IEA INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS IN SELECTED IEA MEMBER COUNTRIES

THE SECOND OF A SERIES OF SURVEY REPORTS

Task I
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PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

IEA PVPS TASK I

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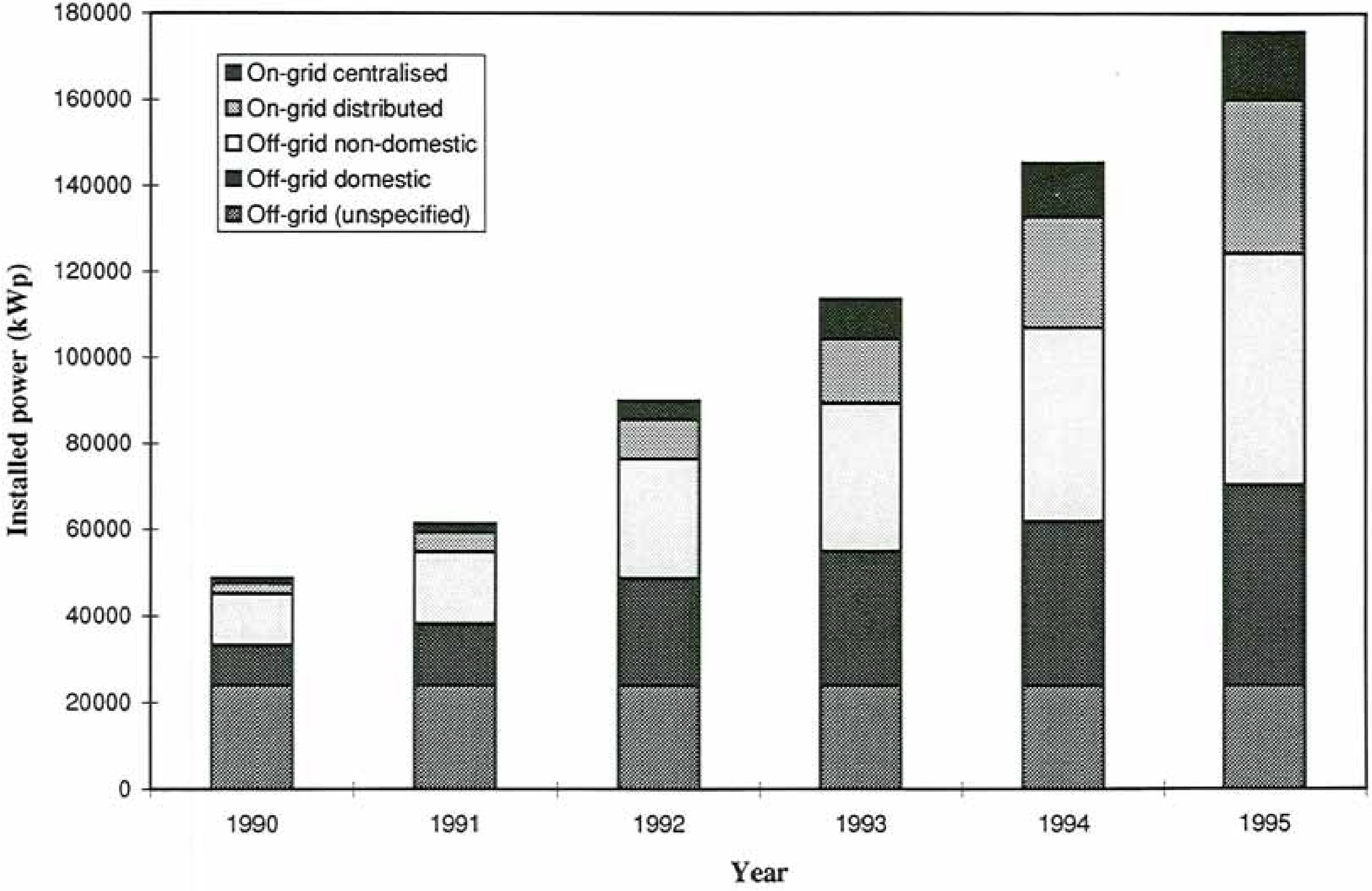


PHOTOVOLTAIC POWER SYSTEMS IN SELECTED IEA MEMBER COUNTRIES

THE SECOND OF A SERIES OF SURVEY REPORTS

EXECUTIVE SUMMARY

This report presents a description of the status of photovoltaic (PV) power systems in the 17 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 report summarises the results of the second survey and presents a description of PV power systems at the end of 1995 and analyses the trends in PV system implementation since 1992.

Photovoltaic Power Systems

Terrestrial PV systems have traditionally been used as high capital cost power sources for off-grid non-domestic (professional) applications such as telecommunications and navigational aids. However, in the past 20 years costs have steadily decreased and the use of PV in remote areas for both domestic and non-domestic applications has increasingly proved to be a commercially attractive proposition. More recently, the potential for the connection of PV systems to the utility power supply (grid) has been recognised and demonstration projects have been installed in many countries.

The installed power for all the applications has increased steadily since 1992. 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 and these are summarised below. The PV power systems market is defined here as the market for all nationally installed (terrestrial) PV applications with a PV power of 40 Wp[2] or more. Data were provided on a voluntary basis for smaller systems such as parking meters and traffic monitoring. This does not diminish the importance of these smaller systems which have been an important driving force for the introduction on PV.

Figure 1 shows the cumulative PV power installed by application in the reporting countries for the years 1990 to 1995. The installed power increased from 53.5 MWp in 1990 to 175.7 MWp in 1995, an average year on year growth rate of over 27%. This growth has not been steady as can be seen from Table 1. The large increase of 37% seen in 1992 decreased to 22% in 1995. This was primarily due to the completion of large government demonstration programmes in some of the reporting countries.

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

[1] Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), Finland (FIN), France (FRA), Germany (DEU), Italy (ITA), Japan (JPN), Korea (KOR), the Netherlands (NLD), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), the United Kingdom (GBR), the United States of America (USA).

[2] Wp is the peak power under standard test conditions of 1000 Wm^{-2} irradiance and 25 °C.

Figure 2: PV module production the in reporting countries in 1995: total 56.1 MWp

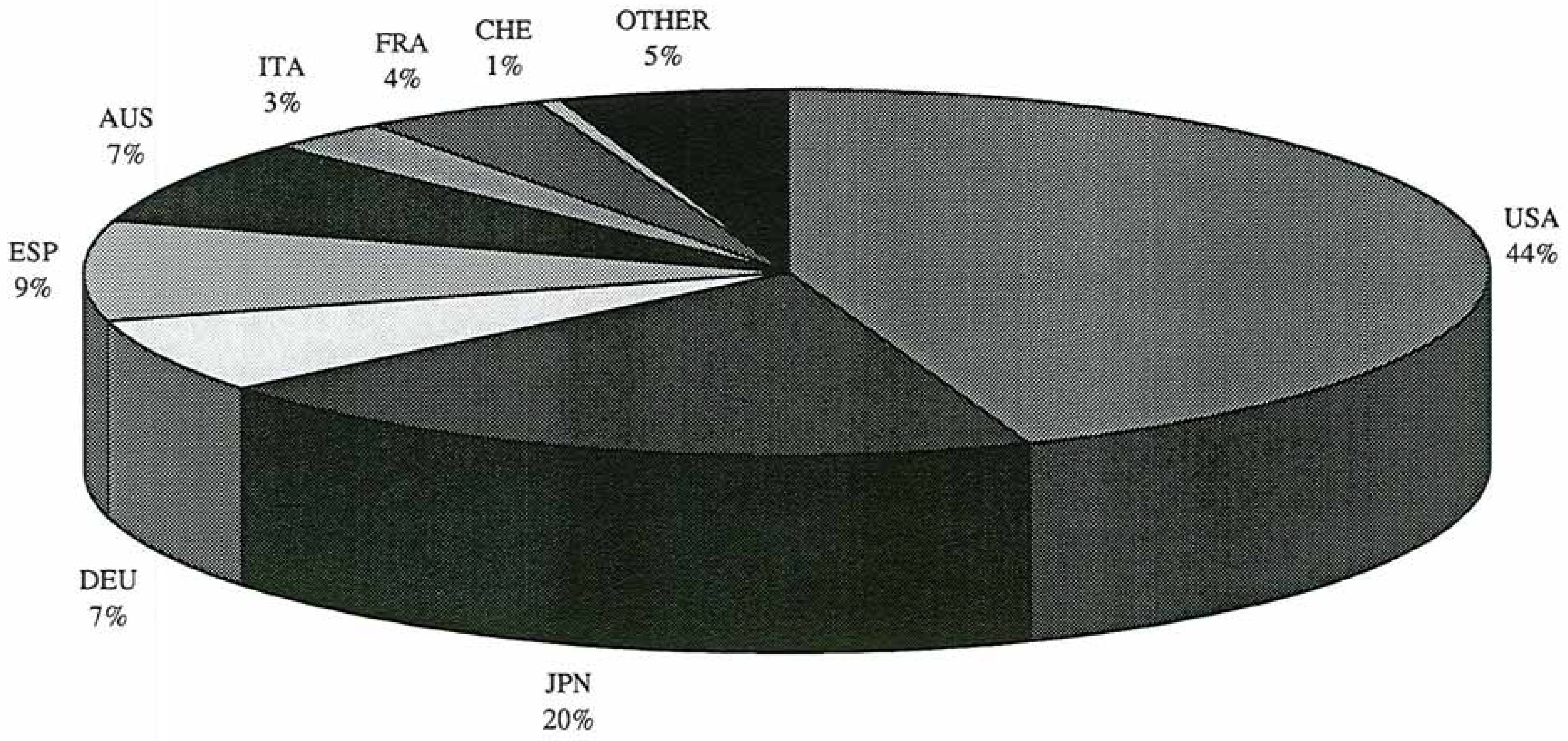


Table 1: Installed PV power and module production in the reporting countries.

Year	Cumulative installed off-grid power (MWp)	Increase in installed off-grid power (%)	Cumulative installed on-grid power (MWp)	Increase in installed on-grid power (%)	Cumulative installed power (MWp)	Total power installed per year (MWp)	Increase in installed power (%)	Module production (MWp)
1990	49.8		3.7		53.5			
1991	61.1	22.7	6.5	76	67.6	14.1	27	
1992	79.0	29.3	13.5	108	92.5	24.9	37	
1993	92.3	16.8	24.3	80	116.6	24.1	26	47.6
1994	107.7	16.7	35.5	46	143.6	27.0	23	
1995	124.2	15.3	51.5	45	175.7	32.1	22	56.1

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.

Production of PV modules for power applications in the reporting countries in 1995 was 56 MWp, estimated to be approximately 80% of world production. Of this 56 MWp, 63% was produced in the U.S.A. and Japan and 27% in Europe. The breakdown of PV production for the reporting countries is shown in Figure 2.

Figure 2: PV module production in reporting IEA countries in 1995.

Table 2 shows the total quantity of PV power modules produced in the reporting countries in the years 1993 and 1995 and compares this to the total production capacity at the time. It can be seen that although production and capacity have both increased, the utilisation of capacity for module production has remained fairly constant at around the 50% mark. This does not mean that PV production facilities are operating below capacity, but that significant numbers of vertically integrated module manufacturers sell a part of their production on as PV cells rather than modules.

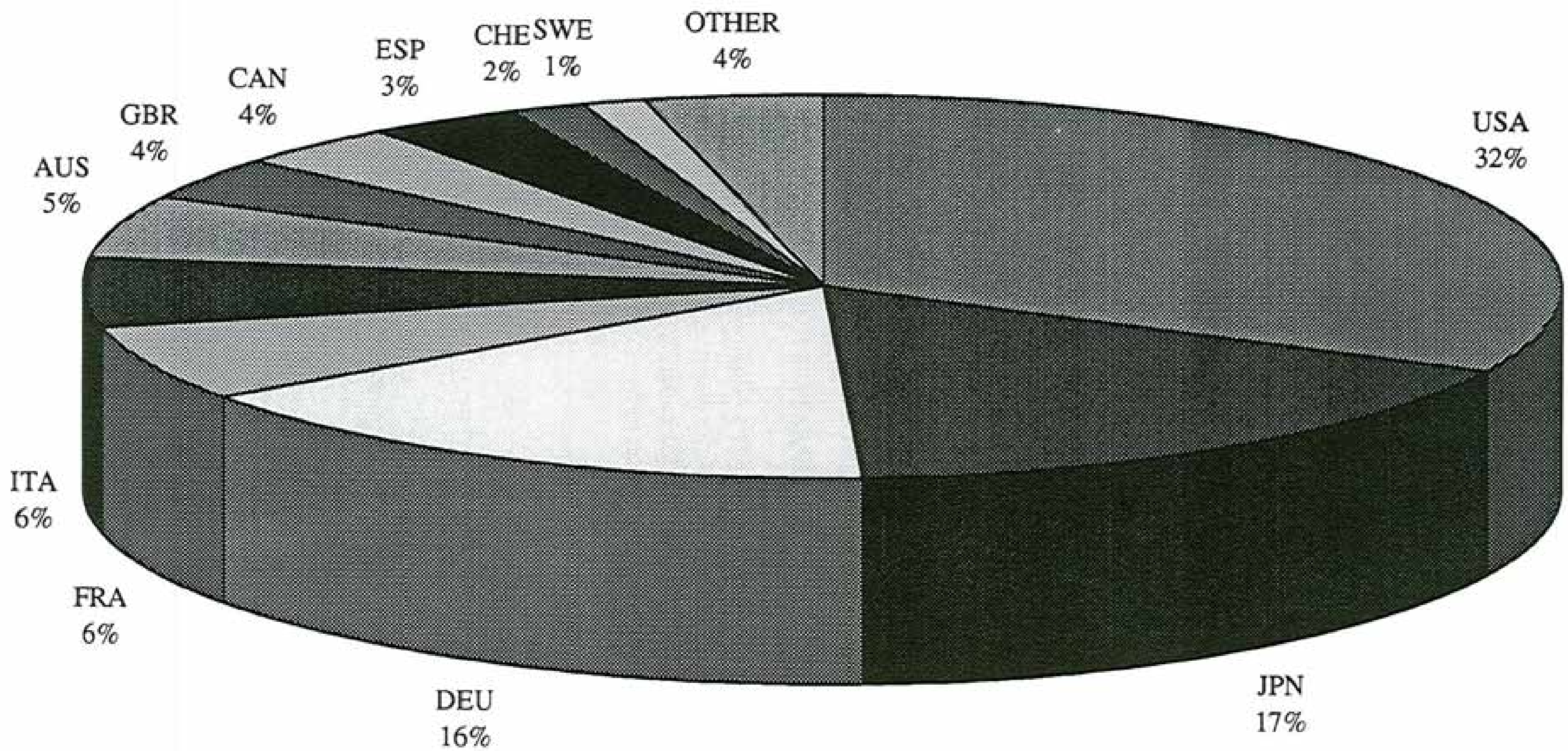
Table 2: PV module production and capacity in the reporting IEA countries in 1993 and 1995.

Year	1993	1995
Capacity (MWp)	91.6	114.8
Production (MWp)	52.1	56.1

In 1995, crystalline silicon accounted for nearly 90% of module production and just under 91% of production capacity: the remainder was amorphous silicon production. Crystalline silicon dominates the world market for PV power producing modules, as distinct from consumer products, where amorphous silicon dominates.

Thin film technologies, using materials such as amorphous silicon, cadmium telluride, copper indium diselenide and thin film silicon are continually improving. 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 has

Figure 3: Value of business in the reporting countries in 1995: total 713 MUSD



been undertaken for many years and some pre-commercial production is now underway with a number of new manufacturing plants being planned. Plans to further increase production capacity of crystalline silicon by 35 MWp and of amorphous silicon by 10 MWp have been announced.

The value of the PV business in the reporting countries was estimated to be in the region of 713 MUSD[3] in 1995, of which Germany, Japan and the U.S.A. shared 65%. The value of business is based on the total turnover of module manufacturers, consultancies and system suppliers. A significant proportion of this business is associated with R & D, demonstration and market stimulation programmes. The total budget for R & D, demonstration and market stimulation in 1995 was reported as being just over 338 MUSD compared to 290 MUSD in 1994. Figure 3 shows the value of business breakdown for the reporting countries.

Figure 3: Value of business in the reporting countries in 1995.

Module and System Prices

Reported manufacturer's prices for a small order (less than 1 kWp) of crystalline silicon modules ranged from 4.4 USD/Wp in the U.S.A. to 11.8 USD/Wp in Switzerland, with an average price in the reporting countries of 5.5 USD/Wp. (The average price was weighted by the module production in each country). The higher price of Swiss modules is because they tend to be non-standard products for building integration. For a large order of crystalline silicon modules (greater than 100 kWp) the weighted average price was 4.9 USD/Wp. For amorphous silicon modules, the weighted average price for a small order was 4.9 USD/Wp, and for a large order was 4.1 USD/Wp.

Prices for different types of PV systems are given in Table 3. The table shows the range of prices from the national reports for installed systems. The large range of prices was due to the fact that some of the systems were demonstration systems and some countries did not include installation costs in their estimations. The particularly low price of grid-connected systems in the 1 to 4 kWp range in Germany was due to a programme which pooled potential customers together to enable them to bulk buy systems.

Table 3: Photovoltaic power system prices in 1995 for different applications in the reporting IEA countries.

	Average Price by Application (USD/Wp)				
	Off-grid 100-500 Wp	**Off-grid 1-4 kWp**	**On-grid 1-4 kWp**	**On-grid 10-50 kWp**	**On-grid > 50 kWp**
Range	14-41	10.5-28	7.3-20	7.5-30	7-11.8

Demonstration of Applications for PV

The uptake of PV technology has been encouraged by demonstration and field test programmes undertaken in many countries. Initially the emphasis of these programmes was on off-grid systems and these are still being supported, particularly in areas with rural populations unconnected to the grid. The demonstration programmes in Canada, France and Korea concentrate on off-grid systems.

[3] The currency unit used throughout the Survey Report is the U.S.A. dollar (USD) or million dollars (MUSD).

In recent years as interest has grown in grid-connected applications, demonstration programmes for on-grid distributed PV systems have been set up in Austria, Denmark, Germany, Japan, the Netherlands and Switzerland. The '1 000 Roofs Programme' set up in Germany in 1990 was oversubscribed and has so far resulted in the installation of nearly 2 000 systems (average power 2.64 kWp) on domestic roofs: in Japan, over 6 MWp have been installed for residential and public facilities, and in Switzerland nearly 1.7 MWp had been installed as a result of demonstration programmes by the end of 1995.

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. PV power plants have been installed in Italy, where a 3.3 MWp system has been installed by the utility company, ENEL; Spain where a 1 MWp system has been installed, and the U.S.A. where a number of programmes involving utilities are underway including the Utility PhotoVoltaic Group (UPVG) Programme.

Policy and Perceptions

Renewable energies and PV in particular are promoted and encouraged by various means. There are a number of international agreements, such as the Rio Convention which committed signatories to stabilising their carbon dioxide emissions, which favour the use of renewable energies. Some countries also have national policies favouring the use of renewable energies which include environmental tax regimes. Promotion initiatives directly aimed at PV such as preferential tariffs offered for the sale of PV generated electricity to the grid, or sales tax exemptions which have been set up in a number of countries have had a positive, if small, impact on the national PV market in these countries.

The perception of PV appears to be generally favourable within the reporting countries. Electricity utilities have been showing an increasing level of interest in PV. In some countries utilities have taken the lead in the installation of PV systems. The public perception of PV also appears to be positive although the level of awareness is still low in many countries.

The Future

Forecasts for future PV module production and installed power in the reporting countries are made in the survey report. It is estimated that by the year 2000, PV module production would be in the region of 140 MWp per year and over 550 MWp of PV power would be installed, of which 64% would be off-grid systems and 34% on-grid systems.

A number of countries have published targets for the installation of PV systems: the Netherlands intends to install 250 MWp of grid-connected PV by the year 2010 and 1 250 MWp by 2020; Japan aims to install 400 MWp by 2000 and 4 600 MWp by 2010; Switzerland intends to install 50 MWp by the year 2000. There are many future opportunities within the field of PV both for those within the PV industry and for potential users of the technology.

Off-grid domestic

Off-grid domestic systems 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. In industrial countries, PV systems have considerable potential for supplying power to people at distances of more than 1 or 2 kilometres from the utility grid. Off-grid domestic PV systems are common in Australia, France, Italy, Spain, Switzerland and the U.S.A. with each country having over 2.0 MWp installed.

Off-grid non-domestic

Photovoltaic power systems are used to power a variety of off-grid non-domestic applications including water pumping, remote communications, safety, control and protection devices. Photovoltaics have been cost effective for a number of years supplying high value applications. Off-grid non-domestic systems have accounted for around 20% of PV power installed since 1990. As PV technologies continue to improve and costs decrease, more such applications will be identified and become viable so the size of the market will continue to grow. In many of the reporting countries, including Australia, Canada, Denmark, Korea, Portugal and the United Kingdom, this is the sector where most PV power systems have been installed.

On-grid distributed

The installation of on-grid distributed PV systems is a relatively recent application where a PV system is installed on the consumers premises on the demand side of the electricity meter. These systems are typically between 1 kWp and 50 kWp and may be integrated into buildings or other structures. As the system is installed at the point of use the distribution losses are reduced and, particularly with systems supplying power to commercial buildings, the production of the PV electricity may match the load profile of the building. The size of this market has grown substantially with the implementation of national and international demonstration programmes: in 1990 on-grid distributed systems accounted for less than 5% of installed power, whereas in 1995 it accounted for over 20%. This application sector is of particular importance in Germany and Switzerland where it accounted for nearly 75% and 50% of installed power respectively.

On-grid centralised

Centralised grid-connected systems have two primary functions: they may be used for bulk power generation or for strengthening the utility distribution-grid. A number of grid-connected, centralised PV plants are in operation, generating power for utility grids in Italy, Japan, Spain, Switzerland and the U.S.A. and providing essential field construction and operating experience. At present, the market for centralised PV power generation is not a real market but consists mainly of demonstration plants funded from national and international programmes. The percentage of installed power in this sector increased from under 3% in 1990 to 9% in 1995.

Chapter 1 Introduction

1.1 The International Energy Agency

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the Organisation for Economic Co-operation and Development. The IEA carries out a programme of energy co-operation among its 23 member countries including joint research and development of new and improved energy technologies.

The IEA committee on Energy Research and Technology is the focus of the Research, Development and Demonstration (R, D & D) activities which are divided into four groups: Energy Efficiency; Renewable Energy; Fossil Fuels, and Nuclear Fusion, each of which is governed by a working party. Within each group of R, D & D activities, such as Renewable Energy, several Implementing Agreements have been made in specific areas. The Renewable Energy Working Party ratified PV systems as an area for co-operation and recommended the establishment of an Implementing Agreement on Photovoltaic Power Systems.

The Photovoltaic Power Systems Programme was established in 1993, since when the reporting countries have been collaborating in a co-operative programme of research, development, analysis and information exchange related to PV power systems for application by electric utilities and other users. A major part of the co-operative activity focuses on current and potential markets for PV systems, and includes work on aspects of PV power systems such as operational performance of components and information exchange on PV technology, economics, and impacts which are relevant in all potential markets.

The IEA Photovoltaic Power Systems Programme is divided into seven tasks as shown in Table 1.1 below.

Table 1.1: Tasks in the Photovoltaic Power Systems Programme

Task	Description
I	Exchange and Dissemination of Information on Photovoltaic Power Systems
II	Operational Performance and Design of Photovoltaic Power Systems and Subsystems
III	Use of Photovoltaic Systems in Stand Alone and Island Applications
IV	Modelling of Distributed Photovoltaic Power Generation in Support of the Electric Grid
V	Grid Interconnection of Building Integrated and Other Dispersed PV Power Systems
VI	Design and Operation of Modular Photovoltaic Plants for Large Scale Power Generation
VII	Photovoltaic Power Systems in the Built Environment

The objective of Task I is to facilitate the exchange and dissemination of information on the technical, economic and environmental characteristics of PV power systems for applications in reporting countries. Information is collected on government and utility activities on: installed PV power and the energy produced; the associated budgets; the costs and performance of PV power systems; the advances in production capability of PV manufacturers; the advances in the use of integrated PV systems, and the legal and institutional factors affecting the adoption of PV.

In order to raise utility and government awareness of PV, the IEA has organised two conferences: the first, held in Taormina, Italy, in 1990 gathered utility executives, PV

- The Market Today
- Demonstration Programmes and Projects
- Industry Status and PV System Development
- Policy, Initiatives and Trends

The data were then collated and this report prepared by the technical writer. The report has been reviewed by the national representatives to ensure the accuracy of the data used.

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 Wp or more. Data were provided on a voluntary basis for smaller systems such as parking meters and traffic monitoring. However this does not diminish the importance of these smaller systems which have been an important driving force for the introduction on PV.

PV demonstration and field test programmes and projects were included if they were in operation at the end of 1995. Projects currently under construction were briefly summarised.

In order to try and avoid double counting, for the purposes of the report, a module manufacturer has been defined as an industry where the encapsulation of the 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 was also collected 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 perceptions of PV.

1.4 International Policy Initiatives

Many of the reporting countries have signed various international agreements and participate in a number of international programmes. It seems reasonable to expect that some of the recent international and regional policies dealing with environmental issues such as the reduction of greenhouse gas emissions or sustainable development will, either directly or indirectly, affect the use of PV power systems.

At the United Nations Earth Summit on Environment and Development at Rio de Janeiro in 1992, signatories committed their countries to stabilising carbon dioxide emissions from all sources at 1990 levels by the year 2000. Inherent in the convention was the adoption of 'the precautionary approach' which states that actions should not be deferred due to lack of scientific certainty. 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. At the present rate of increase it is estimated that to stabilise concentrations of atmospheric pollutants, yearly emission rates need to be reduced by up to 60% world-wide compared to 1990 levels.

The 1994 Madrid Declaration called for renewable sources of energy to play a more important role in the energy balance of individual member states of the European Union. The Declaration acknowledged the wide variations between the policies that have been developed at a state level, but suggested that the establishment of a single market should enable the adoption of a framework to widen the applications of renewable energy technologies. The Action Plan proposed that the European Union should raise the share of renewable energy sources in its primary energy demand from 5.2% to 15% by the year 2010. It suggests that achieving this target would lead to the creation of 300 000 to 400 000 jobs and 350 million tonnes of carbon emissions avoided. The Madrid Declaration was adopted by the European Parliament in July 1996 and a new strategy for the promotion of renewable energy sources throughout the E.U. is being prepared.

The European Commission administers a number of programmes aimed at research and development, and market enablement strategies for renewable energy. These include ALTENER, focused entirely on the promotion of renewable energy in Europe, and JOULE-THERMIE, which 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.

National policies are also extremely important, especially those of the countries most active in PV such as Japan and the U.S.A. These are dealt with in detail in sections 2.3 and 4.2.

Chapter 2 Implementation of PV 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 section discusses PV demonstration and field test programmes in the reporting countries.

2.1 Applications for Photovoltaics

Terrestrial PV systems have traditionally been used as a high cost power source for off-grid non-domestic (professional) applications such as telecommunications and navigational aids. However, in the past 20 years costs have steadily decreased and the use of PV in remote areas for both domestic and non-domestic applications has increasingly proved to be a commercially attractive proposition. More recently, the potential for the connection of PV systems to the utility grid has been recognised, with demonstration projects being installed in many countries.

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 the four primary applications for PV power systems identified above are described below.

Off-grid domestic

Off-grid domestic systems are primarily installed in remote areas such as isolated households, villages or islands, where it is more economical than extending the utility grid. These systems 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. These systems have considerable potential even in industrialised countries at distances of more than 1 or 2 kilometres from the utility grid. The installation of off-grid domestic PV systems is common in Australia, France, Italy, Spain, Switzerland and the U.S.A. with each country having over 2.0 MWp of off-grid domestic PV installed.

Off-grid non-domestic

Photovoltaic power systems are used to power a variety of off-grid non-domestic applications including water pumps, 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 on improving, more such applications will be identified and become viable as costs decrease so the size of this market will continue to grow. In many of the reporting countries, including Australia, Canada, Denmark, Korea, Portugal and the United Kingdom, this is the application sector where most PV power systems (> 40 Wp) are installed.

On-grid distributed

The installation of on-grid distributed PV systems is a relatively recent application where a PV system is installed on the consumers premises on the demand side of the electricity meter. These systems are typically between 1 kWp and 50 kWp and may be integrated into buildings or other structures. There are a number of perceived advantages for these systems: firstly, because the system is installed at the point of use, distribution losses are reduced; and secondly, with systems supplying power to commercial buildings, the production of the PV electricity may match the load profile of the building.

On-grid centralised

Centralised grid connected systems have two primary functions: they may be used for bulk power generation or for strengthening the utility distribution-grid. Several mega-watt scale PV plants are in operation, generating reliable power for utility grids and providing essential field construction and operating experience as well as giving a realistic picture of current total system costs and performance. Photovoltaic power systems for strengthening the utility's distribution grid typically have rated powers of between 100 kWp and 1 MWp. The systems are often, although not necessarily, located at the electrical periphery of the utility system where they can support the local energy needs. For example, there are situations where the installation of a PV plant at the end of a feeder line that experiences heavy peak loads may be a cost effective alternative to upgrading the line.

A number of grid-connected, centralised PV plants have been built in Italy, Japan, Spain, Switzerland and the U.S.A.; the plant at Toledo, Spain will be examined as a case study later in this chapter. The widespread installation of these systems is limited by the availability of land for the plant: this is reported as being a particular problem in Austria and Korea and is likely to be a factor limiting the installation of centralised PV plants in these countries.

The breakdown of installed PV power by application since 1990 in the reporting countries is shown in Figure 2.1 and Table 2.1. It is apparent that the most widespread application for PV power systems is the off-grid sector where their use is now well established. Off-grid applications accounted for 92.5% of the installed power in 1990 and 71% in 1995, which translates to an increase in on-grid applications from 7.5% in 1990 to 29% in 1995. The bulk of this increase was accounted for by a large increase in on-grid distributed systems.

Table 2.1: Breakdown of PV systems installed, by application, since 1990 in the reporting countries. (All numbers are percentages.)

Year	Unspecified power[4]	Off-grid domestic	Off-grid non-domestic	Total off-grid	On-grid distributed	On-grid centralised	Total on-grid
1990	48.9	19.1	24.5	92.5	4.8	2.7	7.5
1991	38.8	23.2	27.3	89.3	7.2	3.5	10.7
1992	26.5	27.6	30.8	84.9	10.0	5.0	15.1
1993	20.9	27.3	30.4	78.6	13.1	8.3	21.4
1994	16.4	26.1	31.1	73.6	17.8	8.7	26.4
1995	13.5	26.4	30.7	70.6	20.3	9.0	29.4

[4] Installed power in the USA for which the application sector is unknown: it is assumed that this power is primarily off-grid.

Figure 2.1: Installed PV power by application in the reporting countries

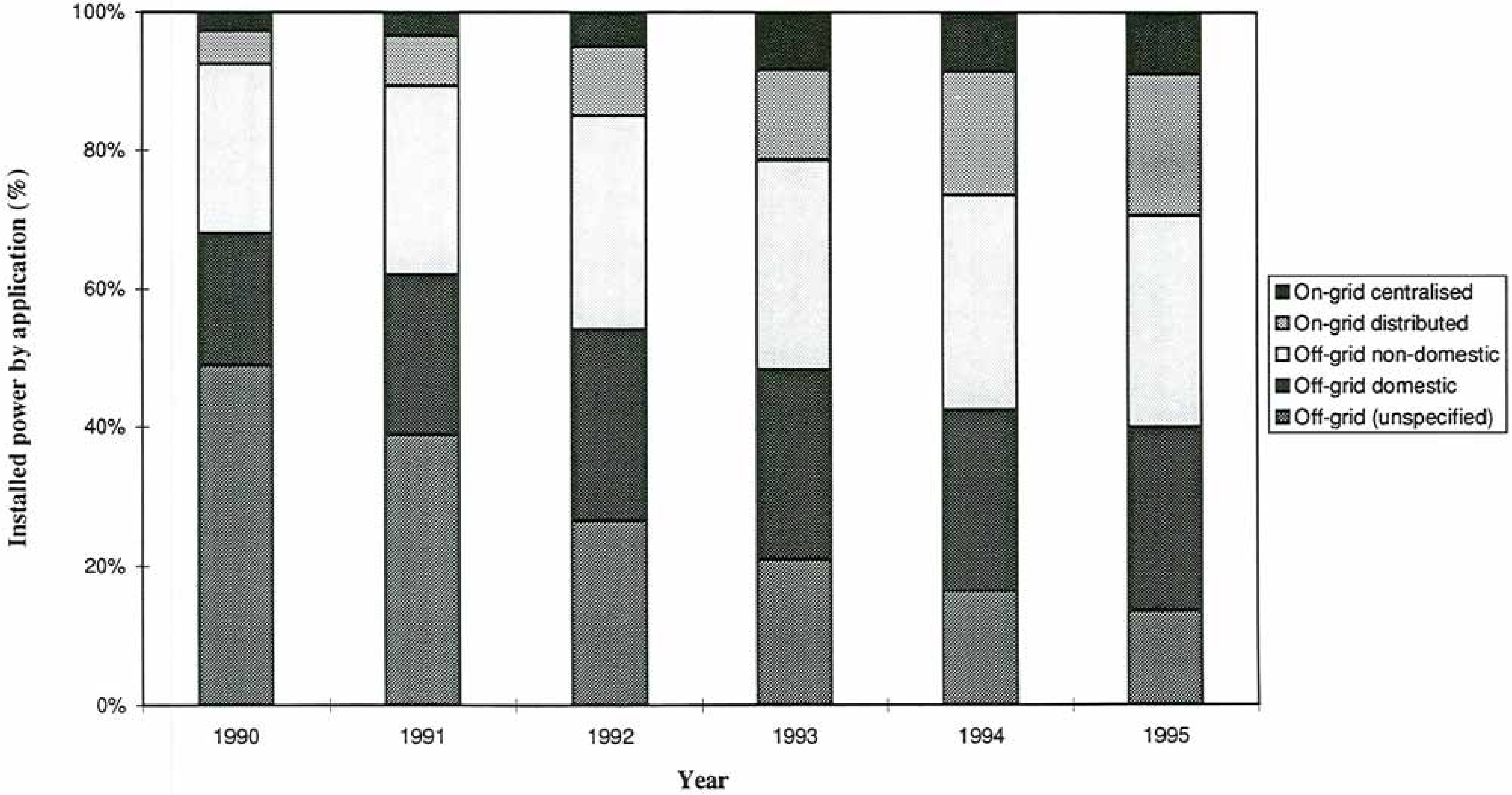


Table 2.2 - Cumulative quantity of PV power installed in reporting countries as of the end of 1995 (kWp)

Sector / Country	Off-grid Domestic (kWp)	Off-grid non-domestic (kWp)	On-grid Distributed (kWp)	On-grid Centralised (kWp)	Total installed power (kWp)	Total installed in 1995 (kWp)
AUS	3 270	9 380	30	20	12 700	2 000
AUT	349	373	567	70	1 361	296
CAN	472	1 136	212	10	1 830	320
CHE	2 245	148	4 050	1 350	8 073	881
DNK	15	85	40	0	140	40
DEU	500	1 187	13 063	3 040	17 790	5 350
ESP	4 168	758	361	1 260	6 547	887
FIN	1 200	125	5	30	1 300	50
FRA	2 180	720	30	0	2 930	520
GBR	57	252	59	0	368	30
ITA	4 830	4 780	335	5 850	15 795	1 705
JPN	978	13 658	10 196	1 190	26 022	6 731
KOR	191	1 577	0	0	1 768	87
NLD	1 423	700	239	98	2 460	480
PRT	105	45	15	0	165	20
SWE	1 285	304	31	0	1 620	280
USA†	22 800	18 800	6 500	2 900	74 800	12 500
TOTAL	46 048	54 048	35 733	15 818	175 727	32 177

† The cumulative figures for the four application sectors do not total the overall value of installed power as it was not possible to provide a breakdown for the 24 MWp installed prior to 1990. It would be reasonable to assume that most of this power is in the off-grid sectors.

The power installed in 1995 for each application is shown for each country in Table 2.2 as well as the total installed PV power. From the table, it can be seen that the total installed power in the reporting countries is 175.7 MWp.

Figure 2.1: Installed PV power by application in the reporting countries.

Figure 2.2: Installed PV power by application in the reporting countries in 1995

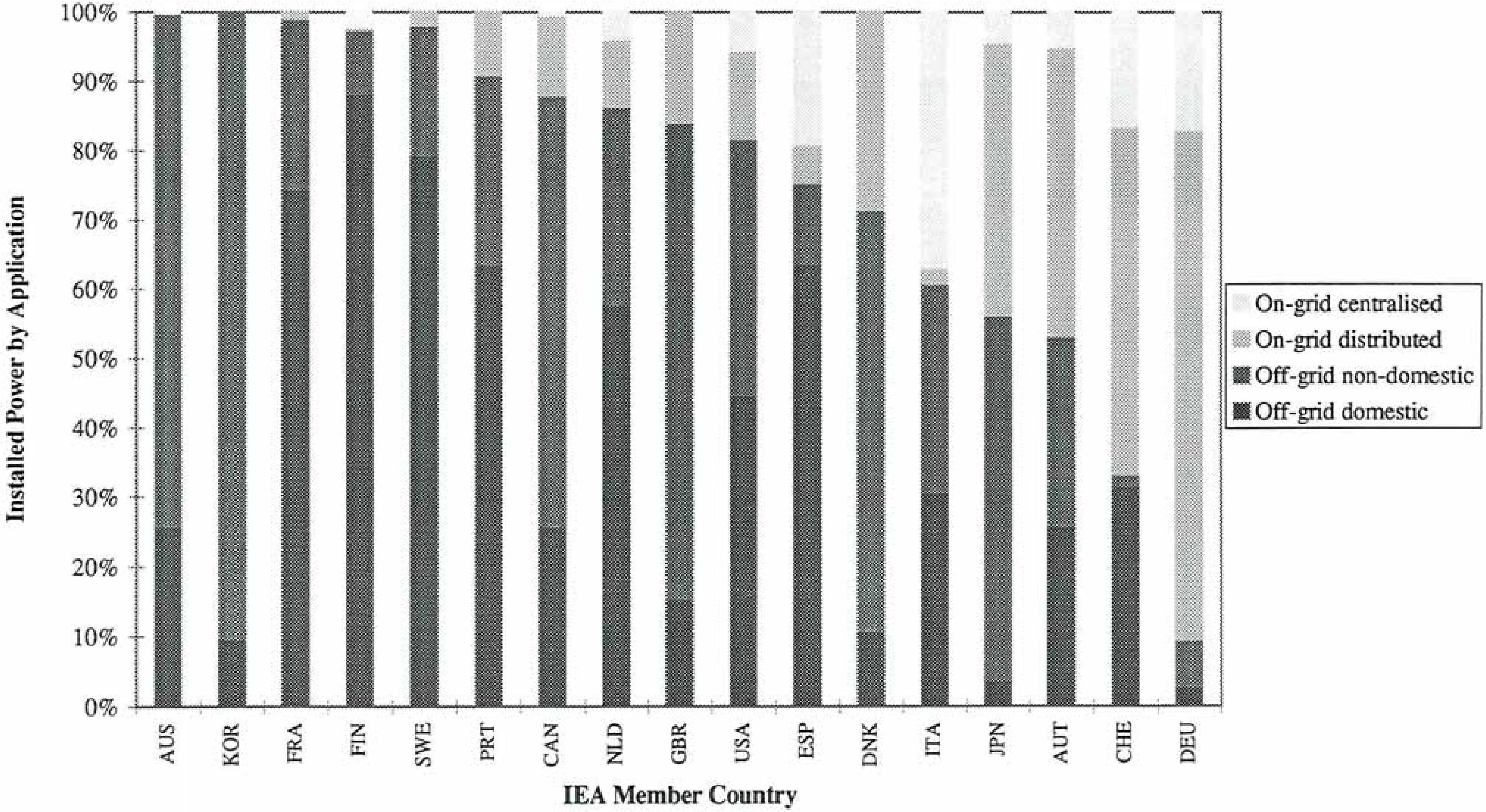


Table 2.3 Cumulative historic power installed in the reporting countries in 1992, 1993, 1994 and 1995.

Country	Cum. Hist. Power 1992 (MWp)	Cum. Hist. Power 1993 (MWp)	Cum. Hist. Power 1994 (MWp)	Cum. Hist. Power 1995 (MWp)
AUS	7 300	8 900	10 700	12 700
AUT		768	1 063	1 359
CAN	960	1 240	1 510	1 830
CHE	4 910	6 125	7 192	8 073
DNK		85	100	140
DEU	5 618	8 900	12 436	17 790
ESP	3 949	4 648	5 660	6 547
FIN	1 000	1 150	1 310	1 360
FRA	1 750	2 050	2 410	2 930
GBR	172	265	338	368
ITA	8 500	12 100	14 090	15 795
JPN	11 171	14 446	19 291	26 022
KOR	1 471	1 631	1 681	1 768
NLD	1 270	1 640	1 980	2 460
PRT	120	125	145	165
SWE	800	1 040	1 340	1 620
USA†	43 500	51 500	62 300	74 800
TOTAL	92 491	116 613	143 550	175 727

The proportion of the installed power used for each application, for each reporting country in 1995, is shown in Figure 2.2. From the figure the different priorities in the reporting countries can be seen.

In 1993, the off-grid sector accounted for the nearly all installed power in Denmark, Japan, the Netherlands, Portugal and the United Kingdom: however in Japan, the Netherlands, Spain and the United Kingdom there has been a significant increase in the grid-connected sectors over the past three years due to the implementation of various pilot projects. In Australia, Canada, France, Finland, Korea, the Netherlands, Portugal, Sweden, the United Kingdom and the U.S.A. over 80% of the installed PV power is off-grid, which contrasts to the situation in Germany and Switzerland, where over 70% and 50% respectively of installed power is grid-connected, and in Austria and Japan, where over 40% of power is grid-connected.

There has been little or no penetration of grid-connected PV systems in Australia, France, Finland, Korea or Sweden, over the 3 years from 1993, although the priorities within these countries is different: over 70% of the installed power in Finland, France and Sweden is off-grid domestic power, whereas in Australia and Korea, by far the largest application is the non-domestic sector. In the U.S.A. the off-grid sector is split almost evenly between domestic and non-domestic applications.

Figure 2.2: Installed power by application in reporting countries in 1995

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 kWp. The final yield, Y_f, is the energy delivered to the load per day per kWp installed. The reference yield, Y_r, is based on the in-plane irradiance and represents the theoretically available energy per day per kWp. 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 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: PV Installation of La Bonde Basse.

The system described is a stand alone PV installation which provides power to a remote house in the Département de Aude in France. The system was installed as part of a rural electrification project which served as the basis of a more ambitious programme where public funds provided funding for PV installations. These funds were provided under FACE (Fonds d'Amortissement des Charges d'Electrifications) which is a public fund for extending and reinforcing electricity networks in rural areas. Under the initial project, 50 houses were equipped with PV and it was demonstrated that the installations provided an optimum service and met the users expectations.

The PV system consists of 540 Wp of Photowatt PWX500 multicrystalline modules, installed to face due south at a tilt angle of 45°. A 1.5 kVA Mastervolt inverter provides a.c. electricity and a 400 Ah battery is included for energy storage. The site is 1.4 km from the nearest utility power line and a quotation for the extension of the utility grid was 94 400 USD.

Monitoring of the 540 Wp PV generator showed a performance ratio of 48% and an average annual final yield of 1.61 kWh/kWp per day.

The price of the installed system was 24 700 USD (excluding VAT) which is equivalent to 45.7 USD/Wp. This includes one battery replacement after 7 or 8 years, indoor wiring and lighting costs. The system is covered by a maintenance and operational guarantee covering 90 months which costs 6 800 USD. Additional costs of 3 500 USD were paid by the user. Funding for the system was provided by ADEME (10%), the Conseil Général (25%), EDF (15%), FEOLA (40%) and the user (10% plus the 3 500 USD).

A breakdown of the turn-key system price for the installed PV system is given in the Table 2.4.

Table 2.4. Breakdown of the turn-key system price for the installed PV system.

Items	Costs (%)
PV modules and mounting structure	25
Storage batteries†	25
Power conditioning unit	15
Civil works etc.	10
Overcost for high efficiency lamps and refrigerator	15
Project management	10

† Includes one renewal after 7 or 8 years

2.2.2 Off-grid non-domestic: Desert Studies Research Centre

The system at Zzyzx in Southern California provides electricity to the California State University's Desert Studies Research Centre. It is an off-grid commercial photovoltaic-propane hybrid power generation system and has been operational since in February 1993.

The power generation system uses two energy sources to charge batteries and supply a.c. loads 24 hours a day to five residences and two laboratories. During normal operation, the PV array powers the a.c. loads through the inverters and charges the batteries directly. When solar energy is insufficient to supply the loads, the propane-generator operates to supply the a.c. loads through an automatic transfer switch.

The PV array is 9.36 kWp and consists of 156 Solarex MSX60 multicrystalline modules, configured as thirty-nine parallel strings of four modules in series. The array is tilted at 36° to maximise year-round production. The propane generator is a 20 kW, engine-generator providing a 240 V, 60 Hz, single phase output. The batteries were sized to provide an average of three days back up at the average usage rate. Two 8 kVA Dimension Unlimited inverters (Model 48/8000) convert the d.c. PV and battery output into a.c. power. The inverters provide a modified square-wave, single phase, 60 Hz output at 240 Volts.

The average annual availability of the system was greater than 99.3% with the down time due to maintenance. The average system load was 42 kWh/day. The PV system and generator combined to produce a total of 25 923 kWh to supply a total a.c. load of 15 137 kWh resulting in 58.4% of the electrical energy produced being delivered to the centre's loads. The losses in the system are attributed to losses in the battery charge/discharge cycle, losses in rectifiers, losses in the distribution transformers, and losses in the inverter and controller. The number of starts for the propane generator in the twelve month period was 26 with generator run time of about 38.3 days. 11 225 kWh of a.c. energy was supplied by the generator at an average output of 12.2 kW.

The system was designed and installed by Northern Power Systems and cost approximately 460 000 USD. Owing to the one-off nature of the system, the price was inclusive of some necessary hardware development. In September 1995, the system was converted from a research agreement to a commercial account with the investment cost given as depreciated to 90 625 USD. The estimated 15 year life cycle investment cost, based on a system value of 90 625 USD was 169 390 USD. The average electricity cost was estimated to be 0.43 USD/kWh at an estimated usage of 72 kWh/day.

2.2.3 On-grid distributed: The PV Plants within the German Thousand Roofs Programme

Within the German '1 000 Roofs Programme' the Federal Ministry of Education, Science, Research and Technology (BMBF) and the States (Länder) supported the installation of 2 250 grid-connected, roof-mounted PV systems between 1990 and 1995.

The '1 000 Roofs Programme' was the first extensive, broadly based test and demonstration of grid-connected PV systems. The installed PV modules were supplied from various manufacturers within the E.U. countries (i.e., Siemens Solar, ASE, BP Solar, GPV, Newtec-Plaston). The systems ranged in size from 1 to 5 kWp, with an average peak power of 2.64 kWp. The total PV power installed in the programme by the end of 1995 was 5.25 MWp.

The systems had an average final yield of 700 kWh/kWp/year, or 1.92 kWh/kWp/day, with the distribution shown in Figure 2.3. The yield is dependent on the system location and was found to be lower at more northerly latitudes. The performance ratio in 1995 for 100 statistically selected PV systems averaged 65% (see Figure 2.4). PV systems with a performance ratio of less than 60% show a clear potential for optimisation. A performance ratio of 80% is achieved with high quality components.

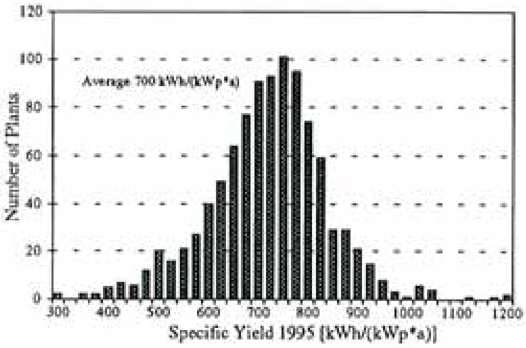


Figure 2.3: Distribution of the specific plant yield in 1995

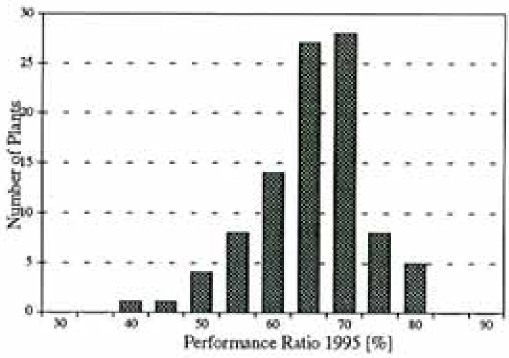


Figure 2.4: The performance ratio of the statistically selected 100 PV plants in 1995

Funding for the PV systems was provided by the BMBF (50%) and the Länder (20%) up to a cost limit of 14.67 USD/Wp excluding VAT. The total funding of the programme was about 56 MUSD. The average system costs over the whole programme were 13.12 USD/Wp (excluding VAT). The cost breakdown for 2, 3 and 5 kWp PV systems installed in 1995 are shown in Table 2.5.

Table 2.5: Cost breakdown of PV systems installed under the '1 000 Roofs Programme'.

Items	Costs (%)		
	2 kWp	3 kWp	5 kWp
PV modules	57.8	62.0	64.2
Support structures	6.0	6.4	6.7
Cabling & d.c. switches	4.9	4.4	4.2
Inverter	13.8	12.9	13.3
Control/Protection and a.c. switches	2.1	1.4	1.9
Installation	12.0	10.7	9.3
Project management	1.3	1.0	0.6
Others	2.1	1.2	0.8

2.2.4 On-grid centralised: Toledo 1 MWp PV Plant

The Toledo PV Power Plant is located at La Puebla de Montelbán (40°N) in the province of Toledo, Spain, and is owned and operated by Toledo PV (AEIE). Toledo PV is jointly owned by Endesa, a public Spanish utility; RWE, a private German utility, and Union Fenosa, a private Spanish utility. The specific objectives of the project were to operate a solar power station, which has its maximum production in summer, alongside a hydro-electric power station, which has its maximum production in winter. This arrangement is intended to achieve a greater continuity of power supply.

The plant consists of 3 PV fields: a 450 kWp field of NUKEM PP204 MC216 modules ; a second 450 kWp field of BP Solar modules, and a third 100 kWp field of BP Solar BP495 modules. The two larger fields are supported on fixed structures, whereas the third smaller field is on a solar tracking system. The tracking system means that Field 3 receives approximately 17% more irradiation than the fixed fields. Fields 1 and 2 each have one line commutated thyristor inverter, and Field 3 has an IGBT inverter.

Field 1 consists of 2 112 single-crystalline NUKEM modules, with 32 parallel strings of 66 series connected modules, each with a rated power output of 216 Wp; the surface area of the field is 4 309 m^2. Field 2 consists of 4 704 single-crystalline BP Solar modules, with 28 parallel strings of 168 series connected modules, each with a rated power output of 90 Wp; the surface area of the field is 2 942 m^2. Field 3 consists of 1 120 single-crystalline BP Solar modules, with 14 parallel strings of 80 series connected modules, the surface area of the field is 703 m^2.

The plant was connected to the 15 kV grid in July 1994 and has operated continuously ever since. The total energy injected into the grid between July 1994 and August 1996 was just over 2.2 GWh. Power production between January 1995 and August 1996, for each field is given in Table 2.6 below. The energy produced from Field 2 is less than that from Field 1 because the installed capacities of each field are not exactly 450 kWp. The average performance ratio of the plant is about 60%. The performance ratios are lower than perhaps would be expected due to inverter shutdowns arising from the poor quality of the 15 kV grid line.

Table 2.6: Power exported to the utility grid between January 1995 and August 1996.

	Field 1	Field 2	Field 3
Power produced (MWh)	851.9	788.8	170.0
Final yield (kWh/kWp/day)	3.11	2.88	2.79

The price of the station was 11 MUSD, which equates to 11 USD/Wp, and was shared between the European Commission DG XII and DG XVII (25%), the Spanish Ministry of Industry (18%), the German Ministry of Industry (9%), Endesa (16%), RWE (16%) and Union Fenosa (16%). A price breakdown for each subfield is provided in Table 2.7 below and a breakdown for the whole plant is given in Table 2.8.

Table 2.7: Price breakdown for each field of the Toledo PV Power Plant.

Item	Field 1 (%)	Field 2 (%)	Field 3 (%)
Modules	63	51.8	37.1
Inverters	3.9	4.7	6.9
Mounting structures	10.9	19.9	24.8
Monitoring	1.6	2.0	4.2
Project management	10.9	12.8	10.9
Others	8.7	8.7	16.1

Table 2.8: Overall price breakdown for Toledo PV Power Plant.

Item	Cost (%)
Modules and mounting	53
Support structures and mounting	12
Power conditioning	4
Civil works and others	9
Land	4
O & M	5
Project management	13

2.3 National Demonstration and Field Test Programmes

This section looks at national demonstration and field test programmes in the reporting countries as 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 or, in Europe, by grants from the European Union. Each country supplied details of their main demonstration projects and described their objectives. The following section briefly describes the main demonstration and field test programmes in each participating country. The emphasis is on government programmes rather than privately funded initiatives, because most funding is from government sources and details of private initiatives are more difficult to acquire.

In **Australia**, the major off-grid demonstration programme has been the Commonwealth Government's Renewable Energy Promotion Programme, which provided 4 MUSD over the 3 years 1993-95. This programme was aimed at overcoming the lack of knowledge and increasing the confidence in renewable energy systems amongst potential users who are currently dependent on petrol or diesel generators. The off-grid market is reasonably well established and in 1994-95 PV demonstration activity moved into the grid-connected system market. This has resulted in increased utility input, with utilities now contributing approximately half of the cost of demonstration systems. Government support accounts for 25-30%, with the remainder contributed by the PV and balance of system (BOS) industries, industry associations, private customers and universities.

In **Austria**, land availability is restricted so large PV plants are seen as impractical, the emphasis of the demonstration projects has therefore been on matching the installation of PV with the use of existing structures such as building facades, roof surfaces and sound barriers. The federal and regional governments and the electricity utilities provided funding towards the installation of 96 grid-connected PV systems, as a demonstration programme. An intensive monitoring programme has been executed to gain information on efficiency and reliability of the system components in operation. The Austrian 200 kWp Photovoltaic Rooftop Programme started in May 1992. The main goal of this programme was the promotion of building integrated PV systems in order to demonstrate the feasibility of decentralised PV electricity generation. Ten systems installed under this programme were equipped with identical measuring systems for a detailed analysis of plant performance.

The main PV demonstration programme in **Canada** is the 'PV for the North' Programme initiated by CANMET's Energy Diversification Research Laboratory (CEDRL). CEDRL is a government operated laboratory under the Ministry of Natural Resources Canada. Launched in 1993, the programme objectives are to develop and implement PV systems in the northern regions of Canada. This 1.4 MUSD programme will assist the development and implementation of a clean, reliable energy source for the North West Territories (NWT), whilst improving the knowledge base and the technical skills of the local population. During the first 2.5 years of operation, the PV for the North programme has been functioning on several levels in an effort to deliver the best combination of technology development and deployment in the NWT.

The Solar Energy Action Plan for **Denmark**, includes PV as a small but integral part of the plan. The objectives are to build a platform of knowledge and experience with PV in Denmark and to demonstrate potentially viable PV applications such as building integrated PV systems. In this context the role of the electric utilities is considered to be crucial. The market is specifically targeted at building integrated applications, and several demonstration and dissemination projects have been supported.

Government programmes in **Finland** focus on R & D and specifically on product development which have acted as a stimulus for the private sector. No active government sponsored demonstration programmes exist and most PV installations are financed with private funds although recent membership of the European Union (E.U.) should enable Finland to benefit from E.U. funding of demonstration projects.

In **France**, in addition to the R & D PV programme co-ordinated by ADEME (Agence de l'Environnement et de la Maîtrise de l'Énergie) public funding for the promotion of PV has been devoted to off-grid systems and, during the considered period, mainly to permanent dwellings, mountain refuges, nature centres and temporary seasonal agricultural facilities. PV systems range from 400 Wp to 10 kWp in size. The promotion programme started in 1984 with the purely technical demonstration approach of installing a significant number of autonomous PV systems in permanently occupied dwellings. More recently the projects have been oriented towards the setting up of comprehensive programmes in selected areas where not only the technical aspects are taken into account but also 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. It is to be noted that the European Commission (EC) has been an important source of funding for the promotion programmes carried out in France. In 1993, the electricity company, Electricité de France (EDF), considered the use of PV generators as a potential source of electricity for remote off-grid houses (ADEME-EDF Agreement) but it was only after public funding (FACE) was made available in 1995 that new types of commercial projects began to emerge. FACE (Fonds d'Amortissement des Charges d'Electrifications) is a public fund for extending and reinforcing electricity networks in rural areas and are also available in overseas Départements.

The national demonstration programmes in **Germany** are promoted and funded by the Federal Ministry for Education, Science, Research and Technology (BMBF), which has supported these programmes since 1988 in order to demonstrate state-of-the-art components and systems and to verify the operational reliability of PV systems. The two main demonstration programmes, the 'Demonstration Programme' and the '1 000 Roofs Programme' have resulted in more than 6.6 MWp installed power. The 'Demonstration Programme' is accompanied by a 2-year scientific measurement and evaluation programme, which aims to gain experience in the operation of PV systems, compare the plant performances of similar system types (grid-connected, stand-alone, hybrid) at different sites, and compare PV plants from the design and operation point of view. The '1 000 Roofs Programme' is accompanied by a measurement and evaluation programme to conduct an assessment of the performance of grid-connected PV systems within the project. In addition to federal government support, the 16 states (Länder) and some utilities such as RWE and Bayernwerk also support PV programmes and projects such as the Sun at School Programme.

The guidelines of the **Italian** PV programme were laid down within the framework of the Italian National Energy Plan, approved in 1988. One objective of this plan was the installation and operation of PV pilot plants for research and demonstration purposes to a total power of 25 MWp. In 1994, a 3-year Agreement on Photovoltaics was signed between ENEA and the Ministry for Industry, Trade & Craft. Within this framework a comprehensive programme, from R & D on materials and devices, to demonstration projects, has been defined with an overall budget of 30 MUSD. To promote the diffusion of PV plants in different market sectors, ENEA has contributed technically and financially to the demonstration of new PV applications. In order to provide technical feedback to system manufacturers, plant operation data have been systematically collected and analysed. Since 1989, ENEA demonstration activities have been focused on power generation from medium scale, grid-connected systems and this has led to the development of a standard 100 kWp plant, the so-called PLUG (Photovoltaic Low-cost utility Generator), which can be used either as a single installation or as an elementary unit for larger power stations. The utility, ENEL has been involved in a demonstration programme since 1982 resulting in a comprehensive programme of research, demonstration and application of PV systems being implemented in 1990. The programme included the installation of the largest centralised PV power plant in Europe, the 3.3 MWp plant at Serre. The programme foresees parallel actions in many different sectors to promote PV as a significant energy source.

In **Japan** a total of 70 MUSD was spent on demonstration PV projects in 1994 rising to 116 MUSD in 1995. In 1994 the Basic Guidelines for New Energy Introduction were introduced. These aim to promote the introduction of new energy sources, including PV and other renewables, for the purpose of solving or otherwise handling global environment problems. Within the guidelines, there are three focus areas for PV which are encompassed within the New Sunshine Programme: the first is to promote overall system standardisation and the reduction of system costs; the second is to promote technical development; and the third is the installation of PV systems on residences and public facilities. To promote the installation, the 'Residential PV Monitor Programme' and the 'PV Field Test Project for Public Facilities' programmes are underway as national subsidised projects. At the end of 1995 a total of 1760 kWp had been installed on museums, schools, community centres etc. as a result of the PV Field Test Project for Public Facilities. The Residential PV Monitor Programme subsidises residential PV systems in return for a commitment to monitor the system in order to provide feedback to manufacturers. By 1995, a total of 5459 kWp had been installed under the programme. Other demonstration programmes include the Demonstrative Research on PVPGS (PV Power Generation Systems) which aims to optimise the PV-diesel hybrid power generation as an auxiliary power source for use on isolated islands and has 750 kWp of PV installed with a 300 kW diesel generator.

In **Korea**, the investment for PV demonstration projects was 0.240 MUSD in 1994 and 0.635 MUSD in 1995. The demonstration projects were off-grid applications and funded by the Ministry of Trade, Industry and Energy (MOTIE). In 1994, 45 PV powered street lights were installed by RaCER (R & D Management Centre for Energy and Resources). Demonstration projects installed in 1995 include a stand-alone system consisting of 8 kWp solar modules, lead-acid batteries, inverter and a back-up diesel generator, installed at a resort cabin in Mt. Hanra National Park in Cheju-do. In addition, solar clock towers were installed in primary schools and parks, 36 PV street lights were installed in parks and several emergency solar telephones were installed along an expressway by Korea Highway Corporation. The Government-funded demonstration projects will be further enhanced in order to expand the PV market and to promote public perception of PV systems. In 1996, a budget of 1.2 MUSD has been provided.

The main R, D & D programme in the **Netherlands** is the Netherlands Photovoltaic Programme, NOZ-PV, which has financed four large projects that were completed in 1995. In 1995 the 'PV in the Built Environment' pilot programme aimed to further develop grid-connected services. The aim is to implement PV pilot projects to provide market experience relevant to the future application of PV in the built environment. Expansion of scale and volume are regarded as sensible subsidiary aims. The main participants in the pilot programme will include local authorities, distribution companies, project developers, property owners and PV companies, as well as researchers and architects each of whom have different priorities on the development of PV. The pilot programme will include small-scale technical innovation projects and around ten larger pilot projects in which PV will be used on both pitched and flat roofs of residential properties, office blocks and façades. The larger PV pilot projects will involve the investigation of non-technical as well as technical problems associated with the large-scale integration of PV in the built environment.

In **Portugal**, most of the activities in PV are supported or conditioned by European Union (E.U.) funded programmes. Besides E.U. support, demonstration and dissemination activities in the area of energy have been supported by various national programmes such as SIURE and currently by the E.U. and the national programme, ENERGIA. This programme is not targeted specifically to PV but addresses the broader area of Renewable Energy.

A large number of demonstration and field test projects have been carried out in **Spain**, from the mid-eighties onwards, with the current emphasis being on building integration. In addition to receiving support from governmental agencies and local authorities, the electricity utilities and private companies have invested in them. The largest demonstration project has been the Toledo 1 MWp power plant which is highlighted as a case study in the following section. The first large grid-connected PV plant to be commissioned in Spain was San Agustin de Guadalix (100 kWp), in 1984. The plant is owned by the electric utility, Iberdrola, which has been involved in a number of PV power systems projects and field tests since 1983. Private companies have also collaborated in several projects, some of which have been subsidised by both local and central government.

The first demonstration programme in **Sweden** started in 1990 with participation in the IEA Solar and Heating and Cooling Programme - Task 16 - PV in Buildings: as a part of this project several systems were built. The main objectives for the Swedish participation in the IEA PV programmes are to gain experience and understanding of the technology and economics for the utilisation of PV systems. The Swedish activities provide national R & D sponsoring authorities and the power industry with a better knowledge of PV technology and thereby support these organisations in judging when and for which applications, PV will be cost effective. Technical experiences from the Swedish demonstration systems give specific knowledge about the performance and electrical output from PV systems at Swedish locations which can be applied when considering larger installations.

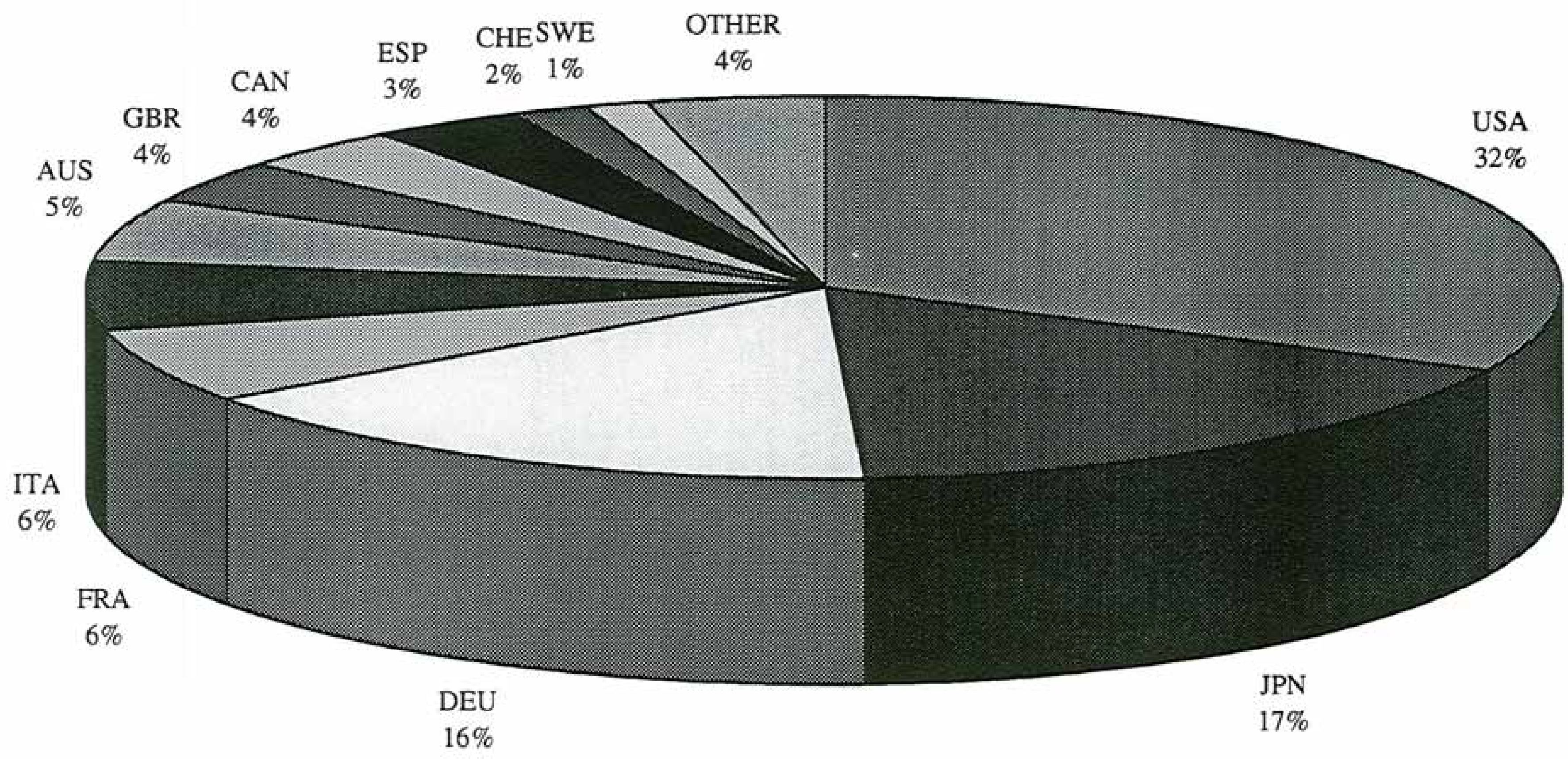
The **Swiss** federal PV-Programme of promotion emphasises Pilot and Demonstration projects and a PV School demonstration programme. For the Pilot and Demonstration projects, the government normally offers financial support amounting to 27%. In 1994, 485 kWp were installed under this programme and 515 kWp in 1995. For these projects, the emphasis is on architectural integration and the built environment. The PV School demonstration programme was launched in Autumn 1992 and by the end of 1995, 605 kWp had been installed. This special promotional programme for grid-connected PV installations is targeted at vocational colleges and gives a subsidy of 3500 USD for state schools and 27% for vocational colleges. The aim of the programme is to motivate students studying in the electrical sector with respect to renewable energies. Results from 1993 and 1994 suggest that the first systems installed under this programme have been successful and more projects are expected in 1996.

The first demonstration project in the **United Kingdom** was built in 1986 as a combined wind and solar system, comprising of 6.5 kWp of PV and 22 kW of wind turbine, to supply 9 houses and a control building. Several other demonstration systems have been installed, including two grid-connected domestic systems, and two non-domestic systems. The largest PV demonstration project in the UK, opened in 1995, is the 40 kWp Northumberland Building in Newcastle-upon-Tyne.

Over the past five years, programmes in the **United States** have evolved from demonstrations and field tests to prove that PV is both economically and technical viable in different applications. A concerted effort involving private sector utility programmes at Sacramento Municipal Utility District (SMUD), Southern California Edison (SCE), Idaho Power and others, to define high value applications and help develop the market is underway. These private initiatives are augmented by the Department of Defence programmes, and other government purchases of off-grid systems deemed 'economic'. Although these programmes are considered to be economically viable without subsidy, they are the result of the early government-funded programmes. This transition to private, non-subsidised purchase, is seen as being very important to the stability of the PV industry. These private programmes were expanded by a multi-year Department of Energy (DoE) assisted utility applications programme. The strategy was for an association of US utilities to define, design, and build a series of on-grid and off-grid PV applications that were 'close to economic': the Utility PhotoVoltaic Group (UPVG) was formed with initial funding from the DoE to fulfil this mission. Over 70 utilities have joined the UPVG, and projects totalling 10 MWp are under contract. The DoE contribution to this multi-year, multi-cycle 50 MWp procurement effort was to be 30% of the project cost, however company contributions reduced the amount required from the DoE to 20%. The goals of this project were to prove the value of PV, quantify the operating costs, and to provide an expanding domestic market through government assisted projects and by establishing fully economic markets for PV systems for utilities. Another small, but important experimental programme is the Environmental Protection Agency programme to place many small PV systems on a variety of utility sites to quantify the PV displacement of toxic substances generated by conventional electricity generation. The purpose is to model the impact of PV penetration on the environmental pollution caused by conventional generation.

The national demonstration programmes in the reporting countries largely reflect the priorities of each country. 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. In addition, Germany, Italy and Holland also have substantial national programmes in place. There is considerable emphasis on on-grid distributed systems, particularly on the integration of PV into commercial and residential buildings. 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 Switzerland and Germany and a similar programme has recently been announced in the United Kingdom.

Figure 3.1: Value of business in the reporting countries in 1995: total 713 MUSD



Chapter 3 Industry and Growth

This chapter discusses the state of the PV industry at the end of 1995, and looks at the employment levels associated with the industry and the value of business. The distribution of the production of PV modules 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.

3.1 PV Production in reporting countries

3.1.1 The PV Industry

The details of the production of PV modules has been based on information supplied by the reporting countries of the IEA Photovoltaic Power Systems Programme and hence does not document the quantity of PV modules produced world-wide. Other sources suggest that total world production of PV modules is around 80 MWp per year. The sum total production in 1995 of nations participating in the IEA PVPS is 56.1 MWp: this includes production for power applications smaller than 40 Wp but not for consumer applications.

Table 3.1: PV module production in MWp in the reporting IEA countries in 1995.

Country	Module Production in 1995 (MWp)
U.S.A. & Canada	25.4
Japan	11.0
Europe	15.0
Rest	4.7
TOTAL	56.1

The national reports provided data on the value of the PV business in each reporting country. The figure was based on the total turnover of module manufacturers, consultancies and system suppliers. If the data were not available to the national representative, estimates based on the data available were made, such as installed power, system prices, imports and exports, R & D etc. The value of the PV business in the reporting countries was estimated to be in the region of 713 MUSD in 1995, of which Japan, Germany and the U.S.A. shared 65%; the precise division is shown in Figure 3.1.

Figure 3.1: Value of PV business in 1995

The employment levels associated with the PV industry are low in the reporting countries that supplied data, with a total of 7 860 full time equivalent labour places. Of these, over 1 600 were in research and development, 3 400 were in manufacturing and 2 700 were in areas such as consultancy, system installers etc. The vast majority of the labour places were concentrated in the U.S.A. (2 000), Japan (1 600) and Germany (1 400). These three countries also have the largest amount of installed PV power of the reporting countries (74.8 MWp, 26 MWp and 17.8 MWp respectively) and the U.S.A. and Japan are the largest producers of PV modules. The average number of labour places per country for those remaining countries who supplied data is 230. The breakdown of labour places in each country is shown in Figure 3.2.

Figure 3.2: Distribution of labour places in the reporting countries

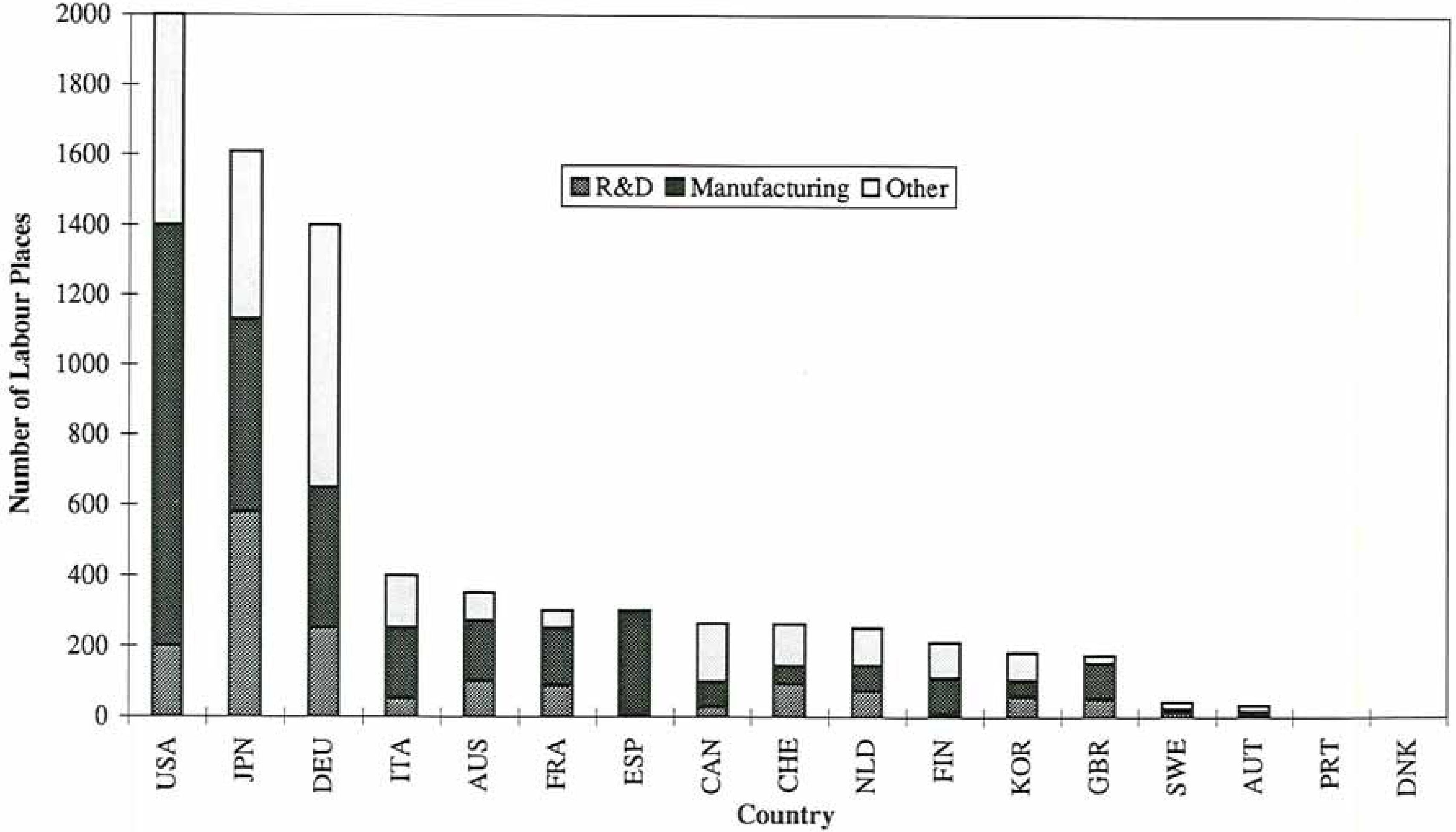


Figure 3.2: Distribution of labour places in IEA reporting countries

In 1993 the total budget for R & D, demonstration and market stimulation was reported as being just over 286 MUSD of which 208 MUSD (73%) was devoted to R & D. In 1995 the total budget had increased to 341 MUSD of which 215 MUSD (63%) was for R & D. Although the bulk of the funding for PV is still directed towards R & D, the budget available for market stimulation increased by nearly 95% between 1993 and 1995. This increase was due to significant increases Germany, Japan and the U.S.A. Unsurprisingly, those countries with the greatest number of labour places in the PV industry are those with large budgets for R & D, demonstration and market stimulation. The budget breakdown per capita between the reporting countries for 1994 and 1995 is shown in Figure 3.3 and the breakdown of the total budgets for 1994 and 1995 in the reporting countries is shown in Table 3.2.

Figure 3.3: Budget per capita for R & D, demonstration projects and market stimulation in the reporting countries in 1994 & 1995.

Table 3.2: Budget breakdown for R & D, demonstration projects and market stimulation in 1994 & 1995.

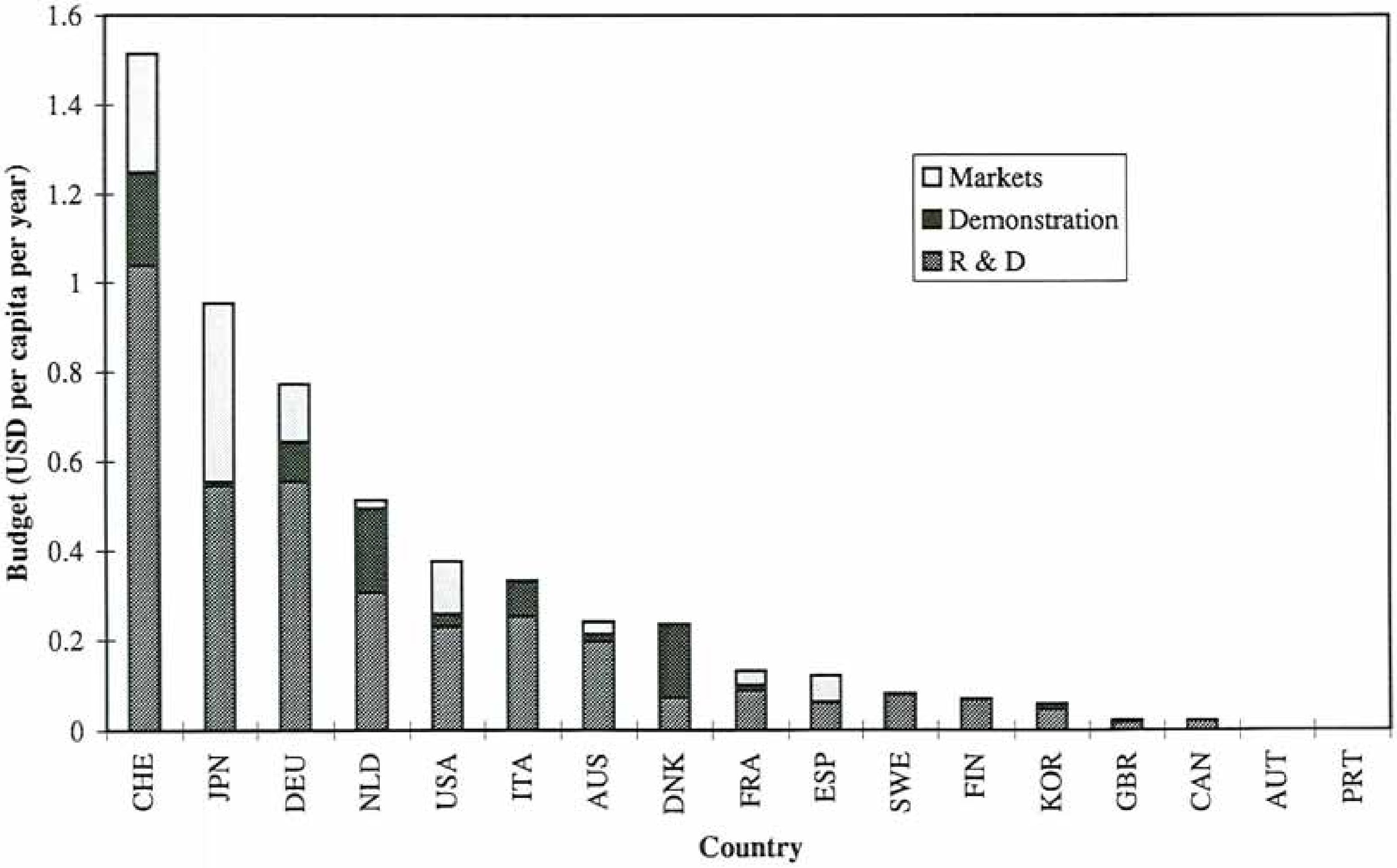
Category	1994 (MUSD)	1995 (MUSD)
Market stimulation	51	99
Demonstration projects	27	27
R & D	208	215
Total	286	341

From Figure 3.3, it can be seen that Switzerland has the highest per capita expenditure on R & D, followed by Germany and Japan, while Japan, Switzerland, Germany and the U.S.A. have the highest per capita budgets for market stimulation. However in monetary terms, Japan, the U.S.A. and Germany have the largest budgets for R & D, market stimulation and demonstration programmes (119, 98 and 63 MUSD respectively).

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 over 90% of power module production manufacturing capacity. A brief description of the different production technologies is given in the box.

Figure 3.3: Per capita budget for R & D, demonstration and market stimulation in 1995 in the reporting countries.



Single crystal silicon cells are usually manufactured from a single crystal ingot most commonly grown by the Czochralski method, where the ingot is doped with boron during the growth process, making 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 their cost of manufacture.

While single crystal silicon remains the most efficient flat plate technology, it is also the most expensive. PV cells made from multicrystalline silicon have become popular as they are 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 thin 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 solar cells.

Thin film modules are constructed by depositing extremely thin layers of photosensitive materials on a low cost backing such as glass or plastic. As much less semiconductor material is required than for crystalline silicon cells, material costs are 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. 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 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 is a promising PV material, partly because of its high absorption of light. The addition of gallium to CIS has enabled laboratory efficiencies of cells to reach over 17%.

Typical module and cell conversion efficiencies (at Standard Test Conditions, i.e., 1 kWm^{-2}, 25°C) for the different PV technologies are given in the table below.

Type	Typical *(Maximum recorded)*[5] Module efficiency (%)		Maximum recorded laboratory cell efficiency (%)[3]
Single crystalline silicon	12-15	*(22.3)*	24.0
Multicrystalline silicon	11-14	*(15.3)*	18.6
Amorphous silicon	6-7	*(10.2)*	12.7
Cadmium telluride	7-8	*(9.1)*	15.8
Copper indium diselenide	-	*(9.7)*	16.4

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.

[5] *'Solar Cell Efficiency Tables, Version 8'* M.A. Green, K. Emery, K. Bücher, D.L. King, S. Igari, Progress in Photovoltaics: Research and Applications, **1996** 4 321-325.

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 3.3 summarises details of cell and module manufacturers with 1995 module production greater than 1 MWp, and shows production levels in 1993 for those companies who produced above 1 MWp at that date.

Table 3.3: Module manufacturers with a 1995 module production greater than 1 MWp.

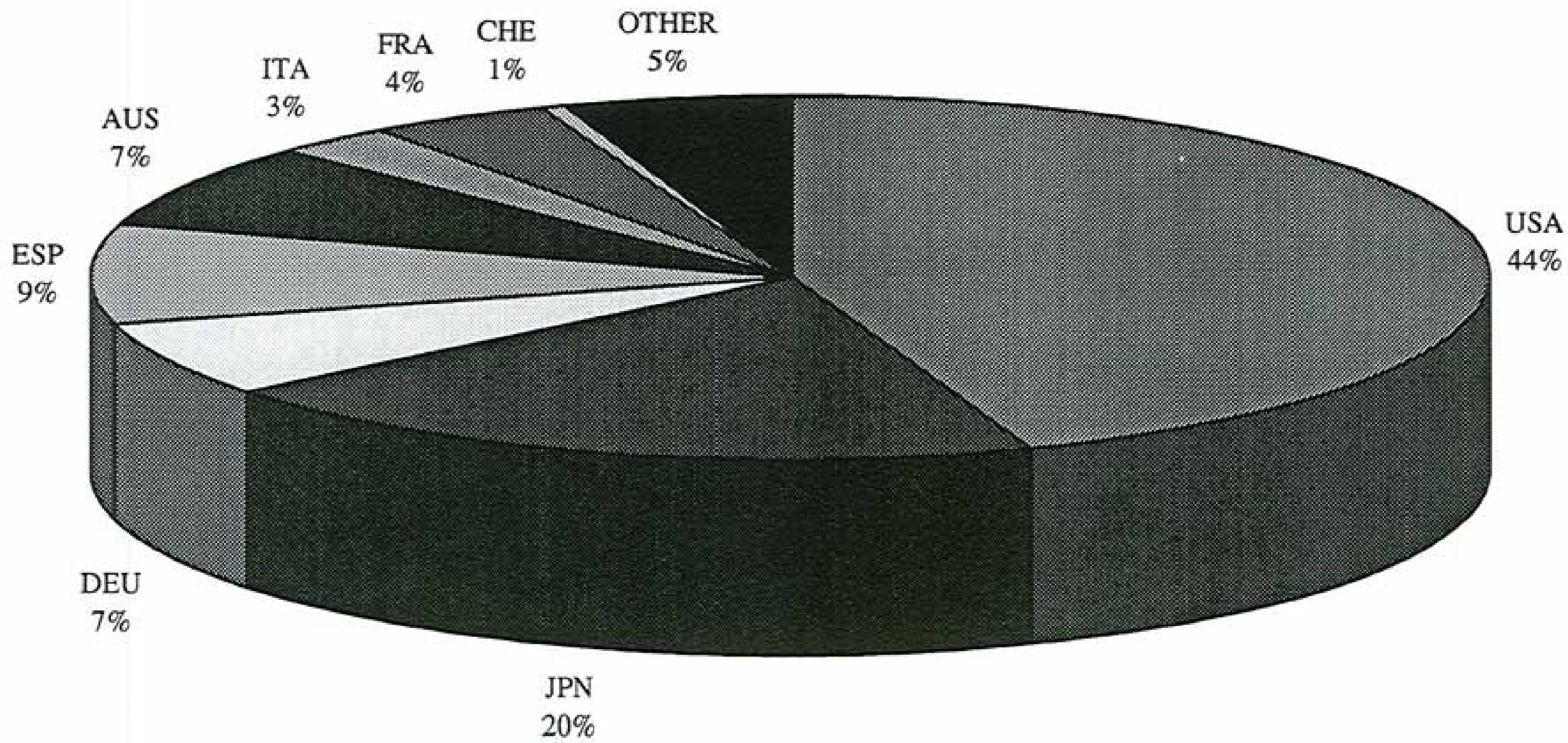
Company	Country	Module Production in 1995 (MWp)	Module Production Capacity (MWp)	Module Production in 1993 (MWp)	Module Type
ASE	DEU	1.5	3.8	}1.9	sc-Si/mc-Si
ASE Americas	USA	2	3 to 5		sc-Si
BP Solar	AUS	3	4	}4.5	sc-Si
BP Solar	ESP	3.3	4		sc-Si
Eurosolare	ITA	1.6	2.7	2.3	mc-Si/sc-Si
Isofoton	ESP	1.7	3	-	sc-Si
Kyocera	JPN	6.1	12	4.8	mc-Si
MSK	JPN	1	1	-	mc-Si
Photowatt	FRA	1.8	4.5	1.5	mc-Si
Sharp	JPN	4	4	1	sc-Si
Showa Shell Sekiyu	JPN	1.2	2	1	sc-Si
Siemens Solar	USA	11.5	20	11.8	sc-Si
Solarex	AUS	1.2	3	-	mc-Si
Solarex	USA	6.8	15	6.5	mc-Si
Solec	USA	2.6	3	1.3	sc-Si
Total		49.3	85 - 87	36.6	

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

Table 3.3 needs a few words of explanation. In order to try and avoid 'double counting', modules are considered to be manufactured in a country only if the encapsulation takes place in that country. The table therefore may not show companies who produce cells rather than modules, for example, the American company Astropower, produced 2.5 MWp of single crystalline silicon cells but over 2.2 MWp were exported as cells rather than modules. In addition to their module production, a number of companies sold on cells to other module manufacturers: Siemens Solar exported a further 5 to 6 MWp of cells from their U.S.A. plant and produced an additional 0.9 MWp in Germany; Solarex U.S.A. exported between 2.5 and 3 MWp of their production as cells. The Italian company, Eurosolare had a production capacity of 2.7 MWp for crystalline silicon modules in 1995, and produced 1.6 kWp of modules and exported 1.1 kWp of cells.

Total PV module production in the reporting countries from all companies was estimated to be 56.1 MWp in 1995, an increase of 4 MWp since 1993: the size of this increase is small because production of PV modules for consumer applications have been excluded in this report. PV module and cell manufacturing capacity was estimated to be 114.8 MWp in 1995, an increase of 23 MWp since 1993. The production of PV power modules is concentrated mainly in the U.S.A. (40%) and Japan (23%), although the European countries accounted for

Figure 3.4: PV module production in the reporting countries in 1995: total 56.1 MWp.



26.7% of production and 28.5% of capacity. This represents an increase in European production of 24% from 12.1 MWp in 1993 to 15.0 MWp. The quantity of modules produced is shown in Figure 3.4 and the distribution of production capacity is shown in Figure 3.5. The production figures are of course lower than the capacity figures, the utilisation of production capacity was 50% in 1995. This figure is slightly misleading, particularly for the production in the U.S.A., where utilisation of capacity is above 90%, as significant quantities of cells were sold on to other manufacturers for module encapsulation.

It can be seen from Table 3.3 that the number of manufacturers producing more than 1 MWp increased from 12 in 1993 to 15 in 1995. In 1993 those manufacturers producing more than 1 MWp accounted for over 75 % of module production, whereas in 1995 they accounted for 88%.

Figure 3.4: PV module production in IEA participating countries in 1995

Figure 3.5: PV module production capacity in IEA participating countries in 1995

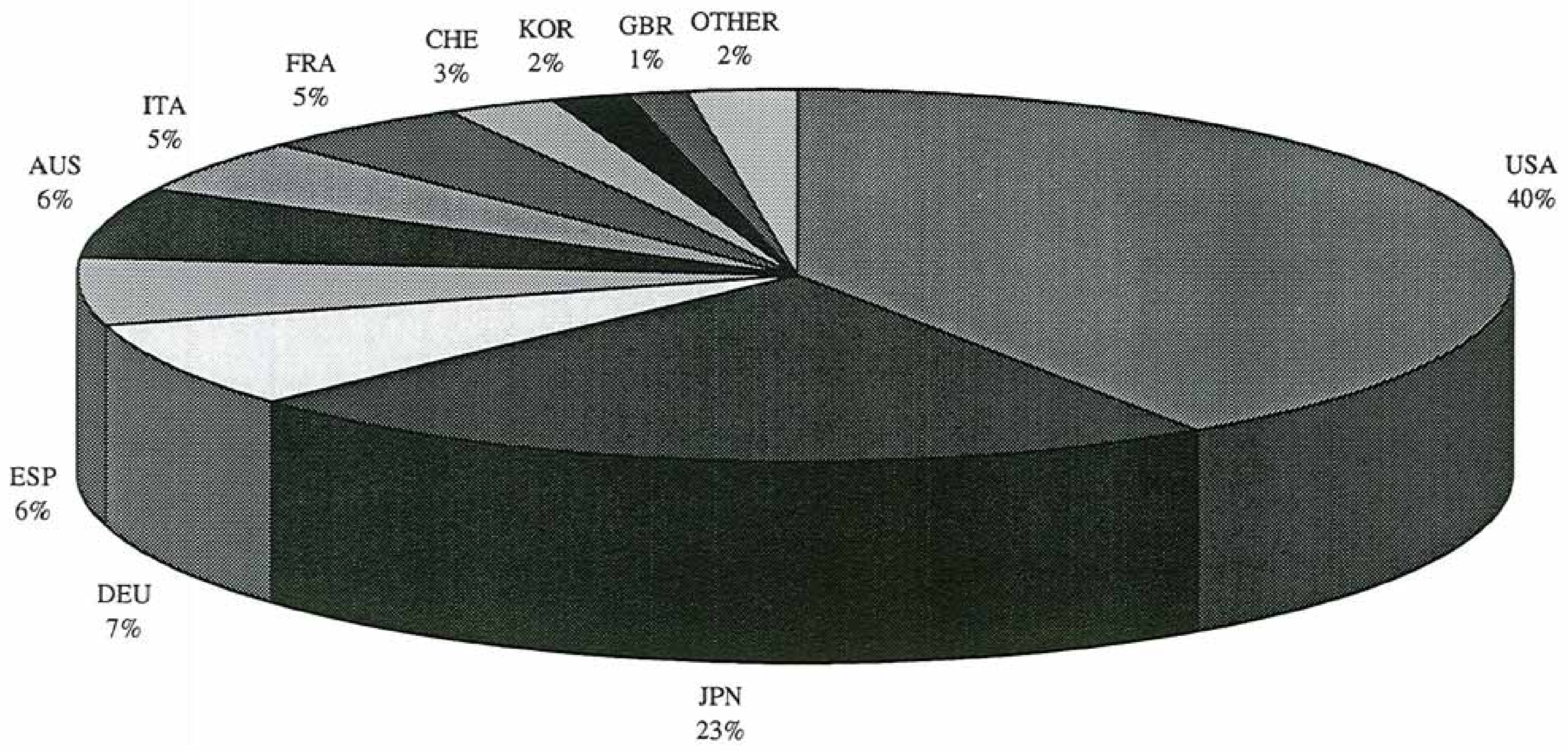
3.1.3 PV Module Manufacturing

Table 3.4 highlights the module manufacturers in each of the reporting countries, showing module production and production capacity, and module type. The additional information is the information available from the national reports which was provided on a voluntary basis.

Table 3.4: Module manufacturers in the reporting countries.

Country	Company	Production (MWp)	Module Type	Additional Information
AUS	BP Solar	3.0	sc-Si	Involved in cell, module and system manufacture using imported wafers and screen printing technology.
AUS	Solarex	1.2	mc-Si	Involved in cell, module and system manufacture using imported wafers and screen printing technology.
CAN	Astropower Canada	<0.2	sc-Si	Production ceased in August 1996
CAN	Canrom	<0.2	sc-Si	Manufactures wafered silicon solar cells and modules. It can manufacture custom-made modules but it has developed a standard line of multicrystalline modules which it distributes directly. Developing a proprietary thin film CdTe/CdS PV technology which it plans to bring to a pilot manufacturing stage in 1997.
CHE	Newtec	0.1	sc-Si	Roof integrated tiling system using Siemens cells. The tiles are weatherproof and designed to be installed without the need for roof alterations.
CHE	Solution	0.30	sc-Si	Produce PV laminate modules on request, the buyer may specify dimensions, components. Module construction uses either Siemens, Sharp, BP, Solarex or ASE cells.
CHE	Star Unity	0.01	sc-Si a-Si	First year of production: prototypes only. 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.

Figure 3.5: PV module production capacity in the reporting countries in 1995: total 114.8 MWp



DEU	ASE Wedel	1.5	sc-Si mc-Si	In July 1994 the manufacturers DASA and NUKEM formed a venture group called ASE (Angewandte Solarenergie GmbH). In November 1994 ASE acquired Mobil Solar Energy Corp, renamed ASE Americas Inc. In 1995, ASE closed their production facility in Wedel. ASE Americas are continuing to manufacture PV modules using the edge-defined, film-fed growth (EFG) technology. A small production line for MIS cells and PV modules remains in Alzenau, Germany.
DEU	ASE Phototronics	0.15	a-Si	The former DASA-Photonics group became a subsidiary of ASE and produces amorphous PV modules for various applications
DEU	GSS	0.17	sc-Si mc-Si	Manufacture modules for building facades.
DEU	Pilkington Solar	0.67	sc-Si mc-Si a-Si	Formerly Flachglas Solar: specialises in integrating modules into buildings and facades and assembles single crystal, multicrystalline and amorphous modules. Rated power of the modules ranges from 5 to 300 Wp.
DEU	Siemens Solar	0.9	sc-Si	Undertakes research and development on cells and modules with a small capacity production line.
DEU	Solaris	0.2		Manufacturer of PV modules for different PV system types.
DEU	Webasto	0.25	sc-Si mc-Si	Specialises in manufacturing flexible PV modules.
ESP	BP Solar	3.25	sc-Si	As AUS, but also production of 'Saturn' Laser Grooved Buried Grid cells. Standard and custom modules. Modules available in a variety of colours.
ESP	Isofoton	1.7	sc-Si	Modules from 5 to 110 Wp in many different configurations.
FRA	NAPS-France	0.4	a-Si	30 cm x 90 cm a-Si modules with stabilised power of 12 Wp ± 10 %, smaller sizes are available from 4 Wp.
FRA	Photowatt	1.8	mc-Si	Photowatt is a vertically integrated company producing very thin multicrystalline wafers. Modules are 2-glass laminate with aluminium frame.
GBR	Intersolar	0.8	a-Si	Manufacture amorphous silicon modules at their plant at Bridgend, South Wales.
ITA	Eurosolare	1.6	sc-Si mc-Si	Vertically integrated manufacturing process. Both single crystal and multicrystalline silicon cells currently produced: multicrystalline wafers are home-made, while single crystal wafers are bought on the international market. Manufacture large area multicrystalline modules with power ranges from 90 to 100 Wp.
JPN	Daido Hoxan	0.5	sc-Si	Purchase of sc-Si substrate and manufacture cells and modules.
JPN	Kyocera	6.1	mc-Si	Purchase raw silicon and cast substrate to manufacture cells and modules.
JPN	MSK	1	mc-Si	Purchase of mc-Si cells and manufacture into modules.
JPN	Sanyo Electric	5.1	a-Si	Purchase of SiH_4 gas & substrate (with TCO) and manufacture a-Si modules. Also purchase sc-Si and mc-Si substrates and manufacture cells and modules. Some sc-Si modules are purchased.
JPN	Sharp	4	sc-Si	Purchase of sc-Si substrate for cell and module manufacture.
JPN	Showa Shell Sekiyu	1.2	sc-Si	Purchase of sc-Si cell for module manufacture.
KOR	Haxime Chemicals	0.072	sc-Si	Largest production capacity in Korea and launched its module production in June 1994. Solar cells are supplied by Siemens Solar. Majority of the modules produced were exported. All the modules have an output power of 53 Wp.
KOR	LG Industrial Systems	0.08	sc-Si	Active in the construction of PV power units since 1985. Currently three types of modules are produced by LG Industrial Systems with rated output powers of 43 Wp, 48 Wp, and 53 Wp.
KOR	Samsung Electronics	0.3	mc-Si	Assembles modules using multicrystalline silicon solar cells supplied by Solarex U.S.A. Two types of modules are produced with peak outputs of 50 Wp and 60 Wp.

NLD	R&S	0.47	mc-Si	Assembles mc-Si modules from cells both produced in house and purchased on the international market. The standard commercial modules consist of 36 cells (area 100 cm^2) with a typical module output of 50 Wp. A 10 year technical warranty is normally offered. Special size modules can be designed and produced.
SWE	GPV	0.8	sc-Si	Modules are fabricated from prefabricated crystalline silicon cells purchased on the international market. Output powers of 55 Wp and 110 Wp. Modules are delivered with a 10 year limited warranty.
USA	ASE Americas	2	sc-Si	Shipped over 2 MWp of 'ribbon' cells and modules in 1995. Formerly Mobil Solar, the operation was purchased by ASE in 1994. Virtually all of the ASE resources are applied to the EFG sheet product with no announced thin-film research and development.
USA	Astropower	2.5	sc-Si	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. In 1995 Astropower shipped over 30 kWp of their new Silicon-Film™ product. Astropower has not announced details, but indicates that full production is coming.
USA	APS	0.1	a-Si	Facility recently purchased by BP Solar
USA	Siemens Solar	17.0	sc-Si	Manufacture and sell modules and cells made from single crystal silicon ingots produced in house. The 1995 cell shipments close to full capacity of about 20 MWp.
USA	Solarex	9.5	mc-Si a-Si	Now a division of Amoco/Enron Solar. Shipped 9 MWp of multicrystalline silicon modules and 0.5 MWp of amorphous silicon modules. The amorphous silicon production (0.53 MWp) is used for 5 to 20 watt panels.
USA	Solec International	2.6	sc-Si	Manufactures single crystal ingots, wafers, cells and modules; Standard line of 50-120 Wp modules, but also makes custom modules. Solec was recently purchased by Sumitomo and Sanyo of Japan. Presently Solec is moving into a new facility and has plans for a three-fold expansion in module production.
USA	USSC	0.6	a-Si	Producers of triple-stacked amorphous silicon modules, with a size range of from 5 Wp to 22 Wp. USSC is a joint venture between Canon (Japan) and Energy Conversion Devices (ECD). The plant is a refurbished pilot plant made by ECD. In order to expand the USSC production in the United States, ECD built a 5 MWp plant which is undergoing final pre-production runs.

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

The total production listed in Table 3.4 is 72.3 MWp and includes both cell and module production.

Modules are manufactured in all the reporting countries except for Austria and Portugal. Although there is no PV module production in **Austria**, approximately 20% 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 has been 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 etc.

Table 3.5 shows average module prices in the reporting countries: typical crystalline silicon prices for a small order (less than 1 kWp), range between 4.4 USD/Wp in the U.S.A. and 11.8 USD/Wp in Switzerland, with the average price being 5.5 USD/Wp. The average price was weighted according to the module production of each country. The high price of Swiss modules is because they tend to be non-standard products for building integration. For a large order of crystalline silicon modules (greater than 100 kWp) the average price is 4.9 USD/Wp. For amorphous silicon modules, the average price for a small order was 4.9 USD/Wp, and for a large order was 4.1 USD/Wp.

Table 3.5: Average manufacturer's module price in the country of manufacture.

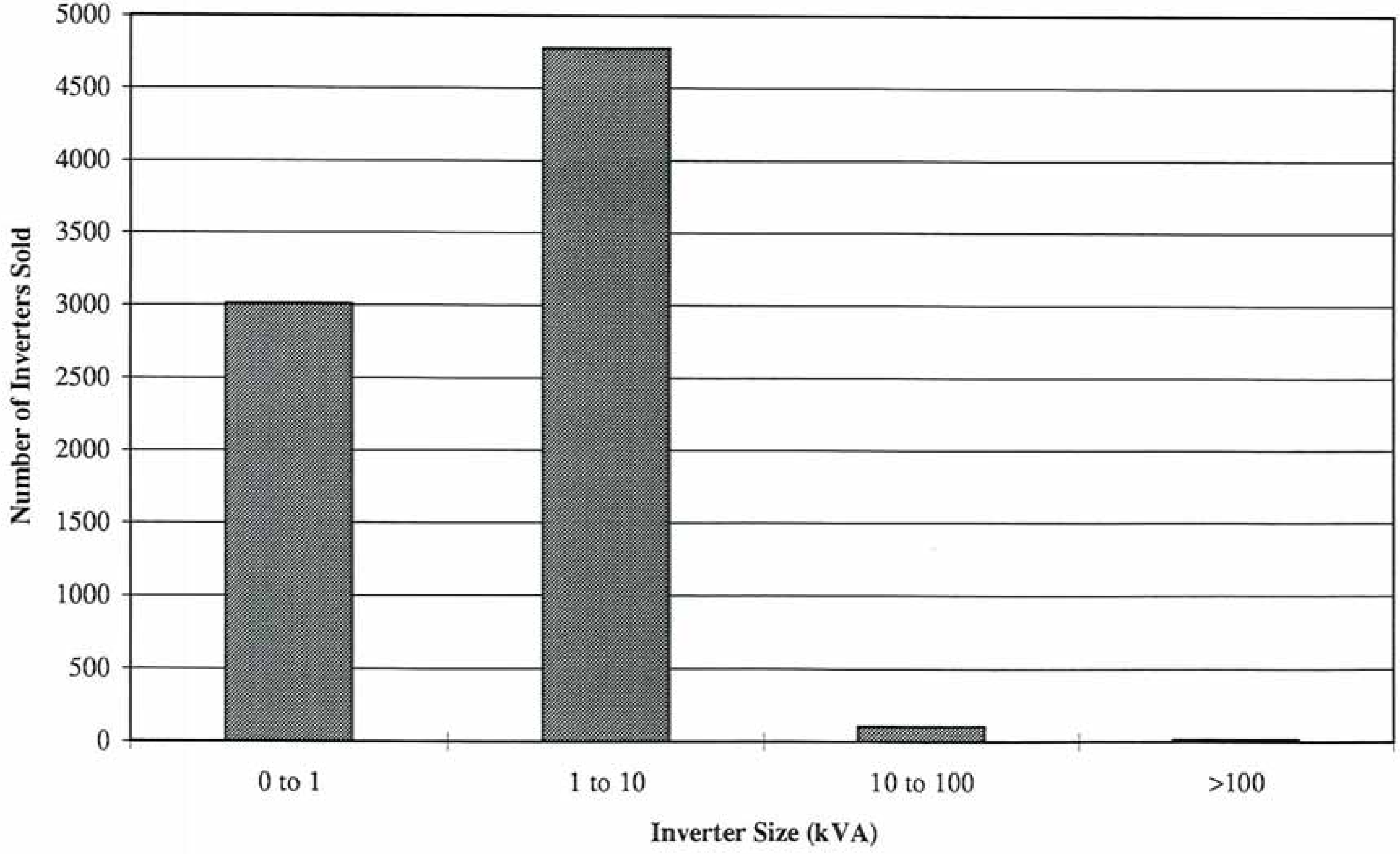
Country	Average Price (USD/Wp)			
	Crystalline Silicon		Amorphous Silicon	
	Small Quantity	Large Quantity	Small Quantity	Large Quantity
AUS	5.1	4.5		
AUT				
CAN	5.8	5.1		
CHE	11.8	7.9 - 11.8		
DNK				
DEU	6.9	5.3	6.1	5.1
ESP	6	5		
FIN				
FRA	7.7	5.3		4.3
GBR			4.5	3.0
ITA		4.3		
JPN	7-9	6-8		
KOR				
NLD	9.1	7.9		
PRT				
SWE	4.8	4.5		
USA	4.4	4.4	5.0	4.50
Average†	5.5	4.9	4.9	4.1

† Averages prices are weighted by the module production.

The prices quoted in Table 3.5 are factory prices to distributors. Approximately 20% should be added for prices to customers. It is also worth noting that a-Si modules are small (<30 Wp) and not yet used much in on-grid applications. If compared to similar sizes of crystalline silicon in the 20 Wp range the prices are equivalent or lower for a-Si.

The data in the 1993 Survey Report combined the amorphous and crystalline silicon module prices, so to enable a comparison to be made, the prices for amorphous and crystalline modules in 1995 have been averaged. The figures in Table 3.6 show a significant fall in module prices between 1993 and 1995: 39% for small orders and 20% for larger orders. This

Figure 3.6: Number of inverters for grid-connected PV systems sold in the reporting countries in 1995



fall in module prices is further supported by a fall in the average cell price in the U.S.A. of 13% in 1995 to 2.54 USD/Wp.

Table 3.6: Average module prices for large and small orders in 1993 and 1995.

Year	Small module order (a-Si + c-Si) USD/Wp	Large module order (a-Si + c-Si) USD/Wp
1993	8.5	5.6
1995	5.2	4.5

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 system 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 3.6 shows the number of inverters for grid-connection sold in the reporting countries broken down by inverter size. The numbers shown underestimate the actual figure as Austria, Canada, Finland, and Italy were unable to provide accurate data: however, the graph shows that most inverters sold are less than 10 kVA in size: the large inverters (>100 kVA) were almost all sold in the U.S.A. The development of small inverters between 100 and 300 W in size for the a.c. module, would suggest that in the future the relative proportion of inverters in the 0 to 1 kVA will increase at the possible expense of those in the 1 to 10 kVA range.

Figure 3.6: Number of inverters for grid-connected PV systems in the reporting countries in 1995.

The price of inverters in USD per VA and the number of inverters for on-grid systems sold in 1995 are shown in Table 3.7. The largest number of inverters sold were in Germany, Japan, the Netherlands and Switzerland: each of these countries have large amounts of grid-connected PV power installed. The total number of inverter manufacturers in the reporting countries in 1995 was 79; of these 70% were located in Australia, Germany, Italy, Japan and the U.S.A. As would be expected, the average price per watt is lowest for the large inverters and higher for the smallest inverters. Inverters in the 1-10 kVA range are slightly cheaper than those in the 10-100 kVA range due to the much larger numbers produced. The price of inverters in the 0-1 kVA range is expected to decrease significantly when large scale production for use with a.c. modules gets underway.

Table 3.7: Number of inverter manufacturers (grid and stand-alone), number of inverters sold in 1995 (grid-connect only) and prices per watt in reporting countries.

Country	Number of Manufacturers in 1995	Average Price by Size (USD per VA)				Number of inverters sold
		0-1 kVA	1-10 kVA	10-100 kVA	>100 kVA	
AUS	9		1.88			12
AUT	1		1.0			
CAN	3	1.5	0.75			
CHE	6		1.35	1.5		631
DEU	10	1.24-2.20	0.76-1.88	0.69-1.38	0.63-0.75	3 292
DNK	0					
ESP	3		1.27			4
FIN	1		0			0
FRA	0					
GBR	1					4
ITA	9	1.25	1.13	0.90	0.75	
JPN	10		3.0	3.5		1 460
KOR	3					
NLD	3	1.8	0.9			2 305
PRT	0					
SWE	0					
USA	21		0.83	0.88	1.06	192
Total	80					7 900

In **Korea**, there are no manufacturers producing inverters for grid-connected PV systems, although there are three companies manufacturing inverters for stand-alone systems. In **Denmark**, **France**, **Portugal** and **Sweden** there are no manufacturers of inverters for PV systems.

3.1.6 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. Typical system prices in the reporting countries for on-grid and off-grid applications for various system sizes are shown in Table 3.8.

The system prices in the off-grid, 100 to 500 Wp sector ranged from 14 to 41 USD/Wp, compared to 10.5 to 28 USD/Wp for larger (1-4 kWp) off-grid systems. For the on-grid 10-50 kWp systems, the range was 7.3 to 20.0 USD/Wp, compared to 7.5 to 30.0 USD/Wp for systems between 1 and 4 kWp and 7.0 to 11.8 USD/Wp for systems larger than 50 kWp. The large range of prices was due to the fact that some of the systems are demonstration and some countries did not include installation costs in their estimations. The particularly low price of grid-connected systems in the 1 to 4 kWp range in Germany is due to the Greenpeace *Cyrus* programme which pooled potential customers together to enable them to bulk buy systems. The prices associated with on-grid systems are lower than those for off-grid systems because no batteries and associated components are necessary.

Table 3.8: Photovoltaic power system prices by application in the reporting countries.

Country	Price by Application (USD/Wp)				
	Off-grid 100-500 Wp	Off-grid 1-4 kWp	On-grid 1-4 kWp	On-grid 10-50 kWp	On-grid > 50 kWp
AUS†	15	10.5	7.5	7.5	
AUT	18	15	12		
CAN†	14	10.7			
CHE	22	11.6	11	9.8	11.8
DNK	29.6	25.6	12	13	
DEU	27.6	11.4	7.3	9.2	8.5
ESP	22	15.5			8.5
FIN	20				
FRA‡	41	28	20		
GBR†	15		9	30	
ITA	16.5	15.0	12.6	10.7	7-10
JPN			15	20	
KOR	19.2	13.1			
NLD	24		12	12	
PRT	17	15	12		
SWE†	18.8		10.8		
USA					
Range	14-41	10.5-28	7.3-20	7.5-30	7-11.8

† Price does not include installation as these are very dependent on location.
‡ Includes maintenance costs

3.1.7 Balance of System Component Manufacturers and Suppliers

A specialised industry exists today manufacturing PV balance of system (BOS) components such as battery charge controllers and the inverters discussed in the previous section. No specialised industry exists for d.c. switchgear as such products are readily available. A few battery manufacturers carry a line of batteries specifically designed for PV use. However, the PV market for batteries is generally a small percentage of any battery manufacturer's sales, so little pressure has been put on manufacturers to design PV specific batteries. Lead acid, deep discharge, gel cell sealed, and industrial quality chloride batteries are all suitable for PV applications. Of the reporting countries, eight had two or more battery manufacturers, although no specific data were reported by the U.S.A. or Japan.

In many countries, charge controllers are commonly built by the system supplier and frequently not marketed separately and everywhere the support structures are normally built by the system installer; very few companies sell packaged support structures. Within the reporting countries there are thirteen manufacturers of support structures, most of whom do custom work, although three supply standard systems. This compares with the situation in 1993, where the only country with support structure manufacturers was Switzerland, where seven companies did custom work only.

As would be expected, those countries whose installed power is predominantly off-grid tended 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 tended to be geared towards the manufacture of inverters suitable for grid connection. For example, in Australia, there are a number of manufacturers of PV regulators, array trackers, maximum power point trackers, PV batteries, PV pumps, cathodic protection components, PV lighting components, Remote Area Power Supplies (RAPS) systems and RAPS controllers and only two manufacturers of inverters for grid-connection.

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 charger 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. A basic type costs 80 USD for 10 ampere capacity. More sophisticated ones with long life times can reach 800 USD.

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. Total Energie of France has developed a charge controller with a central processor unit allowing detailed monitoring of PV systems (battery state of charge, remote control payment and alarm). Other companies have developed computer software to carry out data analysis and remote control of autonomous PV systems through satellites or the telephone network. STECA in Germany have developed charge regulators equipped with an integrated circuit containing all the functions needed for controlling the charging and discharging of batteries. The costs of this charge controller are comparable to those of existing regulators with analogue design.

3.1.8 System Suppliers

The number of system suppliers in the reporting countries is given in Table 3.9. The total of 285 compares with 197 in the 1993 report: it needs to be noted that the 1995 figures include Australia and Spain who did not supply data for the 1993 report. Most countries with substantial domestic use of PV have system suppliers and manufacturers of charge controllers, batteries and inverters. However, several countries with relatively small domestic markets also have a BOS industry and system suppliers. For example, the United Kingdom has a relatively small domestic usage of PV but has one module manufacturer, an inverter manufacturer, several battery and charge controller manufacturers and 21 system suppliers.

Having a PV systems industry is also not dependent upon domestic module manufacture: Canada installed less than 0.5 MWp of PV in 1995 and produced less than 0.5 MWp of modules but has 20 system suppliers. A strong government programme to encourage PV use can result in a country that does not manufacture large quantities of modules having a strong BOS and system supplier industry.

Table 3.9: Systems suppliers in reporting countries

Country	System Suppliers	Country	System Suppliers
AUS	42	GBR	21
AUT	30	ITA	13
CAN	20	JPN	20
CHE	19	KOR	5
DNK	5	NLD	21
DEU	30†	PRT	9
ESP	52	SWE	5
FIN	13	USA*	32
FRA	10	Total	347

† The number of small, local systems installers is estimated to be as many as 300; only 30 operate nationally.
* Electrical contractors supply PV systems. This total is for suppliers that regularly advertise PV systems.

3.1.9 AC Modules

Further developments are also occurring with the introduction of the 'a.c. module'. A small inverter (size around 10 cm x 10 cm x 4 cm) combined with a d.c. PV module can be seen as a new product with a new market. The development of the a.c. module will also allow the development of modular PV systems so that additional power can be added after the system has been installed to meet changing demands on the system. This concept is of particular importance for domestic systems. In the Netherlands, over 100 a.c. modules were installed on residential roofs in 1995 and a further 1 200 units were subsequently sold without subsidy in 1996.

A.C. modules have also been developed in Germany and have been installed in a 10 kWp system in Chemnitz utilising 96 Wp modules. In Switzerland, Alpha Real AG, have recently developed the 'Megalino' which consists of a set of modules (with a total power of around 200 Wp) with an integrated inverter for direct connection to the grid. The inverter integrated in the module has a 200 W, 230 Va.c. output and an efficiency better than 90% for power exceeding 20 W, and a maximum of 92.5%. In 1995 a first prototype batch was introduced onto the market; production lines will start operating in June 1996.

In field experiments it was found that the yield of a PV system using a.c. modules was about 4% higher than conventional dispersed PV systems due to reduced mismatch and d.c. losses. A further advantage of the a.c. module is the reduction of losses due to shading. These occur when all or part of a d.c. string of modules are shaded and the output of that string is reduced to the lowest module output, i.e. the whole string output is reduced when only part of it is in shadow.

The development of the a.c. module has the potential to be the first PV power electronics product, other than modules, that is produced in quantities of more than 1 000 per year. According to manufacturers in the U.S.A., sales approaching 50 000 units per year are needed to reduce costs, increase reliability, incorporate the latest semiconductor components and realise a profit.

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 both 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 summarised for each country. The final sections look at new developments in PV some projections on the future of the PV market are presented.

4.1 Indirect Policy Issues

The national reports identified three major issues that may affect the implementation of PV systems:

- the introduction of favourable environmental regulations;
- studies relating to externalities and hidden costs of conventional energy generation when compared to renewable energies,
- taxes on pollution.

Little impact can be directly attributed to the existence of these three factors, although they have undoubtedly had an indirect impact.

Environmental regulations which should limit CO_2 emissions exist in Australia, Austria, Italy, the Netherlands, Spain, Switzerland and the U.S.A., but do not seem to directly influence the PV market. These environmental regulations have had little direct effect because the cost of electricity generation from PV is still too high. However, their long term effects may be large as they may act as an indicator of future business opportunities to decision makers.

The same can be said of the studies on externalities. Studies have been carried out in the majority of countries but, as yet, they have had little if any impact.

Only Denmark, Finland and Sweden have advantageous environmental tax regimes, although this is a subject of discussion in other countries. In Sweden emissions of SO_2, CO_2, NO_x and the use of nuclear power are taxed.

4.2 Promotion Initiatives

From table 4.1 it can be seen that the most common method of stimulating the introduction of PV systems is through the use of preferential tariffs. This can be based on net metering, where PV electricity sold to the grid is valued the same as electricity purchased from the grid, or PV electricity can be sold at a percentage of the normal retail price. Other ways of promoting PV technology is through the reduction or removal of sales taxes, as has been done in Australia, Italy, the Netherlands and Portugal.

Table 4.1: Promotion Initiatives in reporting countries (✓ indicates such an initiatives exists whereas × indicates it does not exist)

Country	Preferential Tariff	Sales Tax Exemption or Reduction	Comments
AUS	✓	✓	Range of tariffs, including bulk supply tariff, 20% off retail and net metering: Varies on a State by State basis.
AUT	✓	×	Tariffs negotiable - based on preferential rates for hydro power 0.039-0.078 USD/kWh (equivalent to net metering). One state has introduced a rate for PV (0.98 USD/kWh). Taxes on electricity of 0.01 USD/kWh to be introduced in 1996 from which renewable energy (RE) will be exempt. Subsidies between 15 and 50% available from regional government
CAN	×	×	Limited net metering - some utilities allow reverse metering from small grid-connected PV systems. Accelerated depreciation for systems >10 kWp
CHE	✓	×	Net metering standard. Various utility initiatives for preferential tariffs and the possibility of buying PV generated electricity at discounted rates.
DNK	✓	×	All power generated from renewables are relieved of carbon tax and certain pollution taxes.
DEU	✓	✓	The basic tariff is 0.11 USD/kWh which the utilities are obliged to pay by law. Some municipal utilities pay a rate based incentive for PV electricity of 1.25 USD/kWh. Sales tax exemption is 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 when available at prices set by national authority.
FIN	×	×	40% subsidies to utilities for investment costs.
FRA	×	×	95% subsidy for off-grid systems within FACE funds programme
GBR	×	×	PV not ready to fit into the Non Fossil Fuel Obligation (NFFO) scheme whereby electricity from non-fossil fuel sources is bought at a premium (0.16 USD/kWh): PV electricity purchased at pool price. Net metering is not allowed.
ITA	✓	✓	Subsidies range from 30 to 80% depending on use: Preferential rates on a sliding scale from 0.26 USD/kWh. VAT reduced from 19% to 9% for PV systems.
JPN	✓	✓	For national taxes, a deduction equivalent to 7% of acquisition value or a special depreciation equivalent to 30% of acquisition value. For local taxes, some reduction in the taxable level of a fixed property depending on the objectives: subsidies range from 50 to 66%.
KOR	×	×	Currently there are no pollution or energy taxes.
NLD	×	✓	Accelerated depreciation on PV installations >250 Wp; Energy from renewable resources is exempt from energy tax (0.02 USD/kWh). Electricity from RE sold at a premium by some utilities; Proposals to reduce VAT from 17.5% to 6% for RE generated electricity and to finance PV systems through discounted finance.
PRT	×	✓	VAT rate reduced from 17.5 to 5% for renewable energy equipment, including PV modules and BOS components.
SWE	×	×	Taxes on SO_2, CO_2 and NO_x and nuclear: recommended purchase of PV electricity at retail price.
USA	✓	×	15 states employ net metering.

4.3 Perceptions of PV

4.3.1 Utility Perceptions

At the end of 1995, the utilities perceptions of PV systems were reported to be generally favourable in the reporting countries, although some utilities were still concerned about the effect of large numbers of small embedded generators on the electricity distribution systems. A number of countries have research programmes either in place, or planned, to investigate this. Research on this topic is also being undertaken under Task V of the PV Power Systems Programme.

Most countries have undertaken studies to quantify the hidden costs of energy generation, particularly the impact of greenhouse gas emissions arising from the generation of electricity from different sources. Although these costs are not routinely used as part of the energy planning process, they are beginning to play a role in policy formulation, environmental assessments and marketing.

In **Australia**, utility interest is increasing in the PV based power supply option for remote areas and in offering grid-connected customers the opportunity to contribute towards the installation of renewable generators in their region. A draft standard for remote area power supply systems is currently under consideration by the Standards Association of Australia. For grid-connected systems, utilities have taken a range of approaches. Some have required additional protection equipment between the inverter and the grid, others have been satisfied with the in-built protection offered with the inverter. The South East Queensland Electricity Board is the only utility to have a technical PV connection policy covering basic requirements for different size ranges. Similarly, a range of tariff options have been applied by the different utilities, including the application of bulk supply rates to PV generated power, 20% less than the retail tariff and net metering. Northpower, a NSW electricity distributor, offers net metering until the PV generated power exceeds the user demand, at which time the standard distributor electricity purchase price applies.

In **Austria**, the utilities have invested substantially in PV and operate most of the major research and demonstration projects, although the construction of large scale PV plants is viewed as uneconomical. No change in the present situation is anticipated in the near future as PV energy production will not be competitive compared to conventional energy generation, except in remote areas where grid support is unavailable or costly to install.

In **Canada** the general perception by utilities is that PV will have little impact in the Canadian electricity grid environment, although perceptions vary between different utilities: Ontario Hydro views PV as having little impact on operations, although it is seen as a business opportunity particularly for exports. Ontario Hydro is investigating using PV to supply electricity to native communities in the northern area of the province. Hydro-Quebec does not appear to be interested in PV as many opportunities for hydro-electricity and wind power exist in their area: BC Hydro and TransAlta have shown some interest without any commitments.

In **Denmark** electric utilities are now a key party investing in PV. They are interested and government programmes are targeting them for both demonstration projects and dissemination activities.

On grid centralised PV systems were not of interest to the utilities in **Finland**. However, a major government owned power company has installed a 30 kWp 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. There are no grid-connected systems owned or managed by EDF and they are not promoting the development of this type of application. Public FACE funds and tax exemptions have boosted the market.

In **Germany**, the '1 000 Roofs Programme' and an information dissemination campaign by solar energy enthusiasts and environmentalists has resulted in a widespread positive perception of the long-term benefits of PV technology by the general public. As an example, in the state of Baden-Württemberg 10 000 people were interested in the 1 000 Roofs Programme, 551 submitted proposals and 176 applicants received funding. The media, utilities and various institutes have all contributed to the widespread dissemination and the use of PV. Almost every regional and local utility company has installed, or are planning to install, their own PV plant for demonstration and research purposes. PV is sponsored by the big utilities such as RWE and Bayernwerk. The largest PV plants have been built and managed by utilities who are also involved in the installation of smaller residential PV plants. The effects of decreasing funding from the federal and state governments will test the commitment of these utilities to PV in the future

In **Italy**, the favourable utility perception of PV is evident in the utility ENEL's 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 MWp 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), with the co-operation of four controlled research companies. Some municipal utilities (Verona, Torino) are also showing an increasing interest in PV and are starting (or have started) small demonstration programmes.

No specific reference to utility perceptions is reported from **Japan,** however, in December 1991 power companies announced plans to install 2.4 MWp of equipment by the end of fiscal year 1995; 1.78 MWp has already been installed and 871 kWp are planned for the final year, giving an estimated total of more than 250 kWp above the target level. Installation sites are mainly on branch offices, power stations and research centres - buildings fully controlled by the utility companies.

In **Korea**, the high initial cost of PV has led the state utility KEPCO to emphasise power generation from nuclear, thermal and hydropower sources. KEPCO has recently constructed two island PV power systems in collaboration with the Korea Institute of Energy Research, and provided financial support for basic research and technology development projects. KEPCO has plans to conduct a long-term project to connect PV systems to the utility line. Under the framework of this project KEPCO is considering installing more PV systems for island applications and a scheme to construct a 1 MWp, grid-connected PV system.

In the **Netherlands** the utilities have been actively involved in the realisation of pilot plants since 1990. These projects are regarded by the utilities as pilot projects for future demand side and supply side energy concepts, although no utility is planning to introduce PV on a fully commercial basis. The largest utility project under construction is 250 kWp roof top systems on 70 houses in Amsterdam (completion June 1996). The largest utility project in preparation is construction of 1 MWp of PV systems on the roofs of 400 houses in Amersfoort.

In **Portugal**, utility perceptions of PV are positive. PV is being considered as a part of the utility EDP's R & D Programme for renewable energy, although at a lower scale when compared to wind and mini-hydro. EDP is currently promoting a national project to supply electricity to remote consumers using PV or hybrid systems as an alternative to grid extension. EDP also owns Portugal's first grid-connected PV system (10 kWp) and is planning to participate in future demonstration projects for stand-alone, grid-connected and building integrated systems.

In **Spain** several electric utilities are involved in PV projects and interest in these technologies is growing steadily. A number of utilities, including IBERDROLA, Union Fenosa, ENDESA and CSE have been involved in the implementation of on-grid PV systems. A number of projects have been carried out jointly by several utilities.

The standpoint of the **Swedish** utilities is that the development and introduction of PV technology is best suited to countries with better climatic conditions than Sweden, in particular countries where there is a better match between the supply of solar energy and electricity demand. PV technology will not be utilised for electric power generation within the next 5 to 10 years and then probably only for users not connected to the grid. The Swedish utilities are sponsoring a project concerning niche applications of PV. Examples of applications under investigation include illumination for bus shelters, cathodic protection of power line pylons and measurements of snow depth. Even at distances of a few kilometres the present cost of grid extension is in the range of several hundred thousand USD, making PV an economically viable alternative.

In **Switzerland**, the utilities are in favour of PV installation, and promote PV plants in a positive manner to the public. Although parity with the retail price (net metering) is standard in Switzerland, some utilities have gone further in their policy in order to contribute to the deployment of the technology. Some utilities have built large PV plants (such as Phalk and Desertasol) and provided different financing schemes to provide electricity to their customers.

Several of the utilities in the **United Kingdom** have begun to seriously consider PV. Although large numbers of small PV generators embedded in the grid may pose operational difficulties to the utilities they are now taking the issues seriously and are actively participating in the search for compatible solutions. PV is still considered to be expensive but it is recognised that the price is falling and that devices such as the a.c. module may open PV to the mass market. In 1992 renewable energy contributed about 2% of the UK electricity supply: the Governments stated target of 1 500 MW of new electricity generating capacity from renewable sources should raise this contribution to about 5% of current electricity supply. It is not likely that this will have a significant impact on the implementation of PV.

In the **U.S.A.**, the utilities have started key programmes involving the use of PV for grid-connected applications where the value is higher than central generation. The UPVG program involving over 70 utilities has funded nearly ten megawatts (most to be built) of PV applications (on-grid and off-grid) that are 'close to economic' now. The total Department of the Energy (DOE) subsidy for the first two rounds of UPVG PV system procurement is about 20%, well below the originally planned 30%. Several utilities have gained state and local approval for PV system deployment, both grid-connected and off-grid. These include: Sacramento Municipal Utility District, Southern California Edison, Public Service of Colorado, Idaho Power, New York Power Authority and Toledo Electric.

4.3.2 Public Perceptions

Throughout the reporting countries, public perception of PV is generally positive, particularly in the Netherlands, Switzerland and the U.S.A. where customers were reported to be willing to pay a premium for PV generated electricity. Evidence of positive public perception is particularly strong in Switzerland where surveys have shown that 80% of the public would be willing to accept a 1% increase in electricity prices to support solar power. A survey by the American utility SMUD indicated that 70% of their residential customers would be prepared to pay a 15% premium on their electricity bill for the installation of a SMUD owned PV system on their roof. A strong public preference for the use of environmentally friendly technologies was reported in Australia where customers were pro-active in their choice for renewable energy based power supplies. In Germany, a financing initiative which allows people to buy shares in PV systems has been developed to enable people to invest in a PV rather than having to buy a complete system. Other countries reporting positive public perceptions of PV were Italy, Japan and Sweden.

In a number of countries, including Canada, France and Spain, although perceptions were generally positive, concern was expressed as to the high cost of PV systems and as a result, they were seen as more relevant to remote applications. In France, a survey of PV system users indicated a high level of satisfaction. In Korea and the UK public awareness of PV power systems was low although it was hoped that demonstration programmes would raise the level of awareness.

4.4 Standards and Codes

At the end of 1995, few countries had specific codes governing PV systems or the grid connection of PV systems. However, the increasing use of PV power systems will eventually require a series of national (or international in the case of the European Union) standards in order to facilitate the construction, grid connection and operation of PV power systems.

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. Many countries have no specific standards or regulations for PV systems concerning the grid-connection of PV systems, but use regulations applicable to other generators. Only Australia, Denmark, Germany, Italy, the Netherlands and Switzerland have either draft or preliminary regulations in place or under development. This means that PV systems have to comply with existing regulations which have been prepared either for other small generators, such as small hydro or wind power, or for conventional generators.

The utilities in a number of countries have been satisfied with the protection offered with the inverter, whilst others have insisted on additional protection for grid-connected systems between the inverter and the grid. The applicable standards and codes in the reporting countries have recently been summarised in a report published by IEA PVPS Task V[6]. Details of country specific regulations and codes are given in Table 4.2.

Table 4.2 Summary of Standards and Codes in reporting countries.

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. Australian and international PV module standards apply, as do PV battery standards. Discussions and workshops on-grid connection standards are underway, but no standard approach or code of practice has been adopted. The South East Queensland Electricity Board in Australia is one of the few utilities that have a PV connection policy covering the basic technical requirements for different size ranges.
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. An updated version has been 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 Wp 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. Canada has two active standards for PV systems: F-380 deals with PV module standards; F-382 deals with batteries for PV uses. Canada is participating in the IEC TC-82 WG 2 and 3 for the development of PV standards. It is hoped that standards developed under these working groups will eventually be accepted as Canadian national standards with the required modifications by the CSA.
CHE	The Federal Inspectorate of High-Current Installations, has issued provisional safety regulations which will be replaced by the future electrotechnical standards of the ASE (Swiss Association of Electrical Engineers), PV systems operating with a voltage lower than 1 000 V d.c. or 1500 V a.c., with or without the possibility of connection to a low-voltage supply network are subject to the provisions of the decree on low-voltage installations (OIBT). Consequently, only those persons licensed according to the OIBT are authorised to install such systems.
DEU	The use of general standards and regulations is advised because they refer to regulations (VDE regulations) generally accepted by engineers. The basic German safety code is the *VDE 0100* (International: IEC 364). This electrical 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. As a result of the 1 000 Roofs Programme, the VDEW drew up a preliminary directive for the operation of private electricity generating plants in parallel with the low-voltage utility grid. This directive, already the third update, is limited to systems with a maximum output of 5 kW. A new VDEW regulation has been drawn up for the implementation of single phase on grid control for the parallel feeding into the grid by small generators.
DNK	A national PV System Laboratory (PVSys-Lab) was established in 1995. Its objectives are to ensure a minimum quality level for components and installations in preparation for an expected government subsidy. In parallel with this work the Government and the Danish electric utilities have started work on establishing national tariffs on general conditions for grid connection of PV systems.
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	In the regulations for connecting small electric power production units to the grid there are no specific requirements for PV plants. Constructors of PV systems have to follow the general regulations for electric power installations. Customers can only 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.

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

FRA	A specification for off-grid PV power systems has been developed by ADEME, Electricité de France and PV companies, with the existing standard NF C 15-100 as its starting point, and is part of a Charter of Quality that PV system companies adhere to.
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 1988. HMSO, 1991; Engineering Recommendation G.59/1 (1991); Engineering Technical Report No. 113 (1989). Various regulations governing harmonics, electro-magnetic compatibility and protection also apply.
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 Vd.c. 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 that self-producers, with installed power up to 3 MW, must be connected to low or medium voltage grid according to the installed power value. These rules have been recently revised and partially modified to take into account the grid interconnection of static a.c. generators to allow the connection of single-phase a.c. generators, with a nominal power of up to 3 kW, to the low voltage grid.
JPN	PV systems are governed by guidelines published by the Public Utilities Department in the Agency of Natural Resources and Energy. This governs grid-connected local power generating equipment with reverse current function and connection either to the high voltage distribution line (6 600 V rotating generators or d.c. power equipment) or to low voltage lines (100 to 200 V d.c. power equipment). The islanding prevention function of local power generating equipment based on voltage and frequency monitoring, and the automatic voltage adjustment functions of inverters are also stipulated.
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.
NLD	There are no specific national standards or regulations for the application of PV in grid- connected or 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.
PRT	There are no specific guidelines for grid-connected PV power systems. The existing regulations (law 189/88, recently revised by law 313/95) allow for independent producers from any type of renewable source and any power (mini-hydro systems are limited to 10 MW) to sell electricity to the national grid 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 talk about 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 NESC-ANSI/NFPA 70-1996. Where local codes exceed this code, the local code takes precedence. Article 690 addresses unique safety issues of PV power systems. There is a list of standards and codes that deal with the installation of PV power systems.

The work to develop standards for PV power systems is ongoing; the International Electrotechnical Commission has issued standards covering various aspects of performance measurement, design qualification and type approval for crystalline silicon modules (IEC 1215) and thin film modules (IEC 1646); Japan aims to standardise PV systems by 2000.

4.5 Future Opportunities

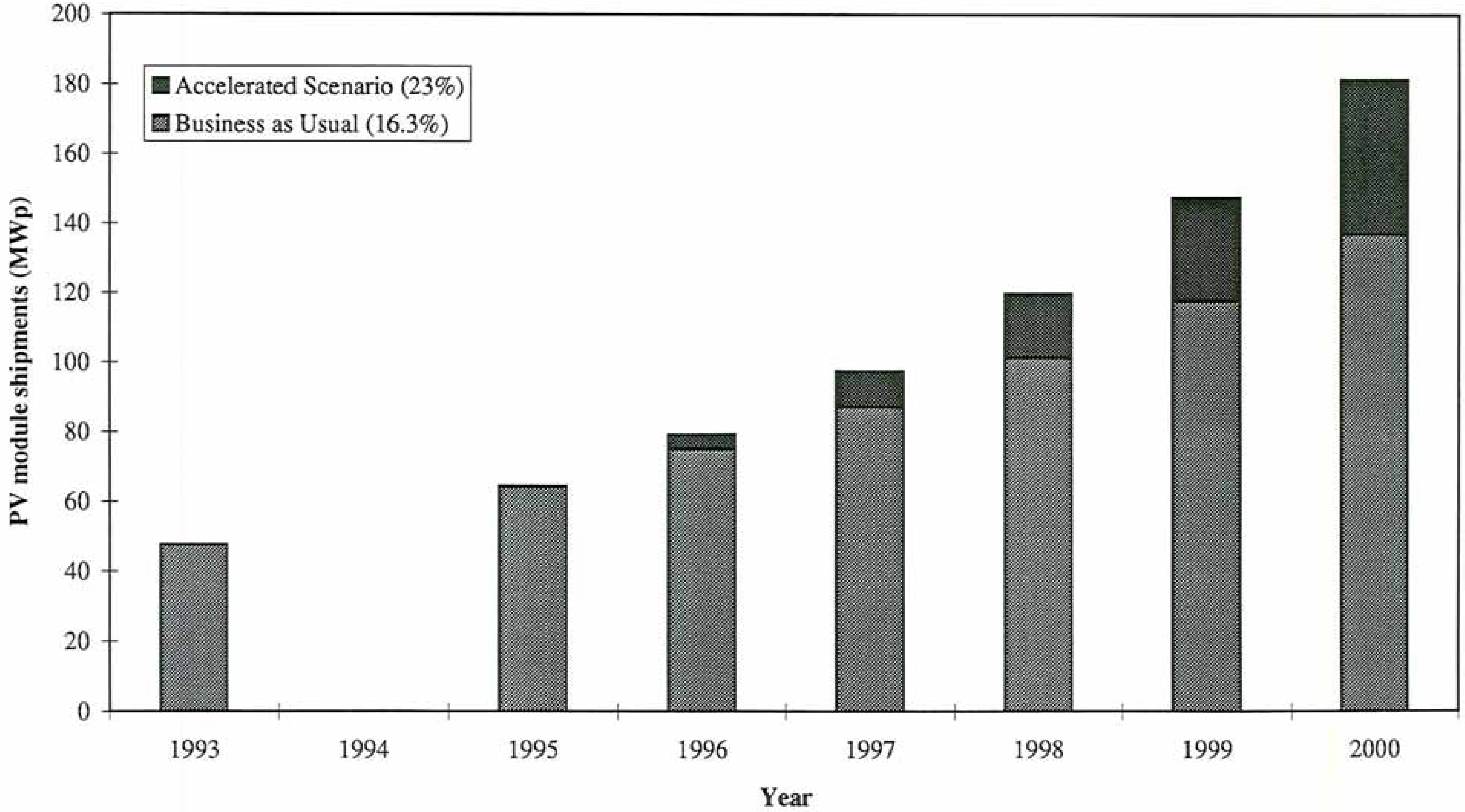
The PV industry is a developing and expanding industry. As such there are many new developments underway, some of which have been detailed in the national reports. A number of companies have announced plans to expand capacity.

- In Canada, Ontario Hydro Technologies has bought the Spheral Solar™ technology and plans to start production in 1998.
- In France, Photowatt and NAPS France should double cell and module production by the end of 1997.
- In Germany, several small and medium sized enterprises have announced plans to start production of solar cells and modules, including ERSOL who intend to transfer the 5 MWp cell production line of ASE to another site, and Solar Nova, who will take over the ASE module production facility. Other companies who have announced they intend to start new cell and/or module production include RAP Mikrosysteme, Solar Fabrik Freiburg and Sunways.
- In Japan, Canon will start to produce amorphous silicon modules at a new 10 MWp facility in 1996.
- In the U.S.A., Siemens Solar Industries have announced that they intend to increase their single crystal capacity from 20 to 30 MWp by the year 2000; Solarex plan to double their multicrystalline capacity to 30 MWp by the year 2000 and to build a series of 10 MWp thin film plants throughout the world in the next decade; Solec have announced their intention to double capacity; ASE Americas should have a new 5 MWp production facility operational in 1996. USSC has plans for an additional 5 MWp production line.
- BP Solar intends to start production of cadmium telluride modules in the U.S.A.

Perhaps the most important development likely to influence PV technology is the introduction of thin film modules. These use materials such as cadmium telluride (CdTe), copper indium diselenide (CIS), thin film-Si, although new materials are also under development. Further improvements in the conventional amorphous and crystalline silicon materials are also being continually introduced. The new thin film materials promise low cost and mass production volume of modules, albeit with lower conversion efficiency than crystalline silicon. BP Solar are producing limited quantities of CdTe modules in the United Kingdom and two US companies, Golden Photon and Solar Cells Inc. (SCI), shipped pilot quantities of cadmium telluride modules in 1995: SCI shipped about 50 kWp of cadmium telluride modules in 1995 and the Golden Photon pilot plant is capable of producing 2 MWp per year. SCI is completing an advanced deposition system capable of producing 10 MWp per year of 60 cm x 120 cm modules of cadmium telluride. NREL measured stable efficiencies approaching 8 percent, and in a glass/glass module, cadmium telluride appears to be stable with a predicted life similar to crystalline silicon. In Canada, Canrom are developing a proprietary electrodeposition process for thin film CdTe/Cds PV modules which it plans to bring to a pilot manufacturing stage in 1998. In addition to Siemens Solar and Solarex, EPV International Solar Energy Technologies are performing research and production engineering on CIS.

In Australia, a thin film multi-layer process developed at the University of New South Wales is part way through a five year development programme by Pacific Solar. Sustainable Technologies Australia, in a consortium with government agencies, utilities and universities is undertaking R & D on dye doped titania solar cells.

Figure 4.1: Five year forecast of PV module production in the reporting countries (MWp per year)



Recently it has been announced (PV News, September 1996) that a new company Global Solar Energy, formed in May 1996, plans to start manufacture of CIS in 1997; initial production is expected to be about 1.5 MWp per year.

There are a number of factors that suggest that the future for the PV industry is a positive one; of particular significance are the targets for installed capacity specified by a number of the reporting countries. Japan plans to install 400 MWp by 2000 and 4 600 MWp by 2010; Korea has a long term goal of installing 20 MWp for island off-grid applications; the Netherlands intends to install 250 MWp of grid-connected PV by 2010 and 1 250 MWp by 2020, and Switzerland hopes to install 50 MWp by 2000. This amounts to a total of nearly 6 000 MWp by 2020 in these countries alone. Current production capacity stands at 120 MWp and to date, plans to install a further 55 MWp have been announced. Assuming these facilities are running by the end of 1997 at 100% utilisation, the maximum that could be produced by the year 2020 is 4 200 MWp.

In order for these targets to be met it is clear that substantial investment in new manufacturing facilities will be necessary and this will further drive prices down, thereby further increasing demand. Even without these targets, and it is not definite that they will be met, the installed PV power has grown from 53.5 MWp in 1990 to 175.7 MWp at the end of 1995 - an annual average increase of 27%.

4.6 Future Trends

This section of the report presents some possible projections on the future of the PV market and industry. Projections were made based on a business as usual scenario of PV module production and installed power in the reporting countries. An accelerated growth scenario was also imposed on the PV module production. These predictions are by their nature speculative and as such should be treated with caution.

Figure 4.1 shows a 5 year forecast of PV power module shipments based on the historic growth rate of 16.3%. (As the PV module production in 1993 included shipments of modules for consumer applications from Japan these data have been added to the 1995 module production of 56.1 MWp to give an adjusted figure of 64.4 MWp). The figure also shows an accelerated growth scenario of 23% in module shipments. According to the figure it is estimated that by the year 2000, PV module production would be in the region of 10 MWp per year based on the business as usual scenario, and 180 MWp per year on the accelerated scenario.

Figure 4.1: Projected PV module shipments until the year 2000, based on the increase in shipments between 1993 and 1995.

Figure 4.2 shows the five year forecast for the installed PV power in the reporting countries for both on-grid and off-grid systems. By the year 2000 it was estimated that 550 MWp of PV power would be installed based on the average historic growth rate of 24% per year since 1993. Assuming that the rate of increase for off-grid systems remains at its historic level of 22.5%, the amount of power installed would be 350 MWp for off-grid systems and 200 MWp for on-grid systems. This implies a future growth rate of 32% for on-grid systems: this figure is very dependent upon the implementation of national demonstration programmes etc.

Figure 4.2: Five year forecast for installed PV power in the reporting countries based on historic growth rates

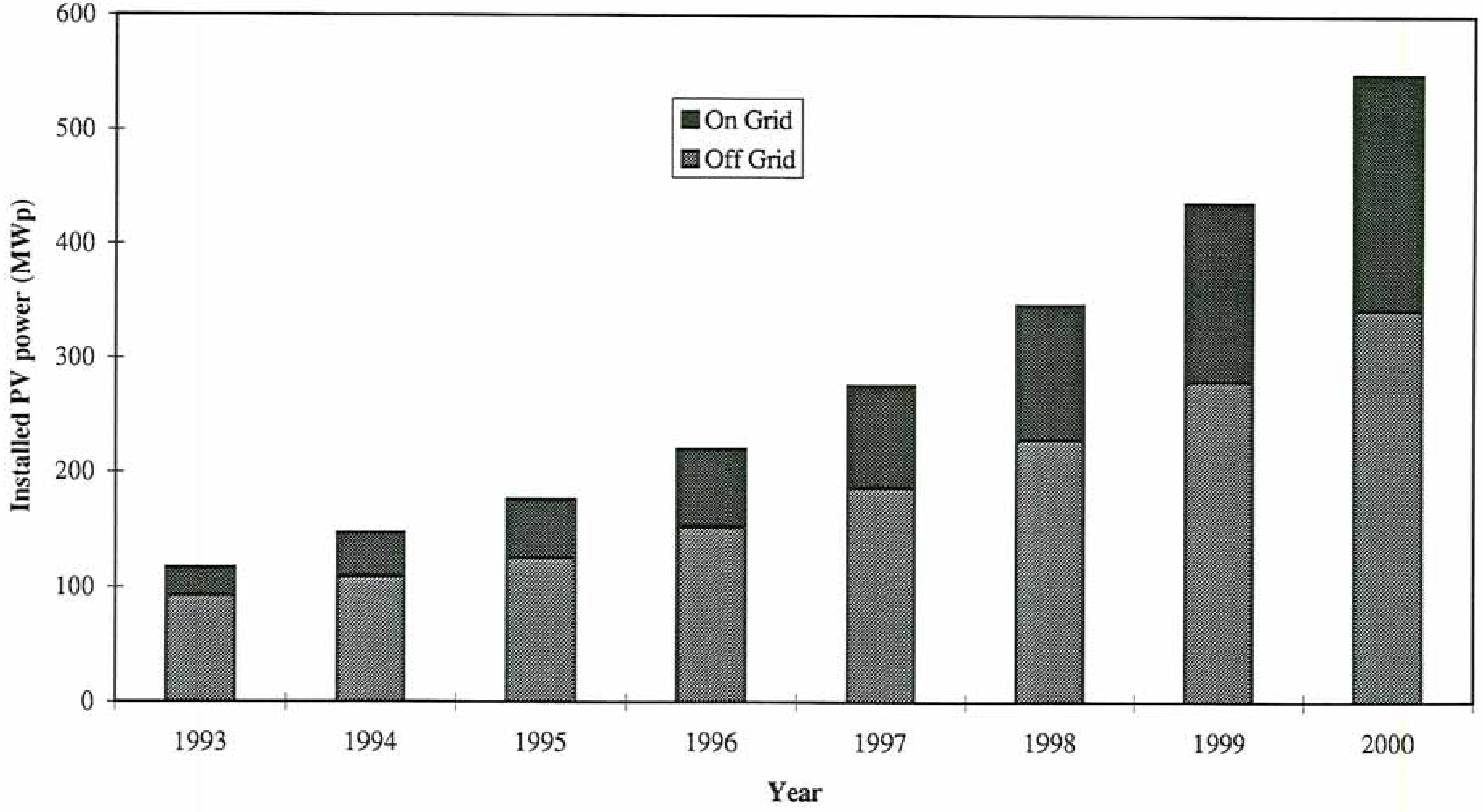


Figure 4.2: Five year forecast for installed PV power in the reporting countries.

Grid-connected systems tend to be concentrated in the developed countries and have shown an historic growth rate since 1990 of 69.7% due to the fact that few grid-connected systems were installed in 1990. The increase in grid-connected power between 1994 and 1995 had fallen to 34%; this compares to the increase in off-grid power which has been relatively steady over the whole period, showing an annual growth of 22.5% since 1990. Although government subsidies of grid-connected programmes have declined in Germany, Italy and the U.S.A., the Japanese programme should ensure a continuing demand in the short term. The increasing support for rate based incentives in Germany, the Netherlands, Switzerland and others should ensure the continued installation of grid-connected residential systems.

Chapter 5 Conclusions

The key issues raised in this second 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 1994 and 1995. These data were collected from primary sources. Information has also been taken from the first International Survey Report which covered the years 1992 and 1993 and has been updated where this has been appropriate and possible. 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 Wp 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.

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

Year	Cumulative installed off-grid power (MWp)	Increase in installed off-grid power (%)	Cumulative installed on-grid power (MWp)	Increase in installed on-grid power (%)	Cumulative installed power (MWp)	Total power installed per year (MWp)	Increase in installed power (%)	Module production (MWp)
1990	49.8		3.7		53.5			
1991	61.1	22.7	6.5	76	67.6	14.1	27	
1992	79.0	29.3	13.5	108	92.5	24.9	37	
1993	92.3	16.8	24.3	80	116.6	24.1	26	47.6
1994	107.7	16.7	35.5	46	143.6	27.0	23	
1995	124.2	15.3	51.5	45	175.7	32.1	22	56.1

- Off-grid domestic systems have been installed throughout the world, particularly in countries outside the IEA. These systems are also common in Australia, France, Italy, Spain, Switzerland and the United States, with each having over 2 MWp installed.

- Off-grid non-domestic systems are widely used in low power applications. These systems have accounted for a steady 20% of installed power in the IEA reporting countries since 1990. This is the sector where most PV power systems are installed in Australia, Canada, Denmark, Korea, Portugal, and the United Kingdom.

- On-grid distributed systems are a relatively recent PV power application. The size of this market has grown substantially with the implementation of national and international demonstration programmes. In 1990 on-grid distributed systems accounted for less than 5% of installed PV power, whereas in 1995 they accounted for more than 20%.

- On-grid centralised systems have been installed, although the market for such systems consists of demonstration plants funded from national and international programmes. The installed PV power in this sector increased from under 3% of the installed power in 1990 to 8% in 1993, although levels remained steady till 1995.

- The most widespread application for PV power systems is the off-grid sector where their use is well established. Off-grid applications accounted for 93% of the installed power in 1990 and 71% in 1995, which translates to an increase in on-grid applications from 7% in 1990 to 29% in 1995. The bulk of this increase was accounted for by a large increase in on-grid distributed systems.

- In the period since 1990, the installed PV power in the reporting IEA countries has grown at an average annual rate of 27%. This growth has not been steady as can be seen from Table 5.1. The large increase of 37% seen in 1992 decreased to 20% in 1995. This was primarily due to the completion of large government demonstration programmes in some of the reporting countries.

- During the period 1993 to 1995, the annual PV power module production (i.e., excluding modules for low power and consumer applications) increased from 47.6 MWp to 56 MWp. The PV power installed in the reporting countries during 1993 was 24 MWp compared to 32.1 MWp during 1995. This implies that in 1993, 51% of the modules produced were installed within the reporting countries and the remainder exported. In 1995, 57% of the modules produced were installed within the IEA.

- PV module production is moving towards the vertical integration of manufacturing facilities, and the continuing development of thin-film technologies is likely to become increasingly important. The continuing demand for PV power has led to announcements from manufacturing industry claiming that a further 55 MWp of annual production capacity will be created.

- The national demonstration programmes have been described for each of the reporting IEA countries, and these largely reflect the different priorities in each country. There is however an increasing emphasis on on-grid systems, particularly on the integration of PV into commercial and residential buildings. On-grid systems are often partially funded by electricity utilities, indicating a positive attitude on their part towards these systems.

- Module prices represent a significant part of the price of PV power systems and as such are of interest to utility and energy service companies. The range of factory prices for PV power modules in the reporting IEA countries is given in Table 5.2. The average prices have been weighted according to the module production volume in each country. The high price of some c-Si modules was due to non-standard products for building integration. It is difficult to make comparisons between prices or to draw firm conclusions as to the trends because systems are often demonstration programmes funded under different conditions. It is also complicated by the fact that amorphous silicon modules are usually of lower power than crystalline silicon, so that although the price per watt peak is lower, the balance of system costs are often higher due to increased wiring costs and the need for more support structures.

Table 5.2: Module prices for small and large orders of crystalline and amorphous silicon power modules.

	Module Price USD/Wp			
	c-Si		a-Si	
	Large	Small	Large	Small
Range	4.4 - 11.8	4.4 - 11.8	4.3 - 6.1	3.0 - 5.1
Weighted Average	5.5	4.9	4.9	4.1

- Data on turnkey system prices were also provided in the national reports for different system types. The system prices in the off-grid, 100 to 500 Wp sector ranged from 14 to 41 USD/Wp, compared to 10.5 to 28 USD/Wp for larger (1-4 kWp) off-grid systems. For the on-grid 1-4 kWp systems, the range was 7.3 to 20 USD/Wp, compared to 7.5 to 30 USD/Wp for systems between 10 and 50 kWp and 7 to 11.8 USD/Wp for systems larger than 50 kWp. The large range of prices was due to the fact that some of the systems were demonstration systems, and some countries did not include installation costs in their estimations. The particularly low price of grid-connected systems in the 1 to 4 kWp range in Germany was due to a programme which pooled potential customers together to enable them to bulk buy systems.

- At the end of 1995, the utility perceptions of PV systems, both on- and off-grid, were reported to be generally favourable, although some utilities were concerned about the effect of large numbers of small embedded generators on the electricity distribution systems. A number of countries have research programmes either in place, or planned, to investigate this. Utilities were also becoming increasingly involved in demonstration systems, providing part or full funding for them.

- The public perceptions of PV systems were reported as generally positive. In a number of countries customers were reported to be willing to pay a premium for PV generated electricity. In some countries public concern was expressed as to the high price of PV systems and as a result they were seen as more relevant to remote applications. The implementation of demonstration programmes was seen to have increased the public awareness of PV.

- Environmental regulations, studies relating to externalises and hidden costs of conventional energy generation and the reduction of taxes on PV systems (where these are available) were not seen as being strong enough to substantially influence the PV market in most countries.

- Projections were made based on a business as usual scenario for PV module production and installed power in the reporting countries. It was estimated that by the year 2000, PV module production would be in the region of 140 MWp peryear based on a business as usual scenario, and 180 MWpper year on an accelerated scenario. By the year 2000 it was estimated that over 550 MWp of PV power would be installed based on the average historic growth rate of 24% per year since 1993. It was estimated that 350 MWp and 200 MWp for off-grid and on-grid systems respectively would be installed by the year 2000.

- The increasing involvement of electricity utilities in PV is seen as a positive development and PV is seen as offering new business opportunities to both utilities and energy service companies. The increasing support for rate based incentives in some of the reporting countries should ensure the continuing installation of grid connected systems on residential and commercial buildings.

- 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

COUNTRY	ISO COUNTRY CODE	CURRENCY and ISO Code	EXCHANGE RATE (= 1 USD)	COMMENTS
Australia	AUS	Dollar (AUD)	1.33	
Austria	AUT	Schilling (ATS)	10.20	1995 rate
Canada	CAN	Dollar (CAD)	1.37	1995 rate
Denmark	DNK	Krone (DKK)	5.91	
European Union		European Currency Unit (XEU)	0.8	
Finland	FIN	Markka (FIM)	4.76	
France	FRA	French Franc (FRF)	5.0	1995 rate
Germany	DEU	Deutchmark (DEM)	1.6	June 1994
Italy	ITA	Lira (ITL)	1590	1995 rate
Japan	JPN	Yen (JPY)	100	
Korea	KOR	Won (KRW)	780	1995 rate
Netherlands	NLD	Guilder (NLG)	1.65	1995 rate
Portugal	PRT	Escudo (PTE)	150	1996 rate
Spain	ESP	Peseta (ESP)	134	1994 rate
Sweden	SWE	Krona (SEK)	6.75	June 1996
Switzerland	CHE	Swiss Franc (CHF)	1.27	June 1996
United Kingdom	GBR	Sterling (GBP)	0.67	
United States	USA	Dollar (USD)	1.0	