace in the next millennium.

For the purposes of this survey, four primary applications for PV power systems were identified:

- Off-grid domestic
- Off-grid non-domestic
- On-grid distributed
- On-grid centralised

Each of these four applications are described below.

Off-grid domestic

Off-grid domestic systems provide electricity to isolated households in remote areas such as mountainous regions or islands. They provide electricity for lighting, refrigeration and other low power loads such as radio, television and fans and have been installed world-wide, particularly in developing countries, where they are often the most appropriate technology to meet the energy demands of rural communities. Off-grid PV systems generally offer an economic alternative to extension of the utility grid at distances of more than 1 or 2 kilometres from existing lines. The installation of off-grid domestic PV systems is common in a number of countries, with the majority of PV systems installed in Finland, France, Mexico, Norway, Portugal and Sweden powering off-grid domestic applications.

Off-grid non-domestic

Photovoltaic power systems are used to power a variety of off-grid non-domestic applications including water pumps, vaccine refrigeration, remote communications, safety, control and protection devices. Photovoltaics have been cost effective for a number of years in these high value applications. As PV technologies keep improving, and costs decrease, so the size of this market should continue to grow. Australia, Japan and the USA, together account for 73.8 MW_p of installed off-grid non-domestic PV. Other key players are Canada, Germany, Italy and Korea each with over 2 MW_p installed capacity at the end of 1997.

On-grid distributed

On-grid distributed PV systems are a relatively recent application where a PV system is installed to supply power to a building or other load which is connected to the utility grid. The PV system is installed on the consumer's premises on the demand side of the electricity meter. These systems, which may be integrated into buildings or other structures, usually feed electricity back into the utility grid when electricity generated exceeds the building loads. They are used to supply electricity to residential homes, commercial and industrial buildings, and are typically between 1 kW_p and 50 kW_p in size. There are a number of perceived advantages for these systems: distribution losses are reduced because the system is installed at the point of use, no extra land is required for the PV system and costs for mounting systems can be reduced if the system is mounted on an existing structure. Compared to an off-grid system costs are saved because energy storage is not required which also improves system efficiency. With systems supplying power to commercial buildings, the production of the PV electricity may match the load profile of the building. On-grid systems are particularly well suited to regions with high air-conditioning loads, as maximum demand is likely to coincide with maximum supply.

On-grid centralised

There are two main purposes for installation of on-grid centralised PV systems: they may be used as an alternative to centralised power generation from fossil fuels or nuclear, or for strengthening of the utility distribution-grid. A number of grid-connected, centralised PV demonstration plants have been set up in Germany, Italy, Japan, Spain, Switzerland and the

U.S.A. generating reliable power for utility grids and providing experience in the construction, operation and performance of such systems. Utilities in a number of countries were interested in investigating the feasibility of these types of power plants and hence set up a number of demonstration projects. However utility interest is now tending to focus on distributed PV plants and few centralised plants were started in 1996 or 1997. A 1 MW_p PV plant in Munich-Riem, Germany started operation in November 1997 and work is on-going for a 1 MW_p system in Herne, Germany which is expected to start operation in March 1999. A number of other on-grid centralised systems were completed or expanded during 1996 and 1997, including the Serre PV system in Italy described in a case study later in this chapter. The total installed on-grid centralised capacity in the countries surveyed is 35.3 MW_p.

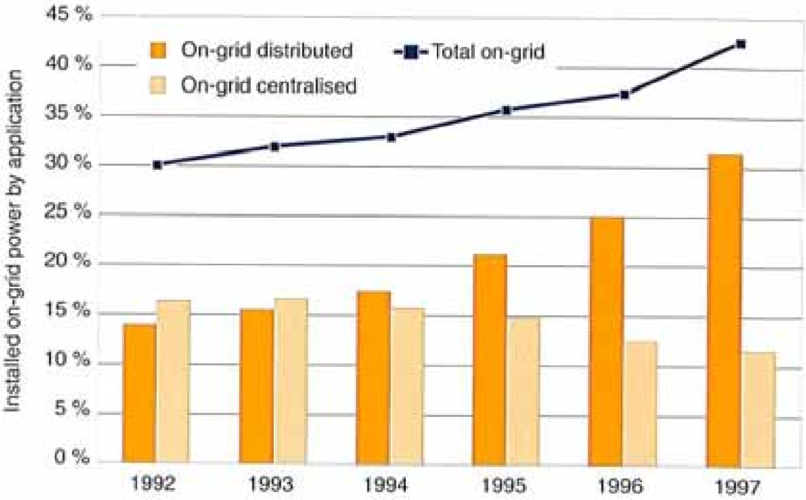


Figure 2.2: Percentage installed on-grid PV power in the reporting countries (centralised and distributed)

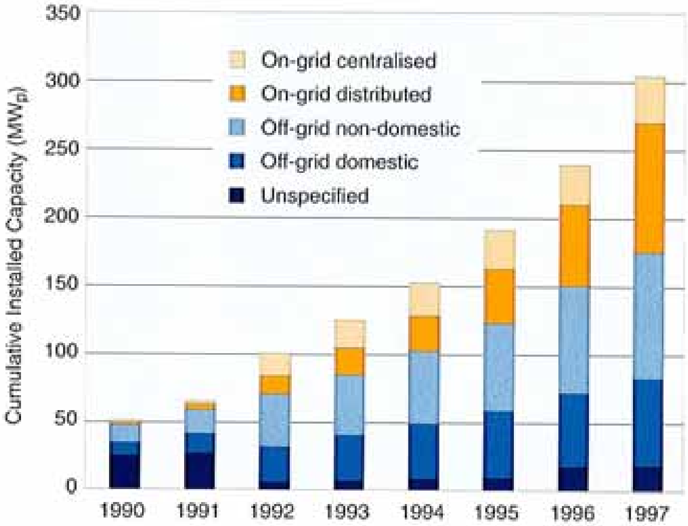


Figure 2.1: Cumulative installed PV power by application in the reporting countries

The breakdown of installed PV power by application in the reporting countries from 1990 to 1997 is shown in Figure 2.1. The unspecified cumulative installed power represents data unable to be separated into application, and mainly represents off-grid systems. The cumulative installed PV power has increased at an average annual rate of 25% since 1992. It must be repeated that this report only covers the 20 countries participating in the IEA PVPS. The world-wide installed power will be significantly higher than the 303.7 MW_p installed in the reporting countries. As a rough estimate the world-wide installed power at the end of 1997 was between 600 and 700 MW_p.

It is apparent from figure 2.1 that the most widespread application for PV power systems is the off-grid sector, although in recent years there has been a significant increase in on-grid systems. Off-grid applications accounted for 70 % of the installed power in 1992 and 57 % in 1997, which translates to an increase in on-grid applications from 30 % in 1992 to 43 % in 1997, as illustrated in figure 2.2. The bulk of this increase was accounted for by a large increase in on-grid distributed systems.

The power installed in 1997 in each country for each application is shown in Table 2.1 *(see page 12)* as well as the total installed PV power and total installed power per capita. From the table, it can be seen that 65.1 MW_p was installed in the reporting countries in 1997. The total cumulative installed power in the reporting countries by the end of 1997 was 303.7 MW_p. The cumulative historic power installed is shown in Table 2.2. *(see page 12)*.

The proportion of the installed power used for each application, in each reporting country in 1997, is shown in Figure 2.3. From the figure the different priorities in the reporting countries can be seen.

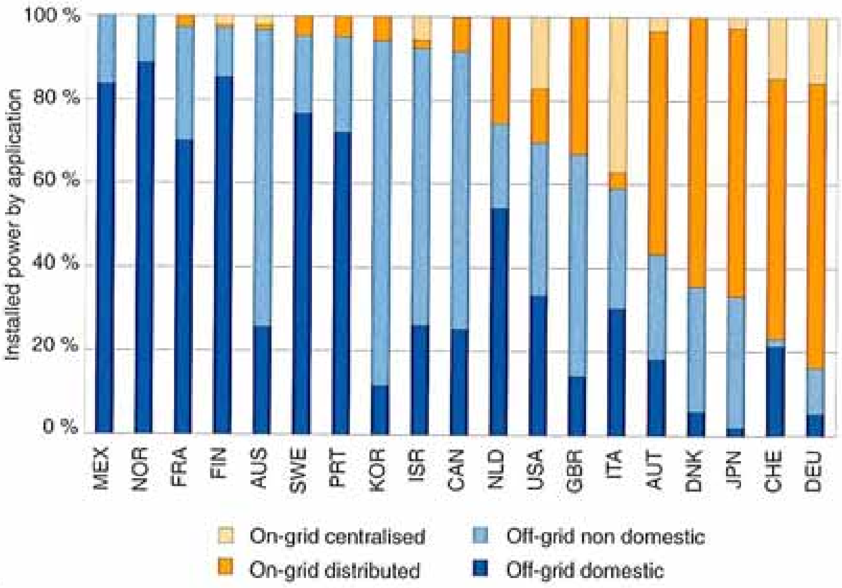


Figure 2.3: Installed power by application in reporting countries in 1997

Table 2.1: Cumulative quantity of PV power installed in reporting countries as of the end of 1997 (kW_p)

Sector / Country	Off-grid domestic (kW_p)	Off-grid non-domestic (kW_p)	On-grid distributed (kW_p)	On-grid centralised (kW_p)	Total installed power (kW_p)	Total installed power per capita (W_p/capita)	Total installed in 1997 (kW_p)
AUS	4 860	13 320	200	320	18 700	1.01	3 000
AUT	403	557	1 178	70	2 208	0.27	469
CAN	853	2 263	254	10	3 380	0.12	820
CHE	2 140	184	6 350	1 450	10 124	1.45	1 032
DNK	25	125	272	0	422	0.08	177
DEU	2 100	4 587	28 676	6 527	41 890	0.51	14 000
ESP	4 168+[1]	758+[1]	361+[1]	1 260+[1]	7 100[2]	0.18	167
FIN	1 500	200	12	30	1 742	0.34	231
FRA	4 330	1 658	131	0	6 119	0.11	1 712
GBR	83	316	190	0	589	0.01	166
ISR	70	176	5	14	265	0.05	55
ITA	5 052	4 814	677	6 166	16 709	0.29	701
JPN	1 078	20 488	41 649	1 490	64 705	0.52	23 905
KOR	296	2 046	133	0	2 475	0.06	362
MEX	9 000	1 998	2	0	11 000	0.12	850
NLD	2 219	821	1 028	0	4 068	0.26	746
NOR	1 470	180	0	0	1 650	0.38	250
PRT	384	102	17	0	503	0.05	92
SWE	1 640	394	93	0	2 127	0.24	278
USA	36 000	40 000	14 000	18 000	108 000	0.41	16 000
TOTAL	**77 671**	**94 987**	**95 228**	**35 337**	**303 776**	**0.32**	**65 013**

1 As at 31 December 1995 *2 Installed capacity as at 31 May 1997*

Table 2.2: Cumulative historic power (kW_p) installed in the reporting countries between 1992, and 1997

Country	1992	1993	1994	1995	1996	1997
AUS	7 300	8 900	10 700	12 700	15 700	18 700
AUT	524	768	1 063	1 361	1 739	2 208
CAN	960	1 240	1 510	1 860	2 560	3 380
CHE	4 910	6 125	7 192	8 133	9 092	10 124
DNK	0	85	100	140	245	442
DEU	5 619	8 900	12 440	17 790	27 890	41 890
ESP	3 950	4 649	5 660	6 547	6 933	7 100[1]
FIN	914	1 034	1 156	1 288	1 511	1 742
FRA	1 751	2 050	2 438	2 953	4 407	6 119
GBR	172	265	338	368	423	589
ISR	100	120	150	180	210	265
ITA	8 480	12 080	14 090	15 795	16 008	16 709
JPN	11 171	14 446	19 291	28 121	40 800	64 705
KOR	1 471	1 631	1 681	1 769	2 113	2 475
MEX	5 500	7 250	8 950	9 350	10 150	11 000
NLD	1 270	1 641	1 976	2 415	3 322	4 068
NOR	300	600	900	1 150	1 400	1 650
PRT	169	219	257	326	411	503
SWE	800	1 040	1 337	1 620	1 849	2 127
USA	43 500	51 500	61 000	77 000	92 000	108 000
TOTAL	**98 861**	**124 543**	**152 229**	**190 866**	**238 763**	**303 776**

1 Installed capacity as at 31 May 1997

In 1997 over 80 % of the installed PV power was off-grid in Australia, Canada, Finland, France, Israel, Korea, Mexico, Norway, Portugal, and Sweden. However the priorities within these countries are different: over 70 % of the installed power in Finland, France, Mexico, Norway, Portugal and Sweden was for off-grid domestic power, whereas in Australia, Israel and Korea the non-domestic sector was by far the largest application. In Italy and the USA the off-grid sector was split almost evenly between domestic and non-domestic applications.

In contrast, in Germany and Switzerland, 84 % and 77 % respectively of the installed power was grid-connected, and in Denmark and Japan, over 60 % of power was grid-connected. In most countries with a high percentage of on-grid systems, the majority of on-grid applications were for distributed PV power. The exceptions to this were Italy and the USA where 90 % and 56 % respectively of the on-grid PV power was centralised.

The annual irradiation levels throughout the world are shown in figure 2.4 along with the final annual yield of selected on-grid PV systems in a number of the reporting countries. The system with the largest annual yield of 1 968 kWh.kW_p^{-1} is located in California where the annual irradiation levels exceed 2 200 kWh.m^{-2}, whilst the systems located at higher latitudes where the trend is for lower irradiation levels, have lower annual yields. It is clear from the figure that the best locations for PV systems are at latitudes of approximately 20° in Africa, the lower United States, the Middle East, Australia and parts of South America. However it should be noted that the most northerly systems are still achieving outputs of over 40 % of the output given for the Californian system.

2.2 Case Studies

In order to provide an illustration of real PV systems in operation, this section describes four PV systems, one from each of the application sectors defined previously. These case studies have been selected to demonstrate the type of systems available, and to give a brief description of their performance, costs and funding sources.

The most appropriate indicators for the performance of a PV system are the yields and the performance ratio. The yields are the daily energy production in kWh normalised by the array rating in kW_p. The final yield, Y_f, is the energy delivered to the load per day per kW_p installed. The reference yield, Y_r, is based on the in-plane irradiance and represents the theoretically available energy per day per kW_p. The performance ratio is the ratio of PV energy actually used to the energy theoretically available, (i.e. Y_f/Y_r) and is normally expressed as a percentage. It is independent of

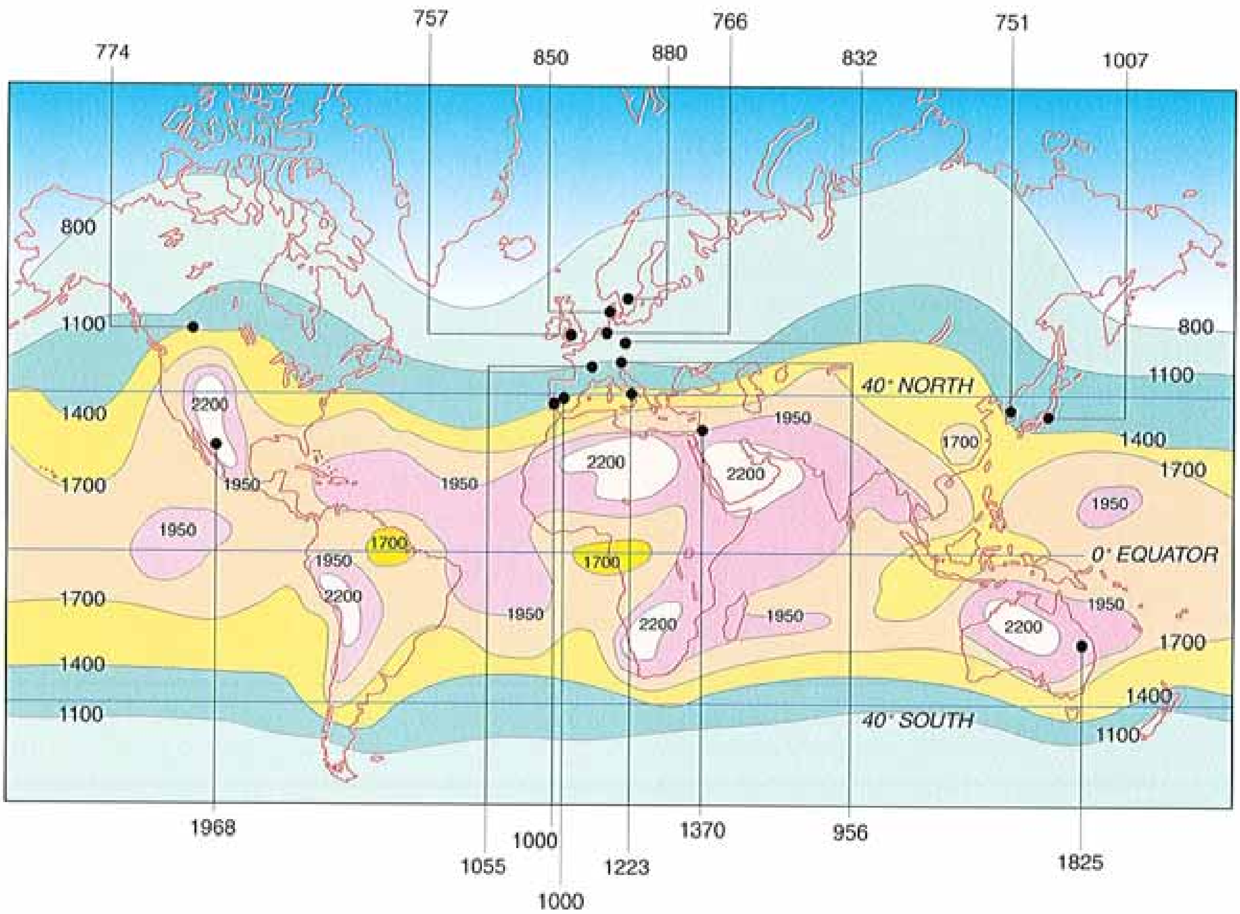


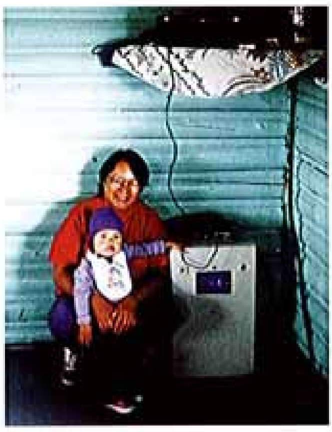
Figure 2.4: Map of world with irradiation levels and final annual yield (kWh .kW_p^{-1}) for one system in each of the reporting countries

location and system size and gives an indication of the combined efficiency of the system components and the extent to which the system is being used. For an off-grid system, performance ratios are typically in the region of 35 % to 60 % whereas for an on-grid system the range is normally between 60 % and 80 %.

2.2.1 Off-grid domestic: Dwellings at the Kitcisakik Summer Ground

Twenty PV systems provide power to the Indian community of Kitcisakik in La Verendrye Park, Quebec, Canada. Financing was received from the Canadian and Quebec governments and operation began in June 1997. The systems, located at 47.5° N, 77° W, operate for five months during the summer when the community is living at their summer grounds.

Each PV system consists of three 50 W_p multicrystalline silicon modules giving an array area of 1.5 m^2 with a nominal rating of 150 W_p. The modules are installed at a tilt angle of 30°, facing 15° E of South, the same angle as the roofs of the dwellings. A 800 VA inverter provides 120 V a.c. (single phase) electricity to the load. Two 220 Ah, 6 volt deep cycle batteries in series provide energy storage with a nominal voltage of 12 V.



The PV systems were installed to meet the electricity demand of 18 families and to power the community centre and water pump. Each household's system typically needs to meet the power requirements of one or two lamps, one television and video, one radio-cassette player and a toaster, totalling a maximum average demand of 750 Wh per day. System performance between May and October is estimated as an average final daily yield of 3.2 $kWh.kW_p^{-1}$ with a performance ratio of 65 %.

Table 2.3: Cost breakdown for Kitcisakik PV systems

Items	Costs (%)
PV module and mounting structure	59
Power conditioning unit	18
Storage batteries	9
Installation	4
DC/AC cabling	2
Other costs (pre-payment system and battery box)	8

The annual useable energy production from each PV system is 72 kWh with an average daily irradiance of 4.9 $kWh.m^{-2}$ in the plane of the PV array.

The price of each installed system was 1 730 USD. If the systems were replicated in greater quantities, it is estimated that the price of each system would drop to approximately 1 440 USD, a reduction of 20 %. In comparison, the local utility Hydro-Quebec estimated that connection of the summer camp to the grid would require a 25 kV line over a distance of 50 km and cost approximately 3.3 MUSD. A breakdown of the system costs is given in table 2.3.

The project was set up as a demonstration of a pre-payment technology which was developed to allow the commercialisation of electricity in remote communities not usually accessible to grid power. The technology requires purchasing of energy units, and if the user has not purchased the required units the controller shuts off access to the electricity. Upon installation, each family paid an initial fee of 360 USD. They received in exchange a "button" with 400 units equivalent to ten days of electricity. Subsequent buttons cost 14.4 USD, of which each family is expected to use three per month, providing an average of 14.4 kWh per month of electricity. Correspondingly, the cost to the families of the PV generated electricity is 3 USD per kWh.

The PV systems replace individual gasoline generators of 1 to 5 kVA. Previously each family carried their fuel over land and water, for a distance of 65 kilometres. Families would spend on average 58 USD per month on gasoline compared with an estimated 43 USD with the PV systems.

The funding for the systems was provided by the Quebec government through the PADTE programme of the Ministère des Ressources Naturelles Québec (22 %), the Canadian government through CANMET's division of Renewable Energy Technologies of Natural Resources Canada (28 %), Enersite International Inc. (22 %) and 28 % by the Mando Co-operative formed by the band leaders of the Kitcisakik community. The recurring maintenance costs are met by the Mando Co-operative and are reimbursed by each family as they purchase their buttons. The remainder of the revenue collected from each family is used to pay back the co-operative's initial investment, after which more systems will be purchased. Including battery replacement every three years, each family will repay the system and operation costs in about ten years.

The cost of purchasing and operating a gasoline generator is compared to the cost of purchasing and operating a PV system in figure 2.5. The actual cumulative PV costs represent the cost of installing and maintaining each PV system met by the co-operative. The cumulative PV costs met by the owner refers to the amount which each family pays to obtain

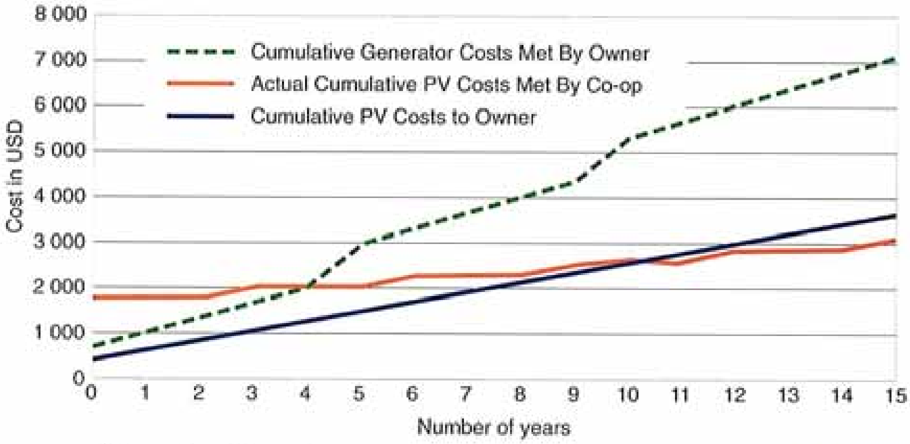


Figure 2.5: Cumulative cost of a gasoline generator and PV system (utilisation of 5 months/year)

their electricity requirements. The PV systems save each family a total of 2 230 USD over ten years, compared to using a gasoline generator.

2.2.2 Off-grid non-domestic: Montague Island Lightstation

An off-grid PV system supplies electricity to the National Parks and Wildlife Service (NP&WS) conference centre on Montague Island off the south coast of New South Wales, Australia. The installation, located at 151° E and 37° S, is complemented by a smaller PV array that powers the lighthouse. The system, which commenced operation in May 1997, was installed to replace diesel generation on the island. It received full funding from the NP&WS.

The installed capacity of the 36 m^2 PV array, providing electricity to the conference centre, is 4 kW_p. The array, which is made up of 48 single crystal silicon modules, has a tilt angle of 45° to the North.

A single phase 10 kVA inverter with an input voltage of 96 V d.c. - 120 V d.c. supplies electricity to the load at 240 V a.c. Storage is achieved with a battery bank with a nominal capacity of 660 Ah. The nominal voltage of the battery is 120 V. The system has a 10 kVA diesel generator back up power supply.

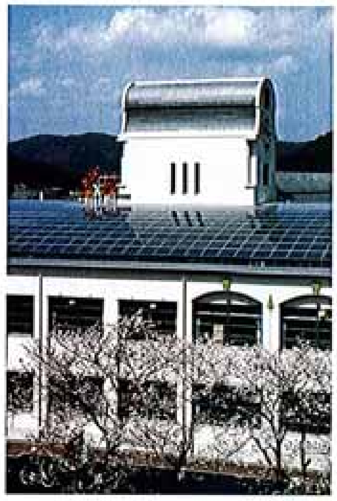
The owner, NP&WS, is very pleased with the performance of the system. Prior to installation of the PV system, 22 000 litres per year of diesel fuel was transported to the island. There has been a significant reduction in the yearly consumption of fuel, resulting in a reduced environmental risk and lower costs for transporting the fuel to the island. Since the introduction of the PV system, the annual generator running costs have reduced from approximately 10 500 USD to 1 200 USD.

Photo provided by the PV Special Research Centre, University of New South Wales.

The price for the PV system was 81 200 USD, giving a payback time of seven years.

The system was designed by the University of New South Wales PV Special Research Centre. The project also involved a systems development company (Natural Technology Systems) and the local electricity utility (Integral Energy).

2.2.3 On-grid distributed: Yagi Junior High School PV System



A 51.4 kW_p roof-top PV system was installed at Yagi Junior High School in Kyoto, Japan. It was set up to demonstrate the availability of PV technology and to promote clean energy within the school and surrounding community. The system, located at 35° N, 135° E was commissioned in March 1995 and began operation in April 1995. The majority of funding was provided by the New Energy Industrial Technology Development Organisation (NEDO).

The system consists of 504 multicrystalline silicon modules. The total area of the PV roof is 362.9 m^2 with a nominal rating of 51.4 kW_p. The modules are integrated into a curved roof with the array tilt angle varying from 5° to 22° (average of 13.1°) and an azimuth angle of 15° East. The modules are connected to one 50 kVA inverter. The inverter receives an input voltage of 210 - 360 V d.c. and has a nominal three phase output of 210 V a.c.

The PV system is used to provide power for lighting and air-conditioning within the school. During weekends and school vacations the power is mainly fed into the utility grid at 6.6 kV. The system incorporates net metering, in which the cost of exported electricity is the same as the cost of electricity supplied from the grid.

For the year from April 1996 to March 1997 the average final daily yield, Y_f, for the PV roof was 2.9 $kWh.kW_p^{-1}$ and the performance ratio averaged 76 %. Over the year the average daily irradiation in the plane of the PV array was 3.8 $kWh.m^{-2}$ with a total annual energy production from the PV system of 54 155 kWh.

Table 2.4: Cost breakdown for Yagi Junior High School PV System

Item	Costs (%)
PV modules and mounting structure	27
Power conditioning unit	17
Installation	32
DC/AC cabling (junction box and cabling)	7
Other costs (monitoring and display, protection and control)	17

The total cost of the system in 1994 was 1 242 000 USD and the price per kW_p of installed capacity was 24 800 USD per kW_p (at an exchange rate of 1 USD = 103 JPY in 1994). A breakdown of the total costs of the system is given in table 2.4.

The annual operation and maintenance costs for this demonstration system are estimated to be 108 USD, this is largely labour costs. Throughout the year in which performance data was collected, there were no repairs needed and no system downtimes for maintenance.

It is estimated that if the system was replicated today, the total system price would be approximately 431 000 USD, a reduction of more than 60 % (with a 1997 exchange rate of 1 USD = 130 JPY). This is an installed capacity cost of 8 610 USD per kW_p. Funding for the installation of the system was provided by NEDO (67 %), with the remainder being met by the school.

The PV system has been used to introduce the concepts of photovoltaic power generation and promote environmental consciousness to the students of Yagi Junior High School. The school, which was rebuilt in 1994 as a building in "harmony with the environment", has been promoted as an "Eco-school". Figure 2.6 shows the average daily reference yields, final yields and performance ratio of the PV system for each month of the year from April 1996 to March 1997.

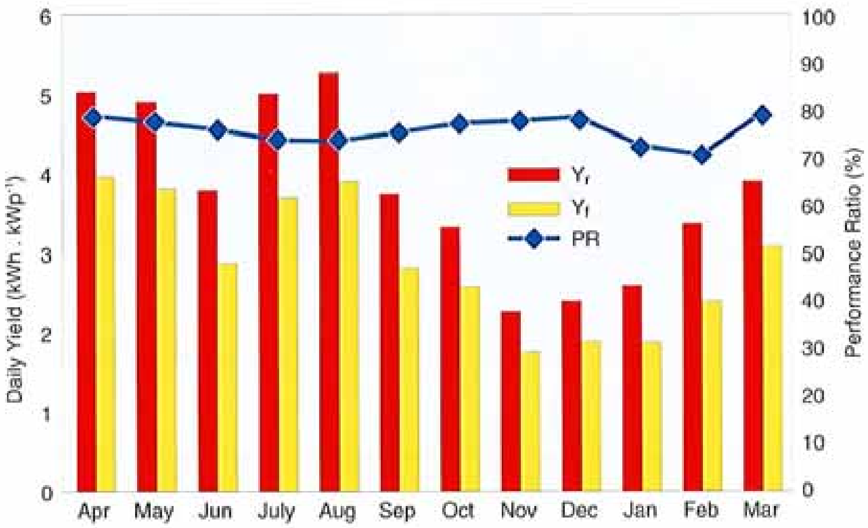


Figure 2.6: Average Daily Yields and Performance Ratio of Yagi Junior High School PV System

2.2.4 On-grid centralised: Serre PV Plant

The Serre PV Plant is a 3 MW_p plant, generating electricity for the Italian national grid. It is located in the province of Salerno in Campania at 40.5° N, 15° E. The system was installed to verify the economic and technical feasibility of large plants connected to the

grid and to evaluate the effect on medium and low voltage networks of PV energy production. It also aimed to assess the effect of the scale factor on the costs of PV systems. It is hoped that new project criteria may be defined which could help to reduce the costs of possible replicas. The plant, which received most of its funding from ENEL, began operation in 1994 and was expanded in 1997 to include a tracking sub-array.

The plant consists of ten electrically independent sub-fields of 330 kW_p with a total array area of 60 000 m^2. The modules, supplied by ANIT-Eurosolare, BP Solar, Helios Technology, Kyocera, Photowatt and Solarex, have either 36 or 72 cells per module. The 72 cell modules have a higher power density with equal cell efficiency, resulting in savings in materials for frame construction and cabling and shortening the time for module assembly and connection. The majority are multicrystalline silicon, although there is one array using monocrystalline silicon modules. The total number of modules is 45 000.

Nine of the ten sub-fields are mounted on fixed structures with an array tilt angle of 20°. They are anchored in concrete foundations and face due south. The tenth sub-field is mounted on a single axis solar tracking structure.

Each sub-field is provided with an autonomous inverter, a maximum power point tracker and step up transformer. The inverters are of the 12 pulse, line commutated type with a nominal rating of 550 kVA. Each inverter consists of two galvanically insulated six thyristor bridges, connected to the low voltage side of the step up transformer. The inverter input voltage is 420 V and the output is three phase at 20 kV.

The sub-fields are divided into 2 x 165 kW segments, each containing 175 parallel-connected strings. The power output from each string, comprising of either ten or twenty series-connected modules, is about 900 -1 000 W. The voltage at the string terminals is about 340 V d.c.

A central building houses the main MV boards, the devices for interfacing with the power grid, the plant's data supervision system and the auxiliary services. Monitoring of the plant performance is achieved with a sophisticated data acquisition system. It provides a large amount of information to visitors and researchers in local and remote ENEL offices.

The plant had an average final daily yield of 3.4 $kWh.kW_p^{-1}$ for the year 1997 with an average performance ratio over the year of 69 %. The average daily irradiance in the plane of the PV array was 4.9 $kWh.m^{-2}$. The total energy produced from the system in 1997 was 3 626 MWh corresponding to an average of 9 934 kWh per day.

Table 2.5: Cost breakdown for the Serre PV power plant

Item	Costs (%)
PV modules and mounting structure	66
Power conditioning unit	5
Project Management	4
DC/AC cabling (junction box and cabling)	17
Other costs (ground supervision; supervision, automation and DAS)	8

The cost of the PV plant was 24.7 MUSD. A breakdown of the costs is given in the table 2.5. The final cost of the power station was about 7 500 USD per kW_p. With an annual electricity generation of 4 500 MWh, the estimated energy cost is 0.5 USD per kWh. As the plant was designed partly for research and development purposes, it includes additional equipment which would not be necessary if a replica was built. The total balance-of-system (BOS) costs would be expected to reduce by 40 % so that the price of PV generated electricity for further plants would drop to approximately 0.34 USD per kWh.
All the funding for the first nine sub-fields came from ENEL which is both the plant owner and the electricity utility. 60 % of the funding for the tenth tracking sub-field came from ENEL with the remaining 40 % provided by the EC THERMIE programme. The first sub-field of the plant was grid connected at the end of 1993, six more sections were connected at the end of 1994 and the eighth and ninth sub-fields were completed at the end of 1995. The last sub-field is due to come on-line in 1998. On completion, the plant will be the largest in Europe and one of the largest in the world.

2.3 National Demonstration and Field Test Programmes

This section looks at national demonstration and field test programmes in the reporting countries. Their objectives, size and number are good measures of the advances in PV power systems.

All the reporting countries have installed demonstration plants, either funded through central or local government, the electricity utilities, the users or, in Europe, by grants from the European Union. Each country supplied details of their main demonstration programmes and described their objectives.
The following section briefly describes the main demonstration and field test programmes in each participating country.

Most PV systems in **Australia** have been installed as commercial projects, either as cost effective options in remote areas, or as part of the Green Power programmes in the competitive electricity market. These programmes were launched by eight New South Wales (NSW) utilities in April 1997, with marketing assistance and an 'accreditation' programme provided by the NSW Sustainable Energy Development Authority (SEDA). They offer consumers the opportunity to fund the development of a range of renewable energy projects by purchasing their electricity from selected retailers. By the end of 1997, there were approximately 15 000 green power customers representing sales estimated at 60 000 MWh per annum. These schemes have funded the construction of an additional 1 MW_p of PV capacity including the 665 kW_p Sydney Olympic village. A new SEDA grant programme is being introduced to increase the visibility of PV systems and improve the experience and product mix available for building integrated PV systems. Grants of up to 20 % of the system costs are available for residential installations and 40 % for installations on public buildings. The programme is expected to significantly increase the number of distributed PV systems in NSW.

Remote Area Power Supply (RAPS) Programmes in Western Australia and Queensland provide subsidies for power systems where grid connection costs would exceed 29 000 USD. The Western Australian State Government's RAPS Programme provides subsidies for renewable components in power systems. In the first 18 months of the programme, 62 kW_p of PV were installed. The Queensland State Government plans to begin a similar programme offering grants of 2 500 USD per year for rural properties operating their own power supplies.

In **Austria**, there is limited land area available for large PV plants, so demonstration projects have concentrated on the integration of PV into existing structures such as building façades, roof surfaces and sound barriers. The Austrian 200 kW_p Photovoltaic Rooftop Programme, which started in May 1992, aimed to demonstrate the feasibility of decentralised PV electricity generation. The project, which has stimulated interest in building integrated PV systems, was viewed as a great success by the promoters of the programme. Most other demonstration programmes have involved the installation of PV façades in retrofits of existing buildings. These include the Handelshaus Wild, Innsbruck and the PV façade at Kelag, Klagenfurt which involved thermal expansion design to compensate for a façade temperature variation between -25° C in winter and +80° C in summer. The most recent PV façade was installed at the Reiden transformer station and began operation in February 1998. In addition to generating electricity, it is an architectural element and offers shading to the building with a reduction in cooling costs.

In 1993, a five year demonstration programme, 'PV for the North' was launched in **Canada**. The programme focused on evaluating and improving PV technology to enable reliable operation in the harsh climate of the Northwest Territories (NWT). A number of training workshops were run, and in September 1996 a renewable energy test and training facility was installed at the Inuvik Research Centre. A further programme was introduced by the Canadian government in 1996 to accelerate the deployment of renewable energy technologies. The aims of the PV component of the programme, run by CANMET Energy Diversification Research Laboratory (CEDRL), are to improve the reliability of PV system components and decrease system costs. The programme focuses on adaptation of technologies for performance in cold climates, with the goal of increasing the rate of penetration of PV in Canada.

In addition, a number of smaller building integrated PV systems have been installed as demonstration projects. The Toronto Healthy House, with a 4.4 kW_p PV system, demonstrates that it is possible to design houses for the Canadian climate in keeping with the principles of sustainable development. The Edmonton Power Corporation (EPCOR) completed a roof integrated 13 kW_p PV grid-connected building in November 1996. It was the highest elevation building integrated PV system ever installed and took only 8 weeks to install.

The Sun-city project in Brædstrup, **Denmark**, involved the installation of 30 roof-top PV systems, with a total installed power of 60 kW_p. The systems were installed in 1996 by a utility, VOH, to investigate grid impact and consumer behaviour. The project found that the effect on the grid was negligible, and in general there was a 7 % - 10 % household saving on the amount of electricity consumed. The programme will continue in 1998 with 300 roof-top PV systems being installed. The Solgård Project involved the installation of a 110 kW_p PV system as part of an urban refurbishment of a large apartment building. The highly visible system was completed towards the end of 1997, and demonstrates architectural integration of PV. The Danish Solar Energy Action Plan intends to increase the focus on PV in 1998-2000.

A number of programmes currently in operation in the **European Union** (EU) are aimed at research and development, and market enablement strategies for renewable energy. This includes the JOULE-THERMIE programme, adopted in 1994, which merges the R&D and demonstration actions that were previously carried out separately within the JOULE and THERMIE programmes. It provides funding for shared-cost collaborative research and demonstration projects in the field of non-nuclear energy where this leads to emission reductions, improved security of supply or the introduction of renewable energy into the European energy system. The budget allocated to renewable energy is 422 MUSD. A further programme, ALTENER II, which follows up the previous ALTENER programme, focuses entirely on the promotion of renewable energy in Europe. Whilst continuing to support studies, pilot actions and dissemination activities at the national, regional and local level, it will also support the Strategy and Action Plan which was set out in a White Paper adopted by the European Commission in November 1997. The White Paper calls for an increase in the renewables' energy share to supply 12 % of the total EU energy demand by the year 2010. It proposes the introduction of 1 000 000 new PV systems, involving a 500 000 PV roof and façade initiative for the domestic market and an export initiative for 500 000 PV village systems to kick start decentralised electrification in developing countries.

Government programmes in **Finland** have focused on R&D and specifically on product development. This has acted as a stimulus for the private sector, however there were no large demonstration programmes or projects in 1996 - 1997. Small PV demonstrations have been installed at universities and industries, chiefly Helsinki University of Technology and Neste Ltd.

PV programmes in **France** have concentrated on promotion of off-grid systems providing electricity to customers in remote rural areas. With the introduction of the public FACE (Fonds d'Amortissement des Charges d'Electrifications) fund, EDF (Electricité de France) in co-ordination with ADEME (Agence de l'Environnement et de la Maîtrise de l'Énergie), embarked on a dissemination programme for decentralised rural electrification in 1995. The aim was to provide users with an electricity service from renewable energy sources. A total of one thousand sites (580 kW_p) were selected for FACE funding in 1996 and 1997. The projects are oriented towards the setting up of comprehensive programmes in selected areas. Factors taken into account included the technical aspects, the dependability of the energy service provided to the PV users and the financial provisions made to cover system operation, maintenance and storage battery replacement. By the end of 1997, 200 systems were operational in both France and in overseas Départements, with the remainder either under construction or awaiting final approval. Systems range in size from 0.5 kW_p to 1.5 kW_p, and have received up to 70 % funding from FACE. The remainder of the funding came from the finance ministry and ADEME, with a 5 % contribution from the users. Making use of both FACE funds and tax exemptions in overseas Départements a total of 1 700 kW_p was installed in 1997.

The Phebus Association had installed 100 domestic grid connected PV systems by the end of 1997, 40 % of funding came from the EC THERMIE programme, with the user contributing 40 % to 60 % and the Région up to 20 %. The PV systems use net metering.

Prior to 1995, the majority of PV systems in **Germany** were installed as part of the 'Demonstration Programme' and the '1 000 Roofs Programme'. Since 1995, there has been an increase in more general programmes and market introduction models receiving state and utility funding. "Sun at School" and "Sun at City Hall" are two such programmes receiving sponsorship from utilities and the Federal Ministry of Economics (BMWi). The latest series of demonstration programmes supported by the Federal Ministry for Education, Science, Research and Technology (BMBF) ended in 1997. It included the installation of a roof mounted, grid-connected 1 016 kW_p PV plant at the new trade fair centre in Munich-Riem. Widespread monitoring, carried out as a major component of these programmes, is providing information about the reliability, yields and performance of the systems. Other important demonstration plants are in operation or under construction, for example, the PV-roof plants at Mercedes Benz in Bad Carnstatt (435 kW_p) the railway station Uelzen (73 kW_p), and ZKM Karlsruhe (100 kW_p) and North Rhine Westafalia's demonstration plant such as the scientific park Gelsenkirchen (210 kW_p) and the 1 MW_p roof integrated PV plant 'Mont Cenis' in Herne equipped with 700 inverters to demonstrate decentralised inverter technology.

Israel began establishing PV experimental sites in 1987. Most Israeli government funding supports research, with attention focused on manufacturing ability, general PV problems and specific problems for the region. The 5 kW_p Mitzpe Adi project was installed in 1995 with the aim of obtaining experience with grid-connected PV systems. The total cost of the project was 100 000 USD and was met by the Israel Electricity Corporation. A number of other projects are running, some of which are demonstrating solar tracking devices.

In **Italy**, an Agreement on Photovoltaics was signed between ENEA and MICA (the Ministry for Industry, Trade & Craft) in 1994. The programme, with a budget of 15 MUSD for the first four years, supports research activities carried out at ENEA laboratories and joint collaborations with universities and manufacturers. The ENEA demonstration activities include research aimed towards upgrading the production processes of PV cells, and further development of the standard 100 kW_p plant, the PLUG (Photovoltaic Low-cost Utility Generator). The PLUG design uses factory pre-assembled components and supporting structures, and can be used either as a single installation or as an elementary unit for larger power stations. Two further PLUG plants have been installed; one in Sardinia at the ENEL Alta Nurra wind turbine test facility to evaluate the combined use of wind and PV; and one in Vulcano to test the high penetration of PV in a small isolated grid. The utility, ENEL, has been involved in a demonstration programme since 1982 resulting in a total installed PV power of more than 4 MW_p by late 1997. The 35 kW_p Cittadella della Carità project in Taranto, Puglia, began operation in January 1997 and aims to improve the technical experience in designing, managing and maintaining grid-connected PV plants. The tenth sub-field of the 3.3 MW_p Serre power plant, which will be equipped with a tracking system, is almost completed. ENEL have a number of recent initiatives with BMBF (the German Ministry for Education, Science, Research and Technology), including 12 grid-connected PV systems totalling 60 kW_p and two hybrid PV/diesel systems totalling 160 kW_p. In 1997, ENEA defined a 5 year national 10 000 roof-top programme aimed at installing a total capacity of 50 MW_p on roof tops. The programme, which is due to begin in early 1999, will be managed and monitored by ENEA and will receive public funding.

In **Japan**, the main demonstration programmes implemented in 1996 and 1997 included the "PV Field Test for Public Facilities". The programme, which aimed to improve the public perception of PV, monitor installed systems and reduce installation costs, was completed in 1997. It resulted in the installation of 1 890 kW_p in 1997 and 1 270 kW_p in 1996 at public facilities, and is to be followed by an "Industrial PV Field Test" programme starting in 1998. The "Residential PV Monitor Programme" has been replaced by the "Residential PV System Infrastructure Maintenance Programme" which began in April 1998. It aims to further promote the use of PV, and subsidise the installation of residential PV systems. The systems are monitored by the users in order to provide feedback to manufacturers, and excess power is bought by the electricity companies. In 1996, 1 986 residential PV systems with a total capacity of 7 221 kW_p were installed with costs amounting to 56 MUSD. The number of residential PV systems installed in 1997 increased to 5 000, with a total capacity of 20 000 kW_p and total costs of 162 MUSD.

Until 1995, demonstration projects in **Korea** were devoted to off-grid systems and received funding solely from the MOTIE (Ministry of Trade, Industry and Energy). In October 1996, Samsung Electronics and Samsung Construction jointly constructed a grid-connected building integrated PV system with a total capacity of 100 kW_p. The system was mounted on the roof, penthouse and sunshades of the R&D centre for Samsung Construction Company, and in 1997 generated a total of 75 121 kWh. It was installed with the aim of developing building integration technologies and obtaining experience with grid-connected PV systems in the built environment. In 1996, the government funded three PV-diesel hybrid systems to provide electricity to areas isolated from the grid. Two systems of 6.2 kW_p and 10.8 kW_p were installed at mountain shelters, and one 30 kW_p system was installed on Wa Island at the south-east of the Korean peninsula. In 1997, demonstration projects funded by the MOTIE with a budget of 1.04 MUSD were more diverse than previous years. One 10 kW_p PV-diesel hybrid system was installed at a mountain shelter on Cheju Island. Two stand-alone PV systems with a capacity of 8.4 kW_p and 10 kW_p were installed at Gwangju Biennale to provide electricity for a fountain and lighting, and promote renewable energy. A 30 kW_p on-grid system was installed on the roof of the Changwon municipal building and from October to December of 1997 generated about 6 500 kWh.

The **Mexican** PV programme started in the late 1980's. Most experience to date in Mexico has been with off-grid PV systems mainly of the Solar Home System type. At the same time around 2 MWp has been installed in professional applications such as telecommunications, off-shore platforms, luminaries, cathodic protection, traffic signals, water pumps and the electricification of rural communities by means of hybrid systems. Since 1995 some small hybrid systems have been installed in an Eco-Hotel.

During 1997 the IIE started a project funded by the Ministry of Energy related to grid connected PV systems. The first Mexican grid-connected system was installed on the roof of an office building in Cuernavaca with the aims of gaining experience with the installation and operation of grid-connected systems and to develop technical specifications for these systems in Mexico.

Most demonstration projects and field experiments in the **Netherlands** form part of the National Photovoltaics Programme, NOZ-PV. The programme, funded by the Ministry of Economic Affairs, has set goals of 12.5 MW_p of installed capacity by the year 2000, 250 MW_p by 2010, and about 1 500 MW_p by 2020. This is equivalent to approximately one million Dutch homes with solar roofs by the year 2020. The 'PV in the Built Environment' pilot programme, which is part of the national programme, aims to implement PV pilot projects to provide market experience relevant to the application of PV in the built environment. Funding is received from the government, utility, user or as part of the THERMIE programme. Projects carried out in 1996 and 1997 include six 2.5 kW_p PV systems for social housing in Gelderse Blom and the integration of PV into shading balconies on homes in Dordrecht. There are currently a large number of projects under construction including a 3.6 MW_p PV-Groei programme (Growing Photovoltaics) with the aim of opening up a niche-market for small grid-connected PV systems made up of 4 AC Modules. The 1 MW_p project under construction in Nieuwland, Amersfoot comprises 600 building integrated PV systems on new homes with a total capacity of 1.3 MW_p.

The number of PV demonstrations in **Norway** is limited. In 1996, two systems were installed: an off-grid PV installation providing power to a house at Venberget in Hedmark county, and the first building integrated PV system in Norway fitted on the roof of an apartment in Hamar. The off-grid system is 2.2 kW_p in size and was installed as an alternative to extending the utility grid a distance of 20 km. It is supplemented by a 9.2 kVA diesel generator. It received 66 % government funding, with the remainder coming from the local utility, Hedmark Energi AS. There are no further projects or programmes presently under construction.

In **Portugal**, most of the PV activities have been supported by the European Union (E.U.) funded programmes and various national programmes such as ENERGIA - SIURE (Incentive Scheme for the Rational Use of Energy). In 1996, a 15 kW_p PV-wind hybrid system was installed to provide electrification of a holiday area. In 1997, four 1.664 kW_p PV-wind hybrid systems were installed to supply power to small TELEVISION rebroadcast stations. Both projects received 40 % funding from THERMIE with the remainder from SIURE. There is currently a 5 kW_p grid-connected system under construction in Faro, Algarve, with the aim of demonstrating AC modules in buildings. Funding for the installation is being met by THERMIE and SIURE.

The Energy Efficiency and Saving Plan (PAEE) in **Spain** aims to increase the role of renewable energy, and includes the development of PV power systems. In 1996, a total of 386 kW_p was installed under the PAEE programme, and in 1997, 167 kW_p was

installed. This included a 2.4 kW_p off-grid system in Socuéllamos to supply water pumping for irrigation of a 3 Ha vineyard. The PROSOL programme, created by the Andalusian Government and managed by a public company, SODEAN, S.A., began in 1996 and by the end of 1997, had installed a total of 113 kW_p.
A further programme created by the Public Works Department of the Andalusian Government is devoted to extending rural electrification to remote areas using PV systems. The largest demonstration project, the Toledo 1 MW_p power plant, has undergone improvements to the inverters and compensation units, which has resulted in an increase in system efficiency from 72 % in 1996 to 87 % in 1997.

Two demonstration systems were installed in **Sweden** in 1996 and 1997. On the island of Bullerö in the Stockholm archipelago, a stand-alone PV system was upgraded from 0.8 kW_p to 1.45 kW_p in 1996. The PV system was installed for electrification of a house and to demonstrate the use of PV at a site with a large number of visitors. Sweden's largest PV system was installed in Älmhult at the end of the summer of 1997. The 60 kW_p building integrated PV system was mounted on the roof and south façade of an office building, and provides information on the electricity production and quality of grid-connected systems. The system received funding from the private company IKEA and the Swedish Board for Industrial and Technical Development, NUTEK. Sweden is participating in the IEA PV programmes with the aim of gaining experience and understanding of the technology and economics for the utilisation of PV systems.

In **Switzerland**, the majority of projects are carried out under the federal Pilot and Demonstration (P+D) programme which receives 27 % funding from the government. The projects cover a range of activities, with an emphasis on new technologies aimed at reducing the costs of PV systems in the built environment. Several different approaches are being demonstrated including new developments on the components side (solar tiles, PV modules with integrated inverters), cheaper carrier structures (fibre-cement elements, mounting systems) and replacement or augmentation of existing building elements (façade elements, motorway noise-abatement structures). The total power installed under the P+D programme was 208 kW_p in 1996, and 84 kW_p in 1997. In 1996 a number of large PV installations over 50 kW_p in size were commissioned. This is one reason why the installed power in 1996 was much higher than in 1997. Another factor reducing the power installed under the P+D programme in 1997 was the start of a new government promotion programme for PV, offering USD 2 000 for each kW_p installed, which eased the load on P+D funding. The long term goals of the Swiss P+D activities are in the areas of industrial cell production and products for module integration, whilst ensuring that they retain a leading position in system technology and engineering.

Demonstration projects in the **United Kingdom**, have recently focused on grid-connected building integrated PV systems. The first speculative PV office to be built in the UK is located in the Doxford International Business Park near Sunderland. The 5 000 m^2 building is fitted with a 73 kW_p PV façade and incorporates a number of low energy measures. It received funding from the EC THERMIE programme, supplemented by national funding. At the Ford Motor Company Jaguar/Zetec engine plant in Bridgend, a 100 kW_p PV power system, the largest in the UK, was installed in 1997. The system, in which 26 PV roof-lights were retrofitted to the factory roof, received funding from the EC THERMIE programme and the Ford Motor Company. A government funded initiative, the Technology Foresight Challenge, has awarded 1.6 MUSD to the Scolar programme to install PV systems in 100 schools and colleges. The systems are free standing PV porches rated at 500 W_p or 650 W_p, which aim to provide an educational resource and raise the awareness of pupils to the benefits of renewable energy sources. Other initiatives include a PV powered, chilled articulated lorry trailer for transportation of fresh fruit and vegetables.

The **United States** PV programme has shifted from non-economic demonstrations or systems tests to market-centred projects with the majority of funding coming from the private sector. The largest US programme to accelerate the commercial use of PV is called TEAM-UP (Technology Experience to Accelerate Markets in Utility Photovoltaics). The programme aims to build PV experience and confidence among utilities, industry and customers by significantly increasing the number of installations. The projects selected must have the potential to lead to large markets and they require a cost sharing of over 70 % by the utility team. Through the first two rounds, a total of 16 on grid and 5 off-grid ventures have been awarded funding, which, when complete, will result in the installation of more than 8 MW_p.

The Sacramento Municipal Utility District (SMUD) PV programme is a ten year private sector initiative, started in 1993, designed to help PV be at a market competitive price by 2002. By the end of the first phase of the programme at the end of 1997, over 450 systems totalling 6 MW_p had been installed. In the final phase of the programme, installation of an additional 10 MW_p of PV systems are planned with the installed system cost decreasing to less than 3 USD per watt.

The "Million Solar Roofs" programme was announced by President Clinton in June 1997. It calls for the nation to install solar hot water and/or PV systems on one million roofs by the year 2010.

Table 2.6: Budget breakdown for market stimulation, demonstration and R&D between 1994 and 1997 in MUSD

Category	1994		1995		1996		1997	
Market stimulation	51	18 %	99	29 %	154	55 %	164	47 %
Demo projects	28	10 %	28	8 %	22	8 %	27	8 %
R & D	208	72 %	215	63 %	105	37 %	159	45 %
Total	287		342		281		350	

Other programmes currently in operation include the PVMaT (Photovoltaic Manufacturing Technology) programme that has invested over 50 MUSD in the production of advanced PV cells and modules with improved performance and significant cost reductions. The PV BONUS (Building Opportunities in the United States for Photovoltaics) programme has resulted in the design of new PV products for the built environment, such as PV shingles, PV standing roof seaming and integrated mullions for curtain walls. A further initiative is the Department of Defence off-grid PV systems programme through which approximately 1 MW_p was installed in both 1996 and 1997.

In conclusion national demonstration programmes in the reporting countries largely reflect the priorities of each country. There is an increasing emphasis on on-grid distributed systems, particularly on the integration of PV into existing structures such as building façades, roofs and sound barriers. A number of countries have programmes to promote residential PV installations, most notably Germany, Japan, the Netherlands and the United States. Canada and Israel are focusing on adapting PV to their specific climates. Within the European Union, grants for demonstration projects are available from the European Commission and these contribute a large proportion of the available funding in member countries. On-grid systems are often part funded by electricity utilities, indicating a positive attitude on their part towards these systems. Demonstration programmes to integrate PV systems into school buildings in order to raise the awareness of students are currently underway in Germany, Switzerland and the United Kingdom.

2.4 Budgets for Market Stimulation, Demonstration and R&D

Table 2.6 shows the total budget for market stimulation, demonstration and R&D in the reporting countries between 1994 and 1997. From the table it can be seen that there has been a trend for the funds spent on market stimulation to increase, due in part to the large Japanese programmes, while the proportion of funds spent on R&D has decreased, from 72 % in 1994 to 45 % in 1997. Funding for demonstration projects stayed fairly constant between 1994 and 1997. The total available budgets have increased to 350 MUSD in 1997, from 287 MUSD in 1994. Note that 1994 and 1995 data exclude Austria, Norway, Mexico and Israel (who in 1997 accounted for 2.4 MUSD of the total budget).

The budget breakdown between the reporting countries in 1997 is shown in Figure 2.7. It can be seen that Japan, the USA, Germany and France had the highest budgets for market stimulation, and for R&D Japan had the highest expenditure followed by the United States and Germany. However France, Germany, Japan and the USA had the largest total budgets for market stimulation, demonstration and R&D programmes (22, 50, 156 and 59 MUSD respectively).

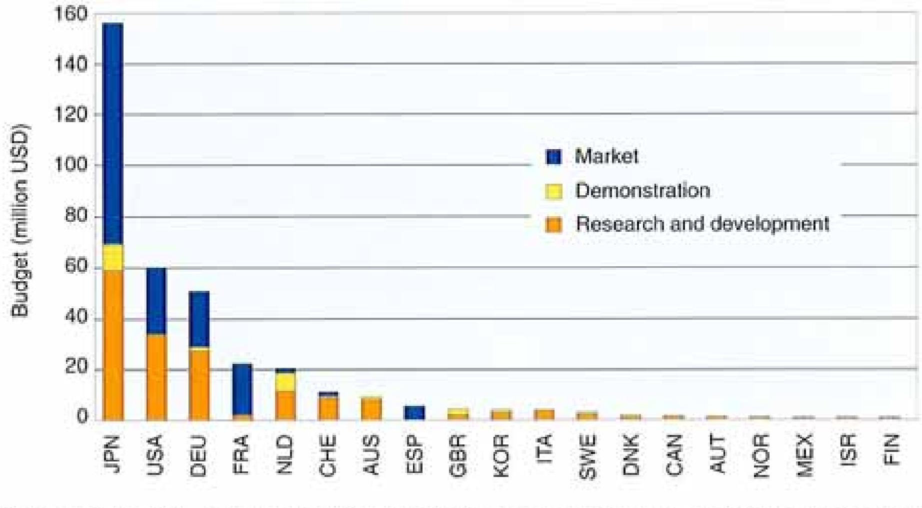


Figure 2.7: Budget for R&D, demonstration projects and market stimulation in the reporting countries in 1997

Industry and Growth

This chapter discusses the industries associated with manufacturing and installing PV systems and components, and looks at the employment levels and revenues associated with the industry. The production of PV modules and cells throughout the reporting countries is discussed and current trends in module and system prices are highlighted. The final sections of the chapter look at the balance of system industry.

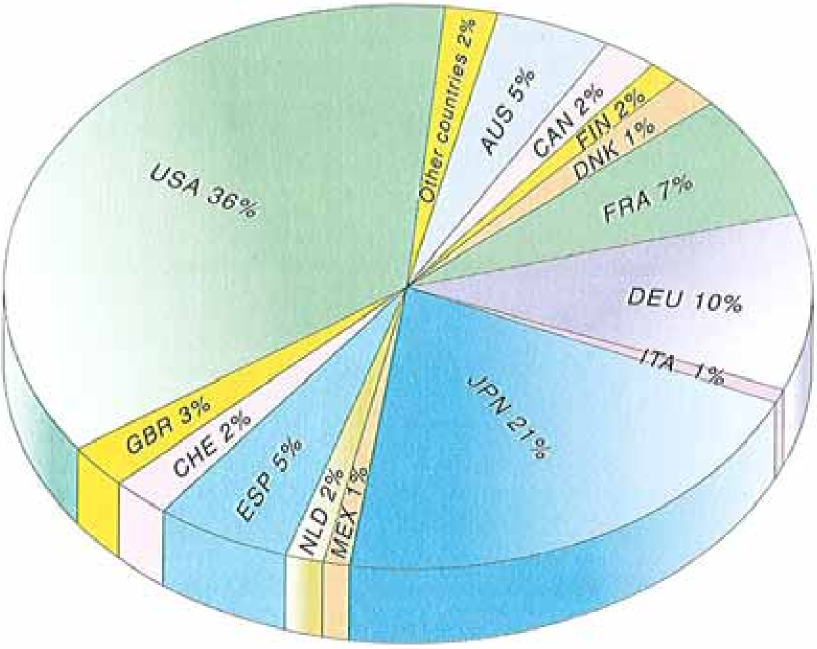


Figure 3.1: Distribution of PV industry revenue between the reporting countries in 1997 (Total 1 133 MUSD)

3.1 Photovoltaic Production in Reporting Countries

3.1.1 The Photovoltaic Industry

The sum total module production in 1997 of nations participating in the IEA Photovoltaic Power Systems Programme was 100 MW_p: this includes production for power applications smaller than 40 W_p but not for consumer applications. The details of the production of PV modules are based on information supplied by the reporting countries of the IEA PVPS and account for approximately 85 % - 90 % of PV modules produced world-wide.

The national reports provided data on the PV industry revenue in each reporting country. The figure was based on the PV related turnover of all the businesses working in the PV sector. This included the turnover of consultants, installers and manufactures of both modules and balance of system components. Government funded research in universities was not included. If the data were not available to the national representative, estimates based on the data available were made, such as installed power and system prices.

The PV industry revenue in the reporting countries was estimated to be in the region of 1 133 MUSD in 1997, and 873 MUSD in 1996, a 29 % annual growth rate. In comparison the value of business in 1995, under a slightly narrower definition than that used for the 1997 survey, was 713 MUSD. Figure 3.1 shows the division of PV industry revenue between the reporting countries.

There were approximately 9 140 full time equivalent labour places associated with the PV industry in 1997 in the reporting countries. Of these, over 1 730 were in research and development, consultancies, government agencies, etc., 4 300 worked for manufacturers of components exclusively made for PV systems including R&D, and 3 100 were in areas such as utilities, distribution companies, system installers etc. Since 1995 the number of labour places, in those countries for which data is available for both years, has grown by an average of 16 %. The vast majority of this growth has been in manufacturing.

The majority of the labour places were concentrated in Japan (1 900), Germany (1 800) and the USA (1 750). These three countries also had the largest amount of installed PV power of the reporting countries (65 MW_p, 42 MW_p, and 108 MW_p respectively). The USA and Japan were also the largest producers of PV modules, with Germany the fifth largest producer. The breakdown of labour places in each country is shown in Figure 3.2. *(see next page)*

3.1.2 Distribution of Capacity and Production

Commercial module manufacture is based mainly on crystalline and amorphous silicon technologies. The crystalline silicon technologies are currently the most prevalent, constituting approximately 90 % of power module production and 80 % of manufacturing capacity at the end of 1997. See the PV Technology Note for a brief description of the different production technologies.

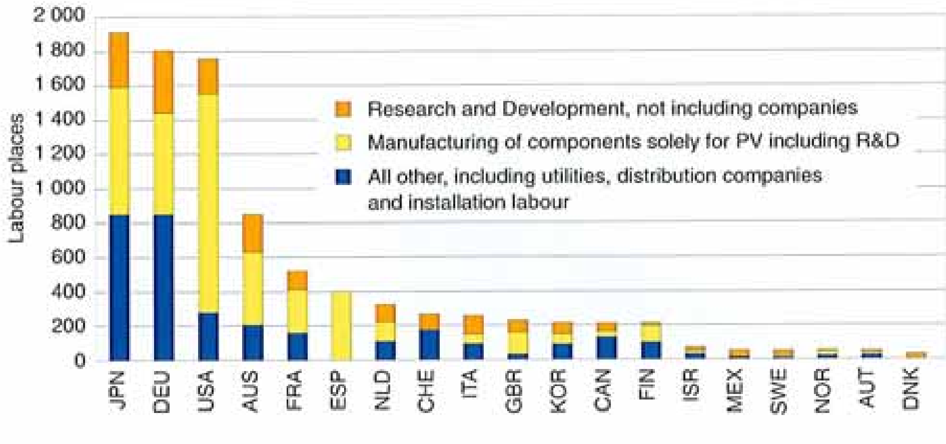


Figure 3.2: Distribution of labour places in IEA reporting countries in 1997

and Japan (34 %), although the European countries accounted for 22 % of production and 23 % of capacity. This represents a 44 % increase in European production from 15 MW_p in 1995 to 21.6 MW_p in 1997.

3.1.3 PV Module Manufacturing

PV module manufacturers can be divided into two broad categories: firstly, those who purchase ready made PV cells and fabricate them into modules, i.e. module assembly; secondly, vertically integrated manufacturers who manufacture their own cells and modules. Manufacturers of crystalline silicon modules fall into either of these categories whereas amorphous silicon module manufacturers are always vertically integrated as the distinction between cell and module is not relevant.

Table 3.1 shows PV production and production capacity in 1997 separated according to world regions. The total module production of 100 MW_p in 1997 is an increase of 78 % from 1995 when total production was 56.1 MW_p. PV module and cell manufacturing capacity was estimated to be 209.7 MW_p in 1997, an increase of 83 % since 1995.

Table 3.1 PV Production in MW_p in the reporting IEA countries in 1997

Region	Cell production	Module production	Module production capacity	a-Si production	Crystalline silicon module production	Other module production
USA and Canada	51.0	36.2	72.0	2.5	29.3	4.4
Japan	29.3	34.3	81.0	2.4	31.9	0
Europe	14.7	21.6	48.3	0.9	20.7	0
Rest	7.5	7.9	8.4	0	7.9	0
Totals	102.5	100.0	209.7	5.8	89.8	4.4

Note rest includes production in Korea and Australia.

The quantity of modules produced in each of the reporting countries is shown in Figure 3.3 separated into the various cell technologies. PV module production and production capacity is shown in Figure 3.4 for the years 1993, 1995 and 1997. The production figures are of course lower than the capacity figures, the utilisation of production capacity was 48 % in 1997. This figure is slightly misleading, particularly for the production in the USA, where utilisation of capacity was above 90 %, as significant quantities of cells were sold on to other manufacturers for module encapsulation. In Germany, where six manufacturers began module production in 1996 and 1997, utilisation was low because the manufactures were not producing, or only producing low quantities, at the beginning of the year.

The production of PV power modules was concentrated mainly in the USA (36 %)

In order to avoid 'double counting', modules are considered to be manufactured in a country only if the encapsulation takes place in that country. For example, the American company Astropower, produced

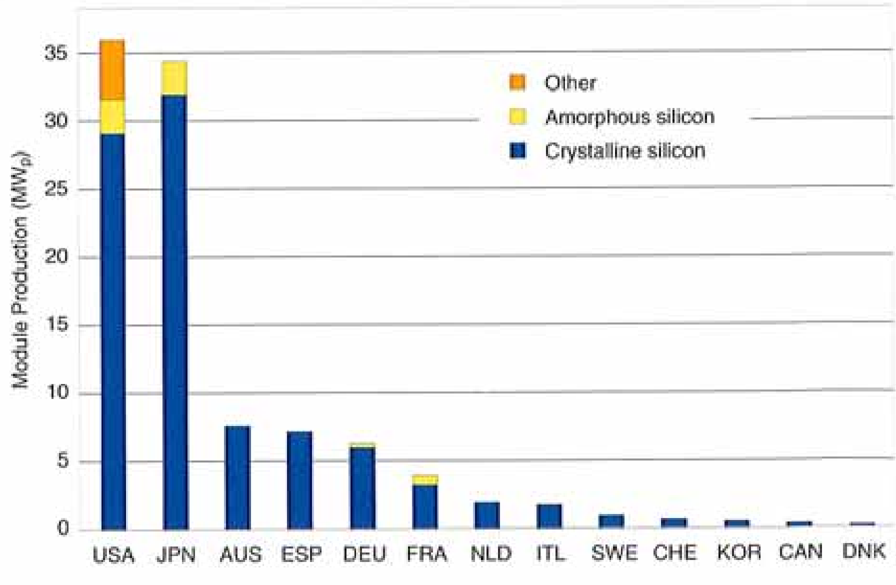


Figure 3.3: PV module production in IEA participating countries in 1997

3.9 MW_p of single crystalline silicon cells but most were sold as cells rather than modules and BP Solar America produced all their modules in 1997 from single crystalline cells imported from BP Solar plants in Europe.

Table 3.2 *(see next page)* lists the module manufacturers in each of the reporting countries, showing cell and module production and module type. The additional information is that available from the national reports which was provided on a voluntary basis. The number of manufacturers producing more than 1 MW_p increased from 15 in 1995 to 22 in 1997.

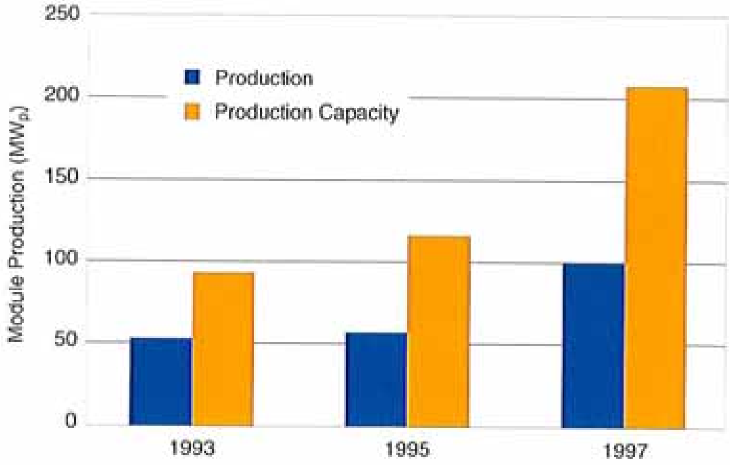


Figure 3.4: PV module production and module production capacity in 1993, 1995 and 1997

PV Technology Note

Single crystal silicon cells are usually manufactured from a single crystal ingot most commonly grown by the Czochralski method. The ingot is doped with boron during the growth process to make it a p-type semiconductor. The ingot is then sawn into wafers and doped with phosphorous to make one side of the wafer n-type, thereby creating a p-n junction. Electrical contacts are attached to each side of the wafer, so that the cell can be connected to an external circuit. Although all crystalline silicon cells have some elements in common, modifications in cell design are steadily increasing the efficiency of single crystal cells and cutting the cost of manufacture.

While single crystal silicon remains the most efficient flat plate technology, it has also the least potential for cost reduction. PV cells made from multicrystalline silicon have become popular as they are potentially less expensive to produce. Multicrystalline PV cell manufacture usually begins with a casting process in which molten silicon is poured in a rectangular block. This produces a block of multicrystalline silicon that is then sliced into wafers that are used to make the PV cells. Although multicrystalline cells are potentially cheaper to produce than single crystal cells, they are slightly less efficient. One way of eliminating the sawing step is to grow ribbons of multicrystalline silicon that are already wafer thin and the correct width for use as photovoltaic cells.

Thin film modules are constructed by depositing extremely thin layers of photosensitive materials on a low cost backing such as glass, stainless steel or plastic. As much less semiconductor material is required than for crystalline silicon cells, material costs are potentially much lower. Thin film production also requires less labour intensive handling as the films are produced as large, complete modules, and not as individual cells that have to be mounted in frames and wired together. Hence there is the potential for significant cost reductions with volume production. Thin films are made by sequentially depositing layers of material directly onto the chosen substrate. The first coating to be deposited is the front electrical contact which is usually a thin layer of a metal oxide such as tin or zinc oxide. Each of the semiconductor layers is then applied before the individual 'cells' are formed by scribing through each layer in turn with a laser. A thin layer of base metal is then added to serve as a back contact.

The most fully developed thin film technology is hydrogenated amorphous silicon which was found to have photovoltaic properties in 1974. The efficiency of commercial amorphous silicon modules has improved from around 3.5 % in the early 1980s to about 7 % currently: prototype modules have been produced with efficiencies as high as 10 %. This is the material normally used in consumer appliances, although it is used, but less frequently, in power modules.

Other types of thin films can be made using polycrystalline silicon, cadmium telluride, (CdTe) and copper indium diselenide (CIS). Cadmium telluride modules can be produced by a variety of industrial processes that do not require expensive capital expenditure, such as electrodeposition and spray pyrolysis. CIS and CdTe are promising PV materials, partly because of their high absorption of light. The addition of gallium to CIS to produce $CuInGaSe_2$ has resulted in laboratory efficiencies of cells of 17.7 %.

Typical and maximum module and cell conversion efficiencies (at Standard Test Conditions, i.e., 1 000 $W.m^{-2}$, 25°C, solar spectrum AM1.5) for the different PV technologies are given in the table below.

Type	Typical (Maximum recorded)[2] module efficiency (%)		Maximum recorded laboratory cell efficiency (%)
Single crystalline silicon	12-15	(22.7)	24.0
Multicrystalline silicon	11-14	(15.3)	18.6
Amorphous silicon	6-7	(10.2)	12.7
Cadmium telluride	7-8	(9.2)	16.0

2 *'Solar Cell Efficiency Tables, Version 11' M.A. Green, K. Emery, K. Bücher, D.L. King, S. Igari. Progress in Photovoltaics: Research and Applications, 1998 6, 35-42.*

Table 3.2: Module manufacturers in the reporting countries

Country	Company	Cell Production (MW_p)	Module Production (MW_p)	Production Capacity (MW_p)	Module Type	Additional Information
AUS	BP Solar	4.5	4.5	4.5	sc-Si	Involved in cell, module and system manufacture using imported wafers and screen printing technology. Most common module size is 70 W_p.
AUS	Solarex	3.0	3.0	3.0	mc-Si	Involved in cell, module and system manufacture using imported wafers and screen printing technology.
CAN	Canrom	-	<0.2	0.5	sc-Si	Canrom manufacture custom-made modules but a standard line of monocrystalline modules which it distributes directly have been developed. A proprietary thin film CdTe/CdS PV technology which it plans to bring to pilot manufacturing in 1999 is under development.
CHE	Newtec	-	0.092	0.092	mc-Si	Roof integrated tiling system using mc-Si cells. The tiles are weatherproof and designed to be installed without the need for roof alterations.
CHE	Solution	-	0.4	1.0	mc-Si custom, sc-Si	Produce custom modules for façade integration and ISPRA-tested "Sunslates3" tiles. Plans to increase production capacity to 2 MW_p per year.
CHE	Star Unity	-	0.01	0.105	mc-Si	Modules integrated into roof tiles. The tiles have the same dimensions as standard roof tiles and are mounted in the same manner as a normal tile.
DEU	ASE Alzenau				sc-Si mc-Si	Since 1996 ASE Alzenau has been 100% owned by NUKEM GmbH, which is itself owned by RWE AG, the largest nationally operating utility. A pilot production line for solar cells and special PV modules is in operation. In Heilbronn high power solar cells were produced for space applications. A new 13 MW edge fed growth cell production line will start up in 1998 at half capacity.
DEU	ASE Phototronics				a-Si	The former DASA-Photonics group became a subsidiary of ASE. Pilot production and R&D of thin film amorphous PV cells and modules is underway. Developed modules with a-Si/a-SiGe tandem cell structures.
DEU	GSS				sc-Si mc-Si	Manufactures mainly custom made frameless PV modules (160 - 290 W) for integration into buildings.
DEU	Pilkington Solar International				sc-Si mc-Si	Formerly Flachglas Solar: specialises in integrating modules into buildings and façades and assembles single crystal and multicrystalline modules. Joint venture underway with Braas for production of solar roof tiles.
DEU	RAP Mikrosysteme				mc-Si	Began module manufacture in 1996 for standard and customer designed modules. Production capacity of 1 MW_p will be extended to 2 MW_p in 1998.
DEU	Siemens Solar				mc-Si sc-Si	Undertakes research and development on cells and modules with a pilot production line in Germany.
DEU	Solaris				mc-Si	Produces standard 50 W_p modules.
DEU	Solarfabrik				sc-Si	Founded in 1996, started PV module production (75 W - 115 W) in 1997 in co-operation with Astropower.
DEU	Solarnova				mc-Si sc-Si	Founded in 1996, Solarnova uses parts of the old PV module production line of ASE in Wedel to produce custom made modules (50 W - 100 W).
DEU	Solarwatt				sc-Si mc-Si	Started production in 1997 and are producing custom made PV modules.
DEU	Solarwerk				mc-Si	Started PV module production in 1997. 40 W and 105 W modules produced.
DEU	Solon				mc-Si	Founded in 1997, produces 70 W_p multicrystalline modules.
DEU	SunWare Solartechnik				sc-Si	Specialises in the production of PV modules for caravans and boats.

Table 3.2: (continued)

Country	Company	Cell Production (MW_p)	Module Production (MW_p)	Production Capacity (MW_p)	Module Type	Additional Information
DEU	VEGLA (KINON GmbH)				sc-Si	Belongs to the Saint Gobain Glas Solar Group. Produces PV modules for integration into buildings.
DEU	Webasto				sc-Si mc-Si	Specialises in manufacturing flexible PV modules for applications in car roofs, caravans, etc..
DNK	Gaia Solar	-	0.025	0.33	mc-Si sc-Si	Modules range from 27 - 150 W_p produced from imported cells. Custom modules also produced.
ESP	Atersa	-	0.85	1.0	sc-Si	
ESP	BP Solar España	4.0	4.0	6.0	sc-Si	Involved in cell, module and system manufacture including production of "Saturn" Laser Grooved Buried Grid cells. Standard and custom modules. Modules available in a variety of colours.
ESP	Isofoton	0.52	2.14	4.0	sc-Si	Modules from 5 to 110 W_p in many different configurations.
FRA	NAPS-France	0.65	0.65	1.0	a-Si	Thin film hydrogenated amorphous silicon modules are produced, size 31 cm x 92 cm, with a stabilised power of 12 W_p ± 10 %, smaller sizes are available from 4 W_p.
FRA	Photowatt	5.6	3.2	9	mc-Si	Photowatt is a vertically integrated company producing very thin multicrystalline wafers. Modules are 2-glass laminate with aluminium frame. Cell production levels to increase to 10 MW_p in 1998.
GBR	Intersolar	not disclosed	not disclosed	1.5	a-Si	Manufacture amorphous silicon modules at their plant at Bridgend, South Wales.
ITA	Eurosolare	0.48 1.77	0.21 1.40	0.7 1.8	sc-Si mc-Si	Vertically integrated manufacturing process. Typical commercial modules consist of 36 sc-Si square cells (10.2 cm x 10.2 cm) or mc-Si square cells (12.5 cm x 12.5 cm) mounted in an aluminium frame. Eurosolare also produce large area mc-Si PV modules with a peak power of 110 to 120 W_p.
JPN	Canon	2.1	2.1	10	a-Si	Purchase of steel substrate and SiH_4 gas to produce a-Si cells and modules. Recently commercialised roof-integrated a-Si PV system.
JPN	Daido Hoxan	0.8 0.2	0.8 0.2	1.0	sc-Si mc-Si	Purchase sc-Si and mc-Si substrate, which is used to manufacture cells and modules suitable for residential installations. Have commercialised coloured modules.
JPN	Kyocera	15.4	15.4	30	mc-Si	Purchase raw silicon scraps and cast substrate to manufacture cells and modules. Have commercialised 135 W and 145 W mc-Si modules for residential use.
JPN	MSK	-	2.0	2.0	mc-Si	Purchase mc-Si cells and manufacture into modules.
JPN	Sanyo Electric	0.2 0.0	0.2 0.0	8 3	a-Si a-Si/sc-Si	Sanyo manufacture amorphous silicon modules some of which are used for power applications. In addition in late 1997 Sanyo built a 3 MW_p plant for a-Si/sc-Si hybrid modules. No modules were shipped in 1997.
JPN	Sharp	8.6 1.9 0.1	8.6 1.9 0.1	22	sc-Si mc-Si a-Si	Purchase of sc-Si substrate for cell and module manufacture. Also purchase of Si scraps for cell and module manufacture.
JPN	Showa Shell Sekiyu	-	3.0	5	sc-Si	Purchase of sc-Si cell for module manufacture. Commercialised triangular module.
KOR	Haxime Chemicals				sc-Si	Temporarily ceased production in late 1996.
KOR	LG Industrial Systems	-	0.25	0.4	sc-Si	Active in the construction of PV power units since 1985. Currently three types of modules are produced with rated output powers of 43 W_p, 48 W_p, and 53 W_p.
KOR	Samsung Electronics	-	0.12	0.4	mc-Si	Assembles modules using multicrystalline silicon solar cells supplied by Solarex USA
NLD	BST					Custom made modules and semi-transparent modules for roofs and shadowing elements. A small manufacturer who assembles custom made modules from cells and modules produced elsewhere.

Table 3.2: (concluded)

Country	Company	Cell Production (MW_p)	Module Production (MW_p)	Production Capacity (MW_p)	Module Type	Additional Information
NLD	Shell Solar Energy (renamed from R&S)	<0.2	1.8	2.0	mc-Si	Assembles mc-Si modules from cells, which in 1997 were mainly acquired externally (90 %). Modules are produced for array mounting and laminates for roof integration. Cell and module production capacity will be expanded to 5 MW_p in 1998.
SWE	GPV	-	0.8	1.0	sc-Si	Modules are fabricated from prefabricated crystalline silicon cells purchased on the international market. Output powers of 55 W_p and 110 W_p.
USA	ASE Americas	4.0	4.0	4.5	Edge Fed Growth ribbon Si	Multicrystalline silicon ingot is purchased, pulled into sheets and cut into 100 cm^2 slices. Both cells and modules are produced with 200 - 300 W modules as standard. Twenty year warranties are offered. Plant expansions with capacities exceeding 10 MW_p are expected in 1998. Formerly Mobil Solar, the operation was purchased by ASE in 1993.
USA	Astropower	3.9 0.4	unknown 0.4	4 0.5	sc-Si Si film	Purchases silicon wafers and processes them into cells, most of which are sold and assembled into small power modules by other companies. Astropower also produces power modules. Astropower have developed and patented a process of manufacturing thin film polycrystalline silicon on a ceramic substrate. The new product, Silicon-Film™, has been in pilot production for three years and Astropower have announced a new 9 MW_p production plant to be in production by late 1998.
USA	BP Solar America	-	unknown	unknown	sc-Si	Recently purchased assets of APS. In 1997 produced single crystal modules with cells imported from BP Solar plants in Europe. Have installed a 9 MW_p cadmium telluride plant which may begin producing modules in 1998.
USA	Siemens Solar	22.0	unknown	24	sc-Si	Manufacture and sell modules and cells made from single crystal silicon ingots produced in-house. Standard commercial modules range from 35 W to 120 W. Have performed research, pilot production and testing on copper indium diselenide modules for over 10 years with efficiencies over 10 %. No formal announcements have been released for production.
USA	Solarex	14.0 0.8	unknown 0.8	16 10	mc-Si a-Si	Now a division of Amoco/Enron Solar. Multicrystalline silicon is purchased and processed into cells and modules with a power output of 33 - 200 W. Pilot quantities of 5 - 10 W amorphous silicon modules have been produced. A 10 MW_p plant producing 60 W a-Si modules was completed in 1997.
USA	Solec International	4.0	unknown	4.5	sc-Si	Solec is owned by Sumitomo and Sanyo of Japan. They manufacture single crystal cells and modules with an output of 40 - 200 W, but custom modules are also made. Most of their product is shipped to Japan for the residential PV roofs programme.
USA	USSC	1.7	1.7	4	a-Si	Producers of triple-stacked amorphous silicon modules, with a size range from 5 W_p to 22 W_p. Full production in their new 5 MW_p plant in Troy Michigan began in 1997. USSC produce marine modules, framed power modules, a PV shingle and standard seam metal roofing material.
TOTALS		**102.52**	**100.01**	**206.68**		**This total includes data from Germany and the smaller companies in the U.S.A. which is not given in this table.**

Key: sc-Si is single crystal silicon; mc-Si is multicrystalline silicon; a-Si is amorphous silicon.

Data on cell and module production for individual companies in Germany is not available for publishing, but data on totals for 1997 are available as follows:

- Total module production - 6.06 MW_p
- Total cell production - 1.3 MW_p
- Total production capacity - 18.75 MW_p

The majority of modules produced are crystalline silicon, with 0.2 MW_p of amorphous silicon produced in 1997. Three German companies produced over 1 MW_p in 1997.

There is no PV module production in Austria, Finland, Israel, Norway or Portugal. However approximately 50 % of the world demand for tedlar for PV modules is produced and exported by the Austrian manufacturer ISOVOLTA/Werndorf, Styria.

3.1.4 Module Prices

Module prices represent a significant proportion of the price of PV power systems and have decreased in the past due to the expanding market and increased production. Future decreases in module prices are expected. Whilst some price data were provided in the national reports, it is difficult to make comparisons between manufacturers or draw meaningful conclusions as to the trends in prices because module prices depend on power output, size of order, application, currency fluctuations, etc.

Table 3.3: Typical factory price for crystalline silicon modules in country of manufacture in 1997. Averages prices are weighted by the module production in each country in 1997

Country	Average Price (USD/W_p)	
	Small Quantity	Large Quantity
AUS	4.6	2.9
CAN	5.5	4.8
CHE[1]	7.0	6.1
DNK[1]	7.1	
DEU	4.5	4.2
ESP	5.1	4.6
FRA	6.6	3.9
ITA	4.6	4.4
JPN	5.9	4.9
KOR	6.8	
NLD		5.0
SWE	4.7	4.5
Average	5.0	4.1

1 Mainly custom made modules

Table 3.3 shows typical prices for crystalline silicon modules in the reporting countries. Typical crystalline silicon prices for a small order (less than 5 kW_p), ranged between 4.5 USD/W_p in Germany and 7.1 USD/W_p in Denmark, with the average price being 5.0 USD/W_p. The average price was weighted according to the module production of each country. The high price of Swiss and Danish modules was because they tended to be non-standard products for building integration. For a large order of crystalline silicon modules (greater than 100 kW_p) the average price was 4.1 USD/W_p.

The prices quoted in Table 3.3 are factory prices to distributors. Approximately 20% should be added for prices to customers.

Prices for amorphous silicon modules were only available from a few countries and ranged between 4.5 - 6.6 USD per W_p for a small order, and 3.3 - 6.0 USD per W_p for a large order.

Table 3.4 shows average module prices for large and small orders in 1993, 1995 and 1997. The 1995 and 1997 data is for crystalline silicon only, but in the 1993 Survey Report the prices for amorphous and crystalline silicon modules were combined. The figures in Table 3.4 show a significant fall in module prices between 1993 and 1997: 41 % for small orders and 27 % for larger orders. Note fluctuating exchange rates may have affected module prices in some countries.

Table 3.4: Average module prices for large and small orders in 1993, 1995 and 1997

Year	Small module order (USD/W_p)	Large module order (USD/W_p)
1997[1]	5.0	4.1
1995	5.5	4.9
1993	8.5	5.6

1 In 1993 and 1995, a small order was <1 kW_p, but in 1997 the definition has been revised to <5 kW_p

3.1.5 Inverters

The electricity generated by PV modules is d.c. and many applications require a.c. power. The conversion from d.c. to a.c. is carried out by an inverter. The two basic categories of inverters for PV systems are grid-connected and stand-alone: grid-connected inverters may be either self-commutated (line-synchronised) or line-commutated systems; stand-alone inverters are all self-commutated types.

Figure 3.5 *(see next page)* shows the number of inverters for grid-connected PV systems sold in the reporting countries, broken down by inverter size, in 1995 and 1997. Austria, Canada, Finland, and Italy were unable to provide accurate data in 1995, and in 1997 a number of countries including Canada, Denmark, France, Italy and Norway did not provide information on the number of inverters sold.

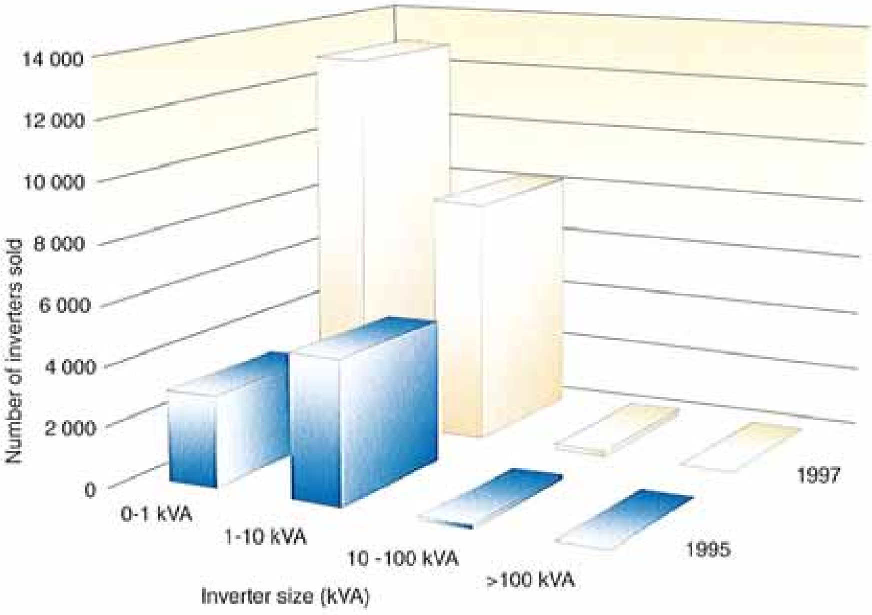


Figure 3.5: Number of inverters sold for on-grid PV systems in the reporting countries in 1995 and 1997

Therefore the numbers shown underestimate the actual figures, however it is clear that the majority of inverters sold in both years were less than 10 kVA in size.

The significant increase in the smallest inverters less than 1 kVA in size, sold between 1995 and 1997, is mainly due to the large numbers of inverters sold for on-grid distributed applications in Germany and the Netherlands. Inverters of the size 1 - 10 kVA increased by approximately 70 % from 1995 to 1997, with the greatest contribution from Japan in which 5 500 inverters in this size range were sold in 1997, mainly for their residential PV system programme. There were no significant changes in the number of inverters of size 10 - 100 kVA sold, whilst all the large inverters (over 100 kVA) reported sold in 1997 were in Germany and the U.S.A.

The development of module integrated converters, for so called a.c. modules, using small inverters between 100 W and 300 W in size, and string inverters of approximately 700 - 1500 W has also contributed to the significant increase in smaller inverters sold in 1997, as multiple inverters are generally required for a single installation. String inverters are currently very

Table 3.5: Number of inverter manufacturers (grid and stand-alone), number of inverters sold in 1997 (grid-connect only) and prices in reporting countries

Country	Number of Manufacturers in 1997	Average Price by Size (USD per VA)				Number of inverters sold
		0-1kVA	1-10kVA	10-100kVA	>100kVA	
AUS	8					70
AUT	1	1.31	1.23			1 200
CAN	4		0.55			
CHE	6	1.41	0.75	0.80		792
DEU	10	1.24	1.02	1.02	0.40	7 724
DNK	0					
ESP	2					16
FIN	1					1
FRA	0					
GBR	1	2.40[1]	1.60	1.92		35
ISR	0					
ITA	10	1.43	1.31	0.57	0.34	
JPN	19		1.31	1.54		5 600
KOR	9		3.53	3.76		2
MEX	1					
NLD	3	1.00	1.00			5 300
NOR	0					
PRT	0					
SWE	0					
USA	5	1.85	0.50	0.50		524
Total	80					21 264

1 Inverter combined with Data Acquisition System.

popular due in part to their low cost. A.C. modules are a relatively recent development and do not yet account for a significant part of the market. However, they are expected to increase in popularity.

The price of inverters, in USD per VA, and the number of inverters sold for on-grid systems in 1997 are shown in Table 3.5. The largest number of inverters sold were in Germany, Japan and the Netherlands, each of which sold more than 5 000 inverters in 1997. The total number of inverter manufacturers in the reporting countries in 1997 was 80; of these more than 75 % were located in Australia, Germany, Italy, Japan, Korea and the U.S.A. As would be expected, the average price per watt was lowest for the large inverters and higher for the smallest inverters, with the exceptions of Japan, Korea, Switzerland and the U.K. where inverters in the 1-10 kVA range were slightly cheaper than those in the 10-100 kVA range.
This may largely be attributed to the larger numbers produced and sales in the lower end of this size range. The price of inverters in the 0 - 1 kVA range may decrease significantly if large scale production for use with a.c. modules gets underway.

In Korea, there were no manufacturers producing inverters for grid-connected PV systems, and the four inverters used for on-grid systems installed in 1996 and 1997 were imported. In Denmark, France, Israel, Norway, Portugal and Sweden there were no manufacturers of inverters for PV systems.

3.1.6 Balance of System Component Manufacturers and Suppliers

A specialised industry exists manufacturing PV balance of system (BOS) components such as battery charge controllers and the inverters discussed in the previous section. As would be expected, those countries whose installed power is predominantly off-grid tend to have a BOS industry geared towards the manufacture of batteries and charge controllers, self commutated inverters etc., whereas in countries with predominantly on-grid power the industry tends to be geared towards the manufacture of inverters suitable for grid-connection. For example, in Australia, there are a number of manufacturers of PV components including regulators, remote diagnostics, maximum power point trackers, PV batteries, PV pumps, Remote Area Power Supplies (RAPS) systems and RAPS controllers.

The lead acid deep cycle battery still remains the most common battery for PV applications, and a number of countries including Spain, Korea and Mexico (for solar home systems) use car batteries as standard in their PV systems. A small number of battery manufacturers produce specific solar batteries. In Italy, there are four battery manufacturers specific to PV, which all produce low antimony lead acid batteries to reduce self-discharge. In the Netherlands and Japan, the manufacture of batteries is of low priority as most systems are grid-connected.

Nine of the reporting countries manufacture battery charge controllers. Battery charge controllers perform the basic function of controlling how the battery is charged, either by limiting the current or by holding the voltage constant. Most battery charge controllers also protect the battery from being too deeply discharged. Charge controllers come in 12 V, 24 V, 36 V and 48 V versions with current capacities ranging from 3 to 240 A. Battery protection is usually achieved through a load disconnection feature or through shunt type regulation. Most of the companies active in PV have their own type of series charge controllers. In the USA five companies manufacture charge controllers, ranging from 10 A to 60 A. In total, an estimated 40 000 charge controllers were produced in the USA in 1997. The majority use semi-conductor based charging circuits with microprocessor controls. Most French companies active in PV manufacture their own charge controllers. Total Energie and Apex have developed a charge controller with a central processor unit allowing detailed monitoring of PV systems; and Tecsol have developed computer software which enables data analysis and remote control of off-grid systems to be achieved through satellites or the telephone network. In Germany, a charge controller equipped with an Application Specific Integrated Circuit (ASIC) has been introduced for small PV systems. The integrated circuit contains all the functions for controlling the charging and discharging of batteries integrated on a single chip.

A number of features are often incorporated into the controller to increase battery protection and to maximise the PV system operation. These features can include maximum power point tracking, low voltage disconnect, automatic battery equalising following deep discharge, automatic sub-array switching etc. Both France and Germany report testing programmes to investigate the reasons for battery ageing and the development of new charge controllers which equalise the state of charge of individual battery cells within a battery system to improve battery lifetimes.

Most PV systems use conventional d.c. switchgear components, which are available through major national and international companies and are not specific to PV applications. Finland was the only country that reported production of a range of models and sizes of switchgear specific to PV, although it is very similar to traditional switchgear and is only sold as part of a PV system.

A number of countries reported the development of support structures for PV systems, mostly manufactured from anodised aluminium or galvanised steel and available only as a part of the complete PV system. In Finland, standardised supporting structures are available from PV companies for summer cottages, boats and caravan systems with an easily adjustable tilt angle. In Germany, the Netherlands and

Switzerland, mounting systems are being developed for on-grid distributed systems. The development of new concepts for building integrated PV systems, with co-operation from the building industry, has resulted in the production of façade constructions in Germany and roof tiles in the Netherlands. In Switzerland, mounting systems for flat-roof PV installations are available using reinforced concrete.

3.1.7 Photovoltaic Installation Companies

The number of installation companies in the reporting countries is given in Table 3.6. The total number of 734 includes a large number of small companies which are not exclusively dedicated to PV. Most PV installation companies also offer consultancy services and component delivery.

In a number of countries, there are large PV installation companies with a large share of the market. In Korea, two large companies, LG Industrial and Samsung Electronics, carried out approximately 93 % of the total installations in 1997. They installed 216 kWp and 120 kW_p respectively. In France, the two main installation companies are Apex and Total Energie, each of which have more than 10 full-time employees covering all stages of a PV project from R&D, component assembly, installation, training and maintenance. In the USA, where there are 8 principle PV installation companies with experience in installing systems over 100 kWp in size, there is a trend towards mergers, acquisitions or collaborations that has resulted in a concentration of PV installers within a small number of companies.

In Israel and Spain, most companies are small, operate at a regional level and are not exclusively devoted to PV. Most installation companies in the U.K. are very small, although some larger companies exist which work in a number of renewable fields. There are few installations in the U.K. as most PV systems are exported.

Table 3.6: Numbers of PV installation companies in reporting countries in 1997

Country	Installation Companies	Country	Installation Companies
AUS	80	ISR	8
AUT	30	ITA	10
CAN	76	JPN	40
CHE	50	KOR	7
DNK	5	MEX	10
DEU	270[1]	NLD	23
ESP	67	NOR	4
FIN	12	PRT	10
FRA	10	SWE	4
GBR	10	USA	8[2]
	Total	734	

1 Largely small, local systems installers; only 20 operate nationally.
2 Installation of PV systems >100 kWp

There has recently been a significant increase in the number of installation companies operating in Japan and the Netherlands. In Japan, numbers have increased due to the PV programmes for the residential sector and public facilities. Most installers are divisions or affiliates of PV cell manufacturers, power supply manufacturers, building contractors, electrical product manufacturers or roof material manufacturers.

3.1.8 System Prices

Prices for entire PV systems vary widely and depend on a range of factors including system size, location, customer and the technical specification. For building integrated systems, the cost of the system varies significantly depending on whether the system is part of a retrofit or is integrated into the roof structure of a new building. Typical system prices in the reporting countries for on-grid and off-grid applications for various system sizes are shown in Table 3.7. Prices do not include recurring charges after installation such as battery replacement or operation and maintenance. The price range for both 1995 and 1997 is shown for each application sector.

- System prices in the off-grid 40 to 1000 W_p sector ranged from 8.4 to 52.8 USD/W_p.The corresponding prices in 1995 were 14 to 41 USD/W_p with a marginally different size range of 100 to 500 W_p.
- For larger (1-4 kWp) off-grid systems prices ranged from 8 to 35.7 USD/W_p compared to 1995 prices of 10 to 28 USD/W_p.
- The price range for on-grid 1-4 kW_p systems was 5 to 20 USD/W_p compared to 6.9 to 20 USD/W_p in 1995.
- For the on-grid 10-50 kW_p systems, the range was 6 to 10.8 USD/W_p for ground mounted systems and 5.8 to 21.4 USD/W_p for building integrated systems. In the 1995 report, which did not differentiate between ground mounted or building integrated systems, the range was 7.5 to 30 USD/W_p.
- The price range for systems larger than 50 kW_p was 5.8 to 35.7 USD/W_p compared to 7.0 to 13.7 USD/W_p in 1995.

Table 3.7: Turnkey photovoltaic power system prices by application in the reporting countries in 1997

Country	Price by Application (USD/W_p) in 1997					
	Off-grid 40-1 000 W_p	Off-grid 1-4 kW_p	On-grid 1-4 kW_p	On-grid 10-50 kW_p Ground mounted	On-grid 10-50 kW_p Building integrated	On-grid > 50 kW_p
AUS	11.6-23.2	14.5-23.2[1]	5.8-7.0	7.0-8.7	5.8-8.7	5.8-7.0
AUT	12.3	10.7	9.8		8.2	
CAN	10.2-13.1	18.2[2]	11.6			
CHE	10.0-13.3[3]	8.7-11.3	9.3	8.0	8.0	8.0
DNK	14.3	35.7[4]	7.1		21.4	35.7
DEU	11.9-18.1	10.2-14.1	7.1	6.6	8.4	8.3
ESP	20.5	10.9	12.3	10.2	13.7	8.2
FIN	14.4				6.9-9.0[5]	
FRA	11.9-17.0	27.2-34.0	7.7-8.5			
GBR	9.6-52.8	8.0	9.6-14.4		9.6	8-24[6]
ISR	10-16	10-13	20			
ITA		17.1	11.4	9.1		7.4
JPN			8.1	10.8	11.5	11.5
KOR	17.6	16	14.1		12.9	15.5
MEX	14[7]	25				
NLD	20	10	10		9	
NOR	8.4-13.0					
PRT	11.8	14.7	8.8		7.6	
SWE	12.7-15.3					12.2
USA	20	12	5-10	6	6	
Range	8.4-52.8	8-35.7	5-20	6-10.8	5.8-21.4	5.8-35.7
1995 Range	14-41	10-28	6.9-20	7.5-30		7-13.7

1 Complete RAPS hybrid systems including container, batteries, diesel and PV.
2 Telecom system
3 Includes costs for DC appliances such as lighting, ice-boxes, etc.
4 The high cost is explained by very specialised systems such as telecom stations for Greenland
5 Price does not include installation as these are very dependent on location.
6 Price varies depending on savings in the costs of building materials, or additional costs incurred when retrofitting.
7 Solar home systems.

The large range of prices was due to the fact that some of the systems were demonstration and some countries used wider definitions than others for turnkey system prices. The high price of the Danish grid-connected systems was because they were very "project specific" and characterised by few large projects. The lowest cost for off-grid systems were in Norway for the 40-1000 W_p applications and in the U.K. for the 1-4 kW_p range. However, the UK had the highest cost in the 40-1000 W_p range, attributable to the installation of PV systems for marine buoys. The high cost for the off-grid Danish PV systems is due to the installation of very specialised systems such as telecommunication stations for Greenland. Australia and the United States had the lowest cost for on-grid systems. The prices associated with on-grid systems were generally lower than those for off-grid systems because no batteries and associated components are necessary.

Chapter 4

Framework for Deployment

This chapter looks at the effects of both direct and indirect policy issues on the PV market. The perceptions of the utilities and the general public towards PV in the reporting countries are discussed, and the standards governing the connection of PV systems to the grid are summarised for each country. The final sections look at new developments in PV and some projections on the future of the PV market are presented.

4.1 Indirect Policy Issues

The national reports identified a number of issues that indirectly affect the implementation of PV systems. In addition, many of the reporting countries have signed various international agreements and participate in a number of international programmes dealing with environmental issues such as the reduction of greenhouse gas emissions or sustainable development. Although these factors have not had a significant impact on PV markets in the reporting countries, they will undoubtedly have some impact, either directly or indirectly, on the use of PV power systems.

The first international agreements on the environment were reached at the United Nations Earth Summit on Environment and Development at Rio de Janeiro in 1992. Signatories committed their countries to stabilising greenhouse gas emissions from all sources at 1990 levels by the year 2000, and to provide financial assistance to developing countries to meet their general commitments. Since the Rio Convention, further evidence from the Intergovernmental Panel on Climate Change has confirmed the need to reduce CO_2 emissions in order to avoid the consequences of global warming induced by human activities.

The 1997 Kyoto Conference of Parties to the Framework Convention on Climate Change agreed to a further reduction in carbon emissions to about 5 % below 1990 levels by the year 2000. These targets had some impact on national policies and programmes concerned with renewable energy and can be expected to have more influence in the future.

National targets for the proportion of electricity to be supplied by renewable sources have been set for various future dates by a number of countries including Australia, Denmark and the Netherlands. Japan has set a target to install 5 000 MW_p by the year 2010, and Switzerland aims to install 50 MW_p by 2000.

In the Netherlands a PV covenant has been signed by 15 parties, including 6 major utilities, who each promised to contribute to realising 7.7 MW_p of on-grid PV installations by the year 2000.

CO_2 taxes are being discussed in many countries but so far have only been implemented in Denmark, Finland and Sweden. In Sweden emissions of SO_2, CO_2, NO_x and the use of nuclear power are taxed. In Finland the use of coal, peat and natural gas are taxed.

These environmental issues have had little direct effect on the market for photovoltaics because the cost of electricity generation from PV is still high compared to conventional power generation. However, their long term effects may be large as they may act as an indicator of future business opportunities to decision makers.

Utility privatisations and restructuring creating increased levels of competition are also on-going in a number of countries and may well impact on the implementation of PV in these countries. The Italian utility ENEL is in the process of being privatised. ENEL has implemented a number of major PV programmes and projects in Italy. Privatisation can be expected to impact on the actions they undertake in the future but it is not yet clear what the effect will be. The United Kingdom electricity industry has been privatised over the last few years and commercial and regulatory issues have limited utilities in the actions they can take in the field of photovoltaics. Privatisation and increasing levels of commercialisation of utility activities are also on-going in the Netherlands and the USA.

4.2 Promotion Initiatives

A wide variety of initiatives for promoting the use of photovoltaics, or renewable energy in general, exist in the reporting countries. Market deployment initiatives are being undertaken in a number of countries particularly where it is felt that the market for a particular application of PV is ready for stimulation. These initiatives often follow on from successful demonstration programmes where it is felt that the market has matured beyond the point of needing demonstration programmes.

Initiatives reported in various countries include:

- Green power schemes run by utilities where voluntary customer contributions are made towards sustainable energy supplies. These types of schemes are reported in Australia, Germany, Switzerland, the United Kingdom and the USA.

- Rate based incentive schemes where a premium price, higher than the cost of electricity purchased from the utility, is paid for PV generated power are reported to be operating in regions of Germany and Switzerland. In a number of other countries preferential tariffs are paid for PV generated power that are higher than the price normally paid by the utility for power generated by conventional sources. Net metering, where the price paid for PV power matches the price normally paid by the consumer for electricity, is available in an increasing number of countries. Countries where preferential tariffs are available are indicated in Table 4.1.

Table 4.1: Promotion Initiatives in reporting countries

✓ indicates such an initiative exists whereas
✗ indicates it does not exist

Country	Grants Available	Preferential Tariff	Tax Exemptions or Reductions	Comments
AUS	✓	✓	✓	Remote Area Power Supply (RAPS) grants are available in Western Australia providing typically 50 % of the total system cost, to a maximum grant of USD 4 640. Tariffs paid for PV electricity vary between utilities, net metering and special PV buy-back rates are available from some utilities. Solar cells are sales tax exempt.
AUT	✓	✓	✗	Some regional governments subsidise the erection of PV systems under environmental programmes (up to 4 000 USD per application). Tariffs vary between utilities, ranging between 0.032 - 0.8 USD per kWh. Taxes on electricity, including that generated by renewables, of 0.008 USD per kWh were introduced in 1996.
CAN		✗	✗	Limited net metering - some utilities allowed reverse metering from small grid-connected PV systems. Accelerated depreciation for systems >10 kW_p
CHE	✓	✓	✓	Grants available in some cantons. In 1997 the Swiss Confederation granted subsidies of USD 2 000 per kW_p for all installations over 1 kW_p in size. The Swiss Decree on Energy Use defines a minimum rate of 0.106 USD per kWh for electricity produced from renewable sources. Income tax reductions for private owners of PV systems in most Cantons.
DNK	✓	✓	✗	From 1997 grants are available to the commercial sector towards the cost of a PV installation. Grants were for 26 % in 1997, expected to increase to 40 % in 1998. Net metering is expected for privately owned roof tops from 1998. All uses of energy are taxed by energy tax, CO_2 tax/green tax, resulting in high consumer prices of about 0.18 USD per kWh for non-industry users.
DEU	✓	✓	✓	Market introduction models are wide spread on the governmental and state levels including subsidies, loans and tax benefits. 10 of the 16 Federal States provide support for PV installations. Grants are available in some areas in combination with rate based incentives. Utilities are obliged to pay a basic tariff of 0.1 USD per kWh by law. Rate based incentives for generating PV power are available widely with approximately 50 cities involved in different variations. Some municipal utilities pay up to 1.13 USD per kWh over 10 or more years for the generated power. Sales tax exemptions are given if the PV generator is part of the cost of a new house (e.g. roof integrated modules).
ESP		✓	✗	Local electricity utilities must purchase renewable energy supplied electricity at prices set by national authority when available.
FIN	✓	✗	✗	The Ministry of Trade and Industry provides grants of up to 40 % for investment in renewable energy technology, including PV, to utilities and enterprises, but not private persons.

Table 4.1: (completed)

Country	Grants Available	Preferential Tariff	Tax Exemptions or Reductions	Comments
FRA	✓	✓	✓	FACE funds provide public subsidies for rural electrification. Since 1995 off-grid renewable energy systems (wind and PV) have been eligible for FACE funds where grid extension is more expensive. Users pay 5 % of system cost, EDF operate and maintain the PV systems, users pay a monthly electricity invoice to EDF. FACE projects are VAT exempt. The PV industry has also taken advantage of investment tax exemptions in overseas departments, (not targeted at PV). In 1996 the French Ministry of Industry recommended that on-grid distributed systems be allowed net metering.
GBR	✗	✗	✗	PV is not considered ready to fit into the Non Fossil Fuel Obligation (NFFO) scheme whereby electricity from non-fossil fuel sources is bought at a premium (0.07 USD per kWh): PV electricity is purchased at pool price. Net metering is not allowed.
ISR	✗	✓	✗	The Israel Electric Corporation purchases electricity supplied by renewable energy sources at time of use tariffs which are slightly higher than average tariffs, if the Electricity Commissioner of the Ministry of National Infrastructures recommends so. However, presently each case is negotiated separately.
ITA	✗	✗	✗	Incentives to PV generation were suspended throughout 1996 and 1997 because the Italian government was considering new incentives for renewable generation. A 10 000 PV roof top programme is expected to start in 1999, with the aim of installing 50 MW_p by 2004. Private individuals will be eligible for 80 % support of the maximum investment costs; private companies and public institutions will be eligible for 75 % support. The support will be reduced over the course of the programme to reflect cost reductions.
JPN	✓	✓	✓	Subsidies available under the Residential PV Systems Dissemination Programme and the PV Field Tests for Public Facilities Programme. Net metering has been available since 1992. Local and national tax reductions for individuals and private companies purchasing PV systems. National reduction is a choice of a deduction equivalent to 7 % of acquisition value or a special depreciation equivalent to 30 % of acquisition value.
KOR	✗	✗	✗	Low interest government loans are available for installing renewable energy systems but no applications received for PV systems due to high initial investment.
MEX	✓	✗	✗	Government grants available to communities for rural electrification.
NLD	✓	✓	✓	Several utilities provide grants of about 1.5 USD per W_p; although for some projects grants can be significantly higher. Most utilities accept net metering. Various financial instruments stimulate the use of PV including green funds, green mortgages, energy taxes, green pricing and tax reductions.
NOR	✗	✗	✗	Taxes on pollution currently being discussed.
PRT	✓	✗	✓	The ENERGIA-SIURE (Incentive Scheme for the Rational Use of Energy) programme can be used to finance PV systems, but is not available to private individuals. Fiscal incentives for renewable energy include reduction of VAT rate from 17 % to 5 % for renewable energy equipment, and deductions on income tax. Green pricing strategies are currently being prepared.
SWE	✗	✗	✗	Taxes on SO_2, CO_2 and NO_x and nuclear but these do not impact on the PV market.
USA	✓	✓	✓	Grants for PV systems in 12 states, loans in 15 states. Over 22 states now approve net metering. Green pricing available from 10 utilities in 8 states. Tax benefits in various states.

- Government grants towards the price of purchasing PV systems are available in a number of countries. These are normally available for a specific application and only certain people or organisations are eligible to apply. Grants for rural electrification are available in Western Australia, France and Mexico. Grants are available to utilities and enterprises installing renewable energy generators in Finland. Grants towards installing PV systems are available to commercial organisations in Denmark and Portugal. In Japan subsidies are available for PV systems installed on housing and on public facilities. See table 4.1 for further details.

- Low interest loans for installing renewable energy systems are available in Korea, the Netherlands and in 15 states in the U.S.A.

- Fiscal measures for promoting PV are employed in a number of countries. Measures taken include reductions in sales tax and customs duties, depreciation allowances and income tax reductions. Table 4.1 indicates those countries where tax exemptions or reductions are available.

- Switzerland and the Netherlands report modifications to building regulations designed to promote or remove hindrances to the installation of PV systems. In several cantons in Switzerland building permission procedures for solar systems up to 10m^2 in area have been simplified to reduce red tape and unnecessary overheads. In the Netherlands, where new buildings are required to have a minimum Energy Performance Ratio, it is currently planned to include PV as a measure which lowers the Energy Performance Ratio of a new house.

4.3 Perceptions of Photovoltaics

4.3.1 Utility Perceptions

At the end of 1997, the utilities' perceptions of PV systems were reported to be generally favourable in the reporting countries, with the utilities in several countries actively promoting PV through various dissemination programmes. Restructuring of the electricity markets in a number of countries has resulted in utilities widening their green energy portfolio to include PV.

Some utilities in the reporting countries were concerned about the effect of large numbers of small embedded generators on the electricity distribution systems. Research programmes are currently being undertaken in a number of countries and through Task V of the IEA PV Power Systems Programme to investigate this.

The Electricity Supply Association of **Australia** is working in co-ordination with the utilities and federal and state governments to develop strategies for implementation of the Federal government target of 2 % new renewables by 2010. Many utilities now offer PV based off-grid systems for residential customers and a number of utilities operate larger, community sized, off-grid PV systems. The development of Australian guidelines for grid connection and restructuring of the electricity industry has opened up the market for private on-grid PV generators. Utilities are encouraged to install PV to meet green power targets required by legislation such as the NSW Electricity Act. Present utility R&D funding tends to focus on the development of components or products aimed at the on-grid market. This includes development of specific PV products, testing and further development of inverters, protection devices, metering and monitoring systems, market surveys and analysis tools, and modelling of PV in grid systems.

The utility companies in **Austria** have invested substantially in PV and operate a number of PV plants for demonstration purposes or to supply isolated systems such as meteorological stations. In 1997, the total capacity of PV systems operated by Austrian utilities amounted to approximately 270 kW_p. The utilities also support public authorities and schools in the planning and installation of PV applications.

The restructuring of the electricity market in **Canada** is encouraging utilities to consider supporting PV installations to increase their green energy portfolio. In 1996, two large Canadian utility companies, EPCOR Utilities Inc. and Ontario Hydro joined the US based utilities group UPVG (Utilities Photovoltaic Group). UPVG is a joint venture to develop and implement market assurance strategies that will enable PV manufacturers to invest and hence reduce costs. EPCOR is currently evaluating several commercial PV applications, and Ontario Hydro is actively involved in the promotion of solar energy for both stand alone and grid-connected systems.

In **Denmark** the electricity utilities have been a key party investing in PV. Recent legislative changes have allowed the utilities to engage in further financing, leasing and servicing of PV systems.

On-grid centralised PV systems are not of interest to the utilities in **Finland**. However, a major government owned power company installed a 30 kW_p grid-connected demonstration system and plans follow-up developments in the field.

In **France**, the utility EDF 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. In 1996, EDF and the ADEME (Agency for Environment and Energy Management) renewed their commitment to promote off-grid PV systems, and at the end of 1995, EDF announced the start of a PV R&D programme. There are currently no grid-connected systems owned or managed by EDF.

In **Germany**, almost every regional and local utility company has installed, or is planning to install, their own PV plant for demonstration and research purposes. A number of PV programmes were promoted by utilities such as Bayernwerk and PreußenElektra. These include the "Sun at School" programme in which about 1 450 schools throughout Germany were supplied with 1 to 3 kW_p PV systems sponsored by each utility. In 1996 about 280 kW_p was installed within this programme, and in 1997 about 400 kW_p was installed. The municipal utilities are currently focusing on rate-based or cost-oriented PV incentives for their customers, while the regional and nation-wide operating private utilities prefer marketing models such as green pricing which is used by RWE.

The **Israel** Electricity Corporation has a small group of researchers that focus primarily on PV experiments, whilst keeping abreast of new developments abroad. There are currently no investments in the installation of systems.

In **Italy**, the favourable utility perception of PV has been evident in the utility ENEL's multi-year comprehensive programme of research and development on PV systems, which is aimed at promoting significant energy generation from PV. ENEL has installed a 3.3 MW_p PV plant at Serre and is carrying out tests at the Adrano plant, which is a test field for innovative components of PV systems (i.e., modules, inverters, sun-trackers and support structures). Some municipal utilities (Verona, Torino and Palermo) have also shown an increased interest in PV and are starting (or have started) small demonstration programmes.

Most utility companies in **Japan** have shown an interest in PV systems. In 1991, power companies announced plans to install 2.4 MW_p of equipment by the end of fiscal year 1995. The installed capacity exceeded targets by approximately 250 kW_p. More recently, utilities have implemented a plan to install PV systems at their own facilities. The Tokyo Electric Power Company has established a new subsidy system to support R&D efforts and provide financial assistance for residential PV installations.

In **Korea**, the state utility KEPCO has shown a continual interest in PV by implementing demonstration projects and providing financial support to universities and research institutes for R&D. Research projects include development of thin-film solar cells, optimisation and performance analysis of PV systems for remote islands and grid connection of PV. In addition, they are implementing their own R&D project on distributed on-grid systems through their research institute. However KEPCO are hesitant to invest further in PV, mainly due to the perception of high initial costs and limited land availability. KEPCO is currently operating only a small-scale on-grid PV system. The government amended the "Promotion Act for the New and Renewable Sources of Energy (NRSE) Development, Utilisation and Dissemination" in late 1997. This is expected to enhance PV dissemination efforts. The government and KEPCO are presently setting up guidelines to solve a number of problems expected with the grid-connection of PV.

Since 1989, the **Mexican** government and electric utility, Comisión Federal De Electricidad (CFE), have considered the use of PV as a viable alternative to extension of the utility grid to supply small amounts of electricity to remote communities. CFE oversees the quality issues of every project financed by the government's rural electrification programme. It has fostered development of technical specifications and design guidelines, in addition to implementing an extensive training programme for utility engineers. The utility, which draws expertise from the Electrical Research Institute of Mexico (IIE), has monitored a number of hybrid PV-wind systems.

In the **Netherlands**, most utilities are actively involved in PV dissemination activities. Several of the utilities, which are all privately owned, view solar power as a potential new business opportunity. One utility, NUON, has developed a package in which they finance grid-connected PV systems to be installed on customers' roofs or land, in exchange for a long term contract for green electricity. Some utilities own the PV system or the whole roof, whilst other utilities lease the PV system or it is owned by the home owner. Only one utility, PNEM, considers PV to be currently too expensive to invest in.

Most utility companies in **Norway** base their activities on hydroelectric power and have seldom been involved in PV. However, several utilities have shown an interest in PV, with the utility, Hedmark Energi AS, sponsoring the Venberget PV-diesel hybrid system described in section 2.3 National Demonstration and Field Test Programmes.

The major **Portuguese** electric utility, EDP, has been considering PV as part of their R&D programme for renewable energy, although at a lower scale compared to wind energy. The near term strategy of EDP is to follow up the technology and the market evolution by participating in international, European and national programmes. They plan to participate in future demonstration projects for stand-alone, grid-connected and building integrated systems.

In **Spain** several electricity utilities have been involved in PV projects. The first large grid-connected PV system, San Agustin, was developed by the utility

IBERDROLA. Union Fenosa and ENDESA jointly operate the 1 MW_p Toledo plant. The law stipulates that utilities must buy the electricity from embedded generation in their area at a reasonable price, although there is no specific treatment for PV.

The **Swedish** utilities consider the development and introduction of PV technology to be best suited to countries with better climatic conditions than Sweden, particularly countries where there is a closer match between the supply of solar energy and electricity demand. PV technology is not considered likely to be utilised for electricity power generation within the next 5 to 10 years, except for off-grid applications as an alternative to extension of the utility grid. The Swedish utilities are sponsoring a programme concerning niche applications with the potential for cost-effective use of PV. Examples of applications under investigation include illumination for bus shelters, cathodic protection of power line pylons and measurement systems for meteorological and hydrological data. More recently, the programme has focused on more long term aspects of PV including analysis of the barriers preventing widespread use of PV. Some companies consider distributed generation to be a strategic option for the long term, whilst a number of companies view PV as a means of providing green electricity.

In **Switzerland**, an estimated 20 % to 30 % of installed PV capacity is owned either directly or indirectly by the utility companies. This proportion is decreasing as more privately funded installations come into service, despite the utilities becoming more active in the PV area in 1996 and 1997. The utilities are now providing increased PV generated electricity in response to demand from customers for green electricity. The "Solar Power from Electric Utilities" project initiated by Switzerland's "Energy 2000" programme and the Swiss Association of Power Utilities supports green electricity with 15 utilities providing programmes by the end of 1997. In addition, the utilities support R&D efforts conducted by universities and research institutions.

Several of the utilities in the **United Kingdom** have begun to seriously consider PV. However, as present embedded generation regulations were written to assist the connection of large single point connection installations, the utilities are reluctant to connect multiple distributed PV systems to the grid. A 640 000 USD experimental programme, part of the UK's contribution to Task V of the PVPS agreement, is currently underway to identify and propose solutions to network interface problems. With the opening up of the electricity market, some utilities are interested in PV as a means of promoting a green image. Although they have helped technically and/or financially with the installation of PV power systems, there are no PV power systems currently owned or operated by the utilities.

In the **USA**, the utilities have started key programmes involving the design, installation and operation of PV for grid-connected applications. The UPVG (Utility PhotoVoltaic Group) program involving over 90 utilities has funded over a thousand systems deemed to be 'close to economic'. The total Department of Energy (DoE) subsidy for the first two rounds of UPVG PV system procurement was about 20 %, well below the 30 % originally planned. With deregulation of the US utility industry growing on a state by state basis, the sale of green electricity, the development of PV programmes for schools and on-site energy generation the number of utilities offering PV generated electricity is increasing.

4.3.2 Public Perceptions

The public perception of PV was generally positive throughout the reporting countries, particularly in Australia, Germany, Japan, the Netherlands, Norway, Switzerland and the United States. In Germany there is wide public awareness concerning the long-term benefits of PV. About 7 million inhabitants of German cities have the opportunity to install PV plants under rate-based incentive programmes offered by municipal utilities. In Japan, there is a positive public response to PV through ambitious programmes such as the Residential PV System Dissemination programme. In 1996, there were 11 192 applications for 1 986 systems, and in 1997, 8 329 applications were accepted. The 1998 budget will increase to correspond to public enthusiasm for PV. In the Netherlands a survey on the public perception of renewables, conducted by the Ministry of Economic Affairs in 1997, showed that the public view solar and wind more favourably than other renewables and that the building industry see PV as the best long-term renewable energy prospect for the Netherlands. The perception of PV in Norway is very good, partly due to the large number of systems installed at mountain cabins and leisure houses, and further stimulated by an annual 'Solar Day' in Oslo. In Switzerland, an increasing number of people are prepared to pay a premium for electricity generated from PV, with 20 000 customers explicitly choosing to buy PV generated power. A survey conducted by the American utility SMUD in 1997 showed that 24 % of the general public were willing to pay more on their utility bill for PV, and a report released in April 1998 by the Sustainable Energy Coalition showed that 32 % of those surveyed prefer the renewable energy section of the US Department of Energy budget for energy R&D.

In a number of countries, including Canada, France, Portugal, Spain and Sweden, although perceptions were generally positive concern was expressed as to the high cost of PV systems. As a result they were seen as more relevant to remote applications. In Israel, where solar thermal energy is widely used for heating, little was known by the public about PV. In Korea and the UK public awareness of PV power systems was low although it was increasing through demonstration programmes. In Korea a CD-ROM and internet website is being promoted to improve awareness for the younger generation.

4.4 Standards and Codes

The increasing use of PV power systems will require a series of national or international standards in order to facilitate the construction, grid-connection and operation of PV power systems. By the end of 1997, a number of countries had specific regulations governing PV systems or the grid connection of PV systems in place or under development.

The issues dealt with in this survey focus primarily on the technical regulations for the construction and operation of PV systems and the regulations for their grid-connection. A number of countries, including Austria, Germany, Italy, Japan, the Netherlands and Switzerland, have either draft or preliminary regulations in place or under development. Many countries had no specific standards or regulations concerning the grid-connection of PV systems, but used regulations applicable to other generators, such as small hydro or wind power. Australia, France and Mexico have developed standards specific to off-grid power systems.

The utilities in a number of countries have been satisfied with the protection offered with inverters, whilst others have insisted on additional protection between the inverter and the grid for on-grid systems. The applicable standards and codes in the reporting countries are summarised in a report published by IEA PVPS Task V[3]. Details of country specific regulations and codes are given in Table 4.2.

Work to develop standards for PV power systems is ongoing; the International Electrotechnical Commission (IEC) has issued 19 standards covering various aspects of performance measurement, design qualification and type approval for crystalline silicon modules (IEC 61215) and thin film modules (IEC 61646).

3 Grid-connected photovoltaic power systems: status of existing guidelines and regulations in selected IEA member countries, Report IEA-PVPS V-101, July 1996.

Table 4.2 Summary of Standards and Codes in reporting countries at the end of 1997

Country	Information on Standards
AUS	Individual PV system components are typically expected to comply with existing power supply standards and building codes. These vary between utilities, states and local government. Specific standards exist for RAPS systems and RAPS batteries. Australian and international PV module standards apply, as do PV battery standards. Australian guidelines for grid connection of inverters have been developed. Protection measures for high DC voltages are required, particularly in building integrated PV systems.
AUT	Regulations concerning the connection of PV generators to the public grid are governed by ÖNORM E 2750 which is applied for planning, erection, and monitoring of small grid coupled PV power installations. In 1995, an updated version was implemented to allow the use of ENS impedance measurement techniques as a means to detect the loss of the grid voltage and hence to prevent islanding.
CAN	Any system larger than 100 W_p is subject to inspection by the relevant utility. The Canadian Electrical Code requires that components must be certified by the CSA or be subject to special inspection and approval. A special certification programme for PV installers has been initiated in British Colombia and offered nation-wide by CanSIA, in an attempt to accelerate approval of systems. Canada has two active standards for PV systems: F-380 deals with PV module standards; F-382 deals with batteries for PV uses, both of which need to be revised. A new inverter standard to include grid connected power conditioners and AC modules is being reviewed. Canada is participating in the IEC TC-82 WG 2 and 3 for the development of PV standards. Section 50 of Part 1 of the CEC published in 1994 specifically addresses the installation requirements for PV systems, and is presently being revised to include regulations developed by the IEC and the American NEC.
CHE	PV systems must meet all requirements which are placed on other electrical equipment as set out in national regulations by the Swiss Electro-technical Association SEV. The Federal Power Inspectorate has published guidelines on the grid-connection of PV power systems and power quality requirements. Switzerland participates in IEC TC-82 WG3 and CENELEC's BTTF 86-2. The Swiss Engineers and Architects Association SIA has produced standards relating to building integrated PV systems. PV systems operating with a voltage lower than 1 000 V d.c. or 1 500 V a.c., with or without the

Country	Information on Standards
	possibility of connection to a low-voltage supply network, are subject to the provisions of the decree on low-voltage installations.
DEU	The use of general standards and regulations is advised because they refer to the VDE regulations generally accepted by engineers. The basic German safety code is VDE 0100 (International: IEC 364). This code covers all issues of electrical safety, including a list of accepted protection measures to prevent electric shocks, although it is not specific to PV-systems. Modules are required to comply with IEC 1215 and inverters with DIN EN 55011/B and DIN VDE 0875.11. Battery systems must meet VDE 0510. The VDEW directive for the operation of private electricity generating plants makes single phase operation compulsory for plants below 5 kW_p and three phase operation compulsory for plants over 5 kW_p in size.
DNK	Denmark participates in the IEC TC-82 and CENELEC, and expects to adapt to the international standards and codes that result. A national PV System Laboratory (PVSys-Lab) was established in 1995. It has set up a certification system for installers, and has prepared a quality assurance system for approved components and systems for installations receiving public incentives. In parallel with this work, the association of Danish utilities have recommended accepting grid connection of inverters approved according to the Dutch or German regulations, with the same tariff as for wind power.
ESP	There are no specific requirements for PV power systems. PV systems have to fulfil the same requirements (low voltage guidelines and electrotechnical standards) as any other generating equipment.
FIN	The regulations for connecting small electric power production units to the grid contain no specific requirements for PV plants. Constructors of PV systems have to follow the general regulations for electric power installations. Customers can install their own (small, summer cottage) low voltage PV systems on condition that the installing instructions of the systems have been approved by the Finnish Electricity Inspection Office.
FRA	"Specifications for the use of renewable energies in rural decentralised electrification" have been developed by ADEME, Electricité de France and PV companies covering construction and operation of off-grid PV power systems. No specific regulations exist relating to grid-connected PV systems. French experts participate in the IEC TC-82 and the GAP approval programme.
GBR	The UK does not have regulations that are directly applicable to small embedded generators, currently those pertaining to large scale rotating generators would be applied. The main regulations that affect the implementation of grid-connected PV are: The Electricity Supply Regulations HMSO, 1991; The Distribution Code of the Public Electricity Suppliers of England and Wales (1998); Engineering Recommendation G.59/1 (1991); Engineering Technical Report No. 113 (1995). Various regulations governing harmonics, electro-magnetic compatibility and protection also apply.
ISR	There are no regulations relating to PV systems, although the Israel Electricity Corporation has general guidelines relating to the quality of the electricity it purchases.
ITA	Technical regulations specially devoted to the design and construction of PV systems are not available. Therefore the existing regulations (i.e. DPR 547/55, Law 46/90) and rules issued by CEI, the Italian Electrotechnical Committee, must be observed. In particular, the Italian rule DPR n. 547 of 27/4/55 imposes restrictive safety conditions for electric systems having a d.c. voltage over 600 V; the observance of these conditions involves very serious technical and economic problems. Therefore, the Italian PV plants generally adopt a working voltage less than 600 V d.c. Safety rules concerning PV systems overvoltage included in EN 61173 must be observed in PV plant construction and operation. Grid-connection standards for PV plants are currently being drafted. In the meantime, general rules (CEI 11-20), must be observed. Internal ENEL regulations (DV1601 and DV1603) stipulate the procedures for connection of self-producers, with installed power up to 3 MW, to the low or medium voltage grid. DK5940 and DK5740 pay particular consideration to the grid-connection of static a.c. generators. These rules have been recently revised and partially modified (CEI 11-20) to take into account the grid interconnection of static a.c. generators to the low voltage grid, both for single-phase a.c. generators, with a nominal power of up to 5 kW_p, and three-phase systems rated up to 50 kVA.

Table 4.2 (completed)

Country	Information on Standards
JPN	The Japanese Industrial Standards (JIS) for PV cover technical requirements of PV cells and modules, measuring methods of characteristics of PV cells and modules, testing procedures of power conditioners and lead acid batteries for PV, general rules for PV arrays and stand-alone PV systems, etc. More than 30 JIS standards have been published. Guidelines for the technical requirements for grid-connection of PV were prepared by the Public Utilities Department in the Agency of Natural Resources and Energy. These guidelines covers power quality (voltage regulation, power factor, harmonics, EMI, etc.), protection co-ordination (internal fault, distribution line fault, islanding, etc.), stability of operation, classification of grid-interconnected systems, specification of protective relays and so on.
KOR	There are no specific requirements for PV power systems: KIER, will on request, carry out PV performance measurements based on the standards of international organisations and third countries.
MEX	Technical specifications and design guidelines have been developed and cover functional, installation and safety aspects of individual PV components and systems. Mexico participates in Task V of the IEA PVPS Agreement with the aim of developing technical specifications and design guidelines for on-grid PV systems.
NLD	Guidelines for the grid connection of PV systems have been developed by KEMA. These include the installation of AC modules in a residential house. There are no building regulations relating to building integrated PV systems. There are no specific national standards or regulations for the application of PV in off-grid systems. All systems have to comply with the low-voltage guidelines and other general electrotechnical and building code standards. In 1995, a national norm commission was formed and participation in IEC TC-82 initiated.
NOR	No specific standards or codes relating to PV systems exist.
PRT	There are no specific standards for PV systems. The technical requirements for grid-connection of photovoltaic power systems are the same as for small hydro power plants or wind power plants (Decreto Lei 189/88) up to 10 MW. Anyone is allowed to produce electricity providing certain technical and security rules are followed.
SWE	The 1992 regulations for connecting small electric power production units to the grid do not explicitly mention PV plants. According to the regulations an application must be made to the local electricity distributor before the installation of the power producing unit. The PV systems that have been installed in Sweden follow the general regulations for electric power installations as far as possible. The lack of national PV-specific regulations regarding grid-connected systems means that the IEC TC-82 standards currently being prepared are followed. Electricity delivered to the grid has to follow the European standard EN 50 006.
USA	Utility owned PV power systems on utility property must meet the National Electric Safety Code NESC-ANSI/NFPA C2-1993: PV power systems not on utility property are governed by NEC-ANSI/NFPA 70-1996. Where local codes exceed this code, the local code takes precedence. Article 690, which addresses unique safety issues of PV power systems, has recently been updated. The Arizona State University Photovoltaic Testing Laboratory has been approved as the PowerMark Corporation testing laboratory, a fully accredited facility for PV module testing.

4.5 Future Opportunities and Trends

The PV industry is a continually developing and expanding industry. As such there were many new developments, some of which were detailed in the national reports. A number of companies have announced plans to expand capacity.

- In Australia significant expansion in manufacturing capacity is planned: BP Solar Australia is planning 20 MW_p of new crystalline silicon production capacity by the end of 1999, Pacific Solar intend to build a 20 MW_p plant for thin film crystalline silicon for the end of 1999 and Sustainable Technologies Australia are planning 2.5 MW_p of titania nanocrystalline production capacity by 1999.
- In Canada, Canrom Photovoltaics Inc. is developing thin film CdTe/CdS technology which it hopes to market at a pilot level in 1999. This is a proprietary technology using electro-plating deposition which is seen as having a strong

potential to bring down costs. The Spheral Solar™ technology was sold by Ontario Hydro Technologies in 1997 and future plans for the technology are unknown.

- In France, production doubled in 1997 and is expected to double again in 1998. Photowatt have announced plans to increase annual cell production to 10 MW_p in 1998 from 5.6 MW_p in 1997.
- In Germany several companies have announced plans to start or expand production lines for silicon feedstock material, wafers, solar cells and PV modules. The most important announcements are the following: PV Silicon will start production of silicon feedstock material (150 tonne/year). Bayer Solar will expand their multi-crystalline wafer production from 6 MW_p to 16 MW_p per year. Antec plan to start production of CdTe thin film modules (approximately 10 MW_p production capacity) by the end of 1999. ASE Alzenau plan to start the production of solar cells (13 MW_p capacity) in 1998. Shell Solar Deutschland and Pilkington Solar International are planning to start crystalline cell production at a new plant with a capacity of 25 MW_p in 1999. Other small and medium sized companies such as Solon AG, RAPS Mikrosysteme, BMC, GSS, Solarcon, Solarwatt, Solar-Werk, SunWare and Webasto are also planning to expand their PV module production capacity. They are all aiming at different niche markets.
- In Japan, a number of companies have announced plans for increasing module production capacity. Planned production capacities for 2000 are Kyocera 60 MW_p, Sharp 60 MW_p, Sanyo Electric 30 MW_p, Kaneka 20 MW_p, Mitsubishi Electric 60 MW_p and Mitsubishi Heavy Industries 10 MW_p. This gives a total production capacity for these companies of 240 MW_p, compared to their total 1997 production capacity of 64 MW_p.
- In the Netherlands R&S renewable energy systems was renamed Shell Solar in the beginning of 1997. This was the beginning of a major expansion in investments and activities by this manufacturer. Shell Solar started producing their own cells in 1997 and expansion of the cell production facility is planned. The module production capacity in the Netherlands will be expanded to 5 MW_p in 1998, and further expansion is expected to a capacity of 10-20 MW_p in future years depending on market development.
- In Switzerland, Solution plan to increase production capacity to 2 MW_p, from 1 MW_p in 1997.
- In the United Kingdom Intersolar intend to increase production capacity at their amorphous silicon production plant at Bridgend to 2.2 MW_p in 1999.
- In the U.S.A. several companies plan to increase their capacity. USSC expect to produce over 4 MW_p in 1998. Solarex started production in 1997 at their 10 MW_p double-stack amorphous silicon plant. Astropower have nearly completed a new Silicon Film™ manufacturing capacity and aim to produce 9 MW_p in 1999. ASE Americas is expanding their silicon sheet growth facility from 4 MW_p to 9 MW_p in 1998 with a planned 20 MW_p capacity in 1999. Solec International also aim to reach a cell production capacity of 20 MW_p. Several companies are in pilot production or nearing production: including Evergreen Solar with a silicon ribbon product, Ebara Solar with a dendritic web silicone product, BP Solar International with Cadmium Telluride modules and EPV which plan to produce copper-indium-diselenide cells. In addition there are five companies involved in early pilot production of concentrator cells and technology: Amonix, Entech, PVI, SunPower and Midway Solar.

Total production capacity in the reporting countries in 1997 was 207 MW_p and plans to install a further 300 MW_p have been announced, this compares to the 55 MW_p announced in the previous report. It is clear that substantial investment in new manufacturing facilities is currently on-going and planned for the future.

Improvements in the conventional amorphous and crystalline silicon technologies are continually being introduced, both in PV cell development and module fabrication processes. Silicon ribbon and silicon sheets are reported to be in production or nearing production in the USA. The beginnings of commercial production of new thin film modules, which offer the promise of low cost and mass production volume, albeit with lower conversion efficiency than crystalline silicon, are becoming apparent. Thin film crystalline silicon is in production or nearing production in Australia and the USA, and is being researched in Germany. Dye sensitised titanium dioxide (or titania) nanocrystalline solar cell production is also planned in Australia. The production of cadmium telluride modules is planned in Germany and Canada, Siemens Solar Industries started production of CIGS solar cells in 1998 and CdTe is already commercially produced for consumer products in Japan. The development of copper-indium-diselenide technology is reported in Japan and the USA. Concentrator cells and technology are also being developed in the USA

Projecting forward the installed power in the reporting countries, based on the average historic growth rate of 25 % per year since 1993, it is estimated that by the year 2000 over 590 MW_p of PV power will be installed.

Targets for installed capacity have been specified by a number of the reporting countries. Japan plans to install 5 000 MW_p by 2010; Korea has a long term goal of installing 20 MW_p for island off-grid applications; and the Netherlands intends to install 250 MW_p of grid-connected PV by 2010 and 1 250 MW_p by 2020. This amounts to a total of 6 270 MW_p by 2020 in these countries alone.

Chapter 5

Conclusions

The key issues raised in this third International Survey Report are highlighted in this chapter. This report has taken data from the national reports of the reporting IEA countries to produce a summary of the trends in PV power systems applications and the PV market for 1996 and 1997. This data was collected from primary sources. Information was also taken from the first and second International Survey Reports which covered the years 1992 to 1995 and updated where this has been appropriate and possible. Some information on the installed power since 1990 was also made available.

For the purposes of the national reports the PV power systems market was defined as the market for all nationally installed (terrestrial) PV applications with a PV power of 40 W_p or more. For the purposes of the survey, four primary applications for PV power systems were identified: off-grid domestic, off-grid non-domestic, on-grid distributed and on-grid centralised. A summary of installed power and module production is given in Table 5.1.

- Off-grid non-domestic systems are widely used in low power applications. The greatest share of the market for off-grid non-domestic PV is in Australia, Japan and the USA, together amounting to 73.8 MW_p of installed capacity. Other key players are Germany Italy, Korea and Canada, each with over 2 MW_p installed capacity at the end of 1997.

- The proportion of PV power which is on-grid has increased from 30 % in 1992 to 43 % in 1997. The bulk of this increase is accounted for by a large increase in on-grid distributed systems, often promoted by demonstration and market incentive programmes. In Germany and Switzerland, 84 % and 77 % of the installed power was grid-connected respectively, and in Denmark and Japan, over 60 % of power was grid-connected. In most countries with a high percentage of on-grid systems, the majority of on-grid applications were for distributed PV power. The exceptions to this were Italy and the U.S.A. where 90 % and 56 % respectively of the on-grid PV power was centralised. The market for such systems consists of demonstration plants funded from national and international programmes.

Table 5.1: Installed PV power and module production in the reporting countries

Year	Off-grid power cumulative installed and percentage increase		On-grid power cumulative installed and percentage increase		Total PV power installed and percentage increase		Power installed per year and percentage increase		Module production
	MW_p	%	MW_p	%	MW_p	%	MW_p	%	MW_p
1992	69		30		99				
1993	85	23	40	34	124	26	25		52
1994	102	21	50	26	152	22	28	8	
1995	123	20	68	36	191	25	39	39	56
1996	148	21	91	31	239	25	48	24	
1997	173	17	131	45	304	27	65	36	100

- In the period 1992 to 1997, the installed PV power in the reporting IEA countries has grown at an average annual rate of 25 %. The cumulative power installed in the reporting countries is 304 MW_p with over 65 MW_p of this power installed in 1997.

- Off-grid domestic systems have been installed throughout the world, particularly in countries outside the IEA. Over 70 % of the installed PV power in Finland, France, Mexico, Norway, Portugal and Sweden was in the off-grid domestic sector.

- The national demonstration programmes in the reporting countries largely reflect the priorities of each country. There is an increasing emphasis on on-grid distributed systems, particularly on the integration of PV into existing structures such as building façades, roofs and sound barriers. A number of countries have programmes to promote residential PV installations, most notably Japan, the United States, Germany and the Netherlands. Canada and Israel are focusing on adapting PV to their specific climates. Within the European Union, grants for demonstration projects are available from the European Commission and these contribute a large proportion of the available funding in member countries. On-grid systems are often part funded by electricity utilities, indicating a positive attitude on their part towards these systems. Programmes to integrate PV systems into school buildings in order to raise the awareness of students are currently underway in Switzerland, Germany and the United Kingdom.

- The total budgets for market stimulation, demonstration and R&D in the reporting countries have increased to 350.4 MUSD in 1997, from 287 MUSD in 1994. There has been a consistent trend for the funds spent on market stimulation to increase, due in part to the large Japanese programmes, while the proportion of funds spent on R&D has decreased, from 72 % in 1994 to 45 % in 1997. Funding for demonstration projects stayed fairly constant between 1994 and 1997.

- The PV industry revenue in the reporting countries was estimated to be in the region of 1 133 MUSD in 1997, and 873 MUSD in 1996, a 29 % annual growth rate. This resulted in 9 136 full time equivalent labour places associated with the PV industry in 1997. Since 1995 the number of labour places has grown by approximately 16 % with the majority of the growth in manufacturing.

- In 1997, the total module production of countries participating in the IEA PVPS Programme was 100 MW_p: (excluding modules for consumer applications). This is an increase of 78 % from 1995 when total production was 56 MW_p. PV module and cell manufacturing capacity was estimated to be 210 MW_p in 1997, compared with 115 MW_p in 1995. Modules are manufactured in all the reporting countries except for Austria, Finland, Israel, Norway and Portugal.

- The majority of inverters sold in both 1995 and 1997 were less than 10 kVA in size. A large increase in small inverters less than 1 kVA in size sold between 1995 and 1997 was mainly attributed to the increase in on-grid distributed systems in Germany and the Netherlands and the development of a.c. modules and string inverters.

- The number of installation companies in the reporting countries is 734. This includes a large number of small companies which are not exclusively dedicated to PV. The significant increase in the number of installation companies operating in Japan and the Netherlands is due to the introduction of PV programmes for the residential sector and public facilities.

- Module prices represent a significant proportion of the price of PV power systems. Crystalline silicon prices for a small order (less than 5 kW_p) ranged between 4.5 USD per W_p in Germany and 7.1 USD per W_p in Denmark, with the average price (weighted according to the module production of each country) being 5.0 USD per W_p. The high price of Danish and Swiss modules was because they tended to be non-standard products for building integration. For a large order of crystalline silicon modules (greater than 100 kW_p) the average price was 4.1 USD per W_p. There was a significant fall in module prices between 1993 and 1997: 41 % for small orders and 27 % for larger orders, further price decreases are expected as additional production capacity comes on line.

- The prices for PV systems varied widely within the reporting countries, depending on a range of factors including system size, customer and the technical specification. The system prices in the off-grid, 40 to 1000 Wp sector ranged from 8.4 to 52.8 USD per W_p, compared to 8 to 35.7 USD per W_p for larger (1-4 kWp) off-grid systems. The corresponding prices in 1995 were 10 to 28 USD per W_p for the 1-4 kW_p systems and 14 to 41 USD per W_p for the smaller systems.

- The prices for on-grid 10-50 kW_p systems ranged from 6 to 10.8 USD per W_p for ground mounted systems and 5.8 to 21.4 USD per W_p for building integrated systems. The price range for on-grid systems between 1 and 4 kW_p was 5 to 20 USD per W_p and for systems larger than 50 kW_p was 5.8 to 35.7 USD per W_p, compared with 6.9 to 20.0 USD per W_p and 7.0 to 13.7 USD per W_p respectively in 1995. The large range of prices was due to the fact that some of the systems were demonstration and some countries used wider definitions than others for turnkey system prices.

- The greenhouse gas reduction targets set at the 1997 Kyoto Conference of Parties to the Framework Convention on Climate Change set the backdrop for many of the national renewable energy programmes but are not seen as having a significant direct impact on photovoltaics during the time frame this report covers. Photovoltaics are not generally expected to have an impact on CO_2 emissions in the short term due to the high costs involved in large scale deployment, but are acknowledged as an important energy supply option in the long term.

- A wide variety of initiatives promoting the use of photovoltaics, or renewable energy in general, exist in the reporting countries. These include Green Power schemes in Australia, Switzerland, the United Kingdom and the U.S.A. where voluntary customer contributions are made toward renewable energy supplies, rate based incentive schemes in Germany and Switzerland, government grants towards the cost of installing PV systems, low interest loans for installing renewable energy systems, and a variety of fiscal measures for promoting PV including reductions in sales tax and customs duties, depreciation allowances and income tax reductions.

- At the end of 1997, the utilities' perceptions of PV systems were reported to be generally favourable in the reporting countries, with the utilities in several countries actively promoting PV through various dissemination programmes. Restructuring of the electricity markets in a number of countries has resulted in utilities widening their green energy portfolios to include PV.

- The public perception of PV was generally positive throughout the reporting countries, particularly in Australia, Germany, Japan, the Netherlands, Norway, Switzerland and the United States. Market deployment initiatives supporting the installation of PV systems on domestic housing have been over sub-scribed. These included the '1 000 roofs' programme in Germany and the Residential PV System Dissemination programme in Japan. Green pricing programmes in Australia, Switzerland and the USA have also proved popular with a significant number of people voluntarily agreeing to pay a premium price for electricity generated from renewable sources. In Switzerland, 20 000 customers explicitly chose to buy PV generated power.

- A number of companies have announced planned increases in PV module production capacity. If these announcements are realised the total annual capacity in the reporting countries will be approaching 120 MW_p by the year 2000. Capacity could exceed this figure as there are other manufactures who have not announced their plans, but who may well be considering increasing production. Of course announcements are not promises; manufacturers will make decisions on whether or not to proceed with plans for increasing capacity based on the state of the market at the time.

- Projections were made of installed power in the reporting countries. By the year 2000 it was estimated that over 590 MW_p of PV power would be installed based on the average historic growth rate of 25 % per year since 1993.

- Two billion people world-wide do not have access to electricity. The potential for PV to help to alleviate this situation is enormous, both through aid programmes and trade agreements. The on-going international climate change negotiations will drive national energy policies to promote a greater domestic use of renewable energy and create a framework of actions implemented jointly between developed and developing countries.

Exchange Rates

The table below lists the participating countries, corresponding ISO country and currency codes, and the exchange rates used to convert national currencies.

Table A.1 - Exchange Rates

COUNTRY	ISO COUNTRY CODE	CURRENCY and ISO CODE	EXCHANGE RATE (1 USD=)	COMMENTS
Australia	AUS	Dollar (AUD)	1.58	1 Aug 1998
Austria	AUT	Schilling (ATS)	12.20	1997 average
Canada	CAN	Dollar (CAD)	1.374	Statistic Canada 98
Denmark	DNK	Krone (DKK)	7.0	1997 average
Finland	FIN	Markka (FIM)	5.54	March 1998
France	FRA	Franc (FRF)	5.88	1996/97 average
Germany	DEU	Mark (DEM)	1.77	5 June 1998
Israel	ISR	New Shekel (ILS)	4.159	December 1998
Italy	ITA	Lira (ITL)	1750	1997 average
Japan	JPN	Yen (JPY)	130	No date
Korea	KOR	Won (KRW)	850	1 Jan 1997
Mexico	MEX	Peso (MXP)	9.0	5 June 1998
Netherlands	NLD	Guilder (NLG)	2.0	1 Aug 1998
Norway	NOR	Krone (NOK)	7.7	15 Sept. 1998
Portugal	PRT	Escudo (PTE)	183.8	June 1998
Spain	ESP	Peseta (ESP)	146.44	1997 average
Sweden	SWE	Krona (SEK)	7.86	5 June 1998
Switzerland	CHE	Franc (CHF)	1.5	1997 average
United Kingdom	GBR	Sterling (GBP)	0.625	1 May 1998
United States	USA	Dollar (USD)	1.0	
European Union		European Currency Unit (XEU)	0.91	

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