PART ONE: SOLARBASICS

The Solar Potential

There is more than enough solar radiation available around the world to satisfy a vastly increased demand for solar power systems. The total amount of energy irradiated from the sun to the earth's surface is enough to provide for annual global energy consumption 10,000 times over. Energy from the sun's light alone is enough to produce an average 1,700 kWh of power annually on each square metre of land.

The statistical information base for the solar energy resource is equally solid. The US National Solar Radiation database, for example, has logged 30 years of solar radiation and supplementary meteorological data from 237 sites.

The greater the available solar resource at a given location the larger the quantity of electricity generated. Tropical regions offer a better resource than more temperate latitudes. The average irradiation in Europe is about 1,000 kWh per square metre, for example, compared with 1,800 kWh in the Middle East.

Figure 1.1 shows the estimated potential energy output from solar PV generators in different parts of the world. The calculation used here takes into account the average efficiency of modules and converters and assumes that the panels are installed at the optimal angle to the sun required at different latitudes.

The most recent study of the potential for PV in the OECD (industrialised) countries is "Solar Electricity in 2010", published in 2001 by the European Photovoltaic Industry Association. This shows that grid-connected PV rooftop systems, the most dynamic growth area in the market, have the potential to generate an average of 16% of final electricity consumption across the OECD. This is more than the 1996 contribution from hydro power (see Figure 1.3).

What is Photovoltaic Energy?

The word "photovoltaic" is a marriage of two words – "photo", meaning light, and "voltaic", meaning electricity. So photovoltaic technology, the scientific term used to describe solar energy, involves the generation of electricity from light.

The secret to this process is the use of a semi-conductor material which can be adapted to release electrons, the negatively charged particles which form the basis of electricity. The most common semi-conductor material used in photovoltaic (PV) cells is silicon, an element found in, amongst other things, sand.

All PV cells have at least two layers of such semi-conductors, one positively charged and one negatively charged. When light shines on the semi-conductor, the electric field across the junction between these two layers causes electricity to flow, generating DC current. The greater the intensity of the light, the greater the flow of electricity. A photovoltaic system does not therefore need bright sunlight in order to operate. It can even generate electricity on cloudy days. Depending on the density of the clouds a PV system still generates 20-50% of its maximum electricity output. Due to the reflection of sunlight, days with only a few clouds can even result in a higher energy yield than days with a completely blue sky.

Figure 1.1: Global variations in irradiation

Source: Gregor Czisch, ISET, Kassel, Germany

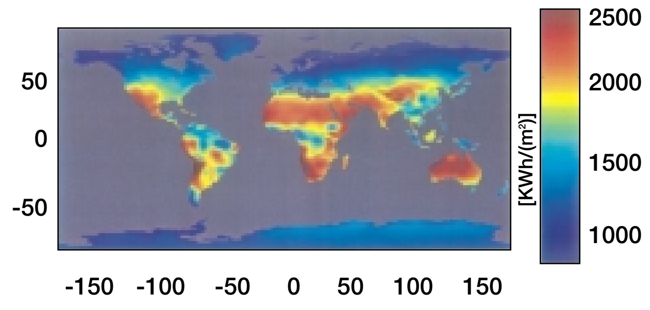


Figure 1.2: Energy potential from PV around the world

Source: Gregor Czisch, ISET, Kassel, Germany

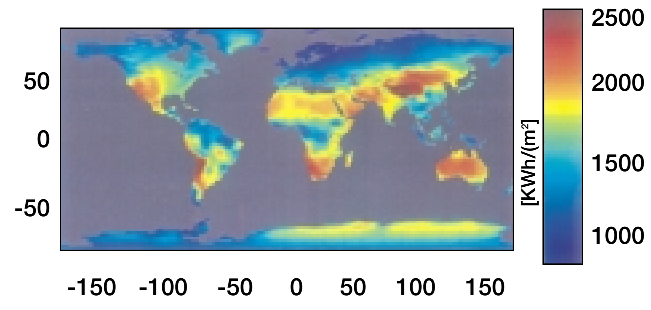


Figure 1.3: Potential PV Contribution to OECD Electricity in 2010

Source: "Solar Electricity in 2010", EPIA, 2001

- Final Electricity Consumption
- Hydro Power Production (1996)
- PV Rooftop Energy Potential

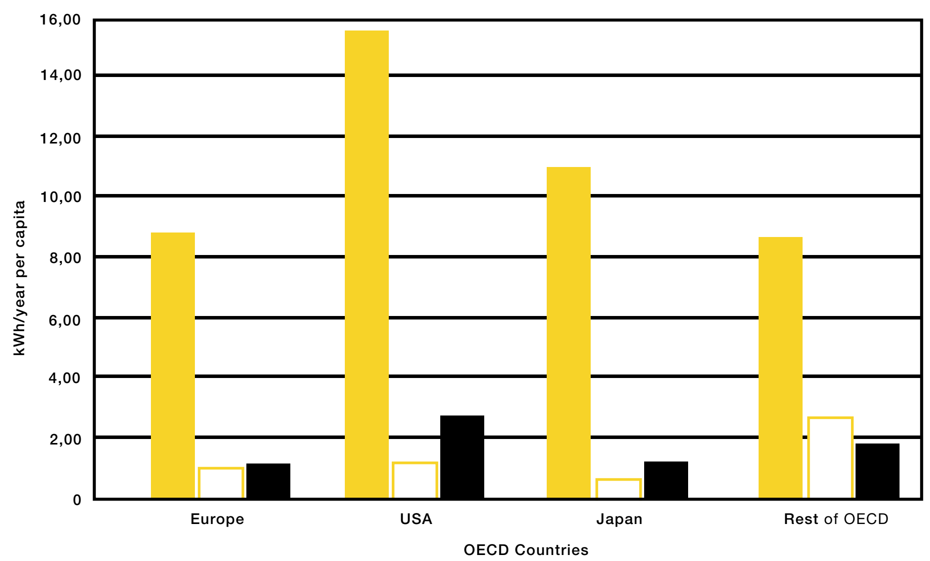


Table 1.1: Module and cell efficiencies

Source: International Energy Agency (IEA) Photovoltaic Systems Programme, 2000

Type	Typical module efficiency (%)	Max. recorded module efficiency (%)	Max. recorded laboratory cell efficiency (%)
Single crystalline cell	12-15	22.7	24.7
Multicrystalline silicon	11-14	15.3	19.8
Amorphous silicon	5-7	-	12.7
Cadmium telluride	-	10.5	16.0
CIS	-	12.1	18.2

Solar PV is quite different from a solar thermal system, where the sun's rays are used to generate heat, usually for hot water in a house, swimming pool etc.

PV Technology

The most important parts of a PV system are the **cells** which form the basic building blocks, the **modules** which bring together large numbers of cells into a unit, and, in some situations, the **inverters** used to convert the electricity generated into a form suitable for everyday use.

PV Cells and Modules

PV cells are generally made either from thick **crystalline silicon**, sliced from ingots or castings or from grown ribbons, or **thin film**, deposited in thin layers on a low cost backing. The majority of module production (84%) has so far involved the former, while future plans centre on the latter. Thin film technology is expected to dramatically increase its share the market for solar panels on buildings because of its advantages in terms of weight, durability and attractive appearance.

Crystalline silicon

Crystalline silicon is still the mainstay of most power modules. Although not the ideal material for solar cells, it has the benefit of being widely available, well understood and uses the same technology developed for the electronics industry. Efficiencies of more than 20% have been obtained with silicon cells in the laboratory, but production cells are currently averaging 13-14% efficiency. The theoretical limit for crystalline modules approaches 30%.

Thin films

Thin film modules are constructed by depositing extremely thin layers of photosensitive materials on a low cost backing such as glass, stainless steel or plastic. Three types of thin film cell are likely to be of increasing commercial importance over the next few years. These are the amorphous silicon cell, most probably in a double junction structure, the copper indium diselenide/cadmium sulphide hetero-junction cell and the cadmium telluride/cadmium sulphide hetero-junction cell. All of these have active layers in the thickness range 1-10 microns, and all are manufactured by processes which are capable of large volume, low cost production.

Other cell types

Concentrator cells focus light from a large area onto a small area of photovoltaic material using an optical concentrator (such as a Fresnel lens), thus minimising the quantity of PV cells required. The two main drawbacks with concentrator systems are that they cannot make use of diffuse sunlight and must always be directed towards the sun with a tracking system.

Spherical solar technology uses minute silicon beads bonded to an aluminium foil matrix. This offers a big cost advantage because of the reduced need for silicon. The technology is still a long way from commercial production, however.

The **organic dye solar cell** invented in 1991 by the Swiss physicist, Michael Grätzel, still has low efficiencies and shows a poor long term stability. In theory, however, it is easier to manufacture than other solar cells.

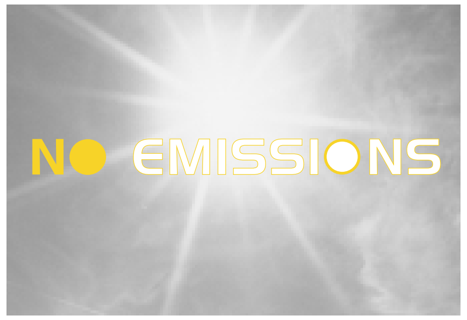
These examples demonstrate that there is considerable momentum within solar cell R&D in order to meet the range of applications demanded by a growing PV market.

Modules

Modules are clusters of PV cells incorporated into a unit, usually by soldering them together under a sheet of glass. They can be adapted in size to the proposed site, and quickly installed. They are also strong, reliable and weatherproof. Module producers usually give a performance warrantee of 20 years on 80% of the rated module power.

THE ADVANTAGES OF SOLAR POWER

- The fuel is free
- No moving parts to wear out or break down
- Minimal maintenance required to keep the system running
- Modular systems can be quickly installed anywhere
- Produces no noise, harmful emissions or polluting gases



When a PV installation is described as having a capacity of 3 MWp(eak), this refers to the maximum output of the system under standardised operating conditions, allowing comparison between the expected production from different systems. In northern Europe a 1.2 kWp rated solar array, covering about 10 square metres, would produce enough power for roughly one third to a half of a typical household's electricity requirements.

Inverters

Inverters are used to convert the direct current (DC) power generated by a PV array into alternating current (AC) which is compatible with the local electricity distribution network. This is essential for grid-connected PV systems. The inverter also often includes elements to protect the system against instability in the grid connection.

Components for Stand-alone PV Systems

Most stand-alone (off-grid) PV systems contain a battery, commonly of the lead acid type, in order to store the energy for future use. This is usually connected to the PV array via a charge controller. The charge controller protects the battery from over charge or discharge, and can also provide information about the state of the system or enable metering and pre-payment for the electricity used. If AC output is needed, an inverter is required to convert the DC power from the array.

Types of PV System

Grid Connected

This is the most popular type of solar PV system for homes and businesses in the developed world. Connection to the local electricity network allows any excess power produced to be sold to the utility. Electricity is then imported from the network outside daylight hours. An inverter is used to convert the DC power produced by the system to AC power for running normal electrical equipment.

Grid Support

This type of system can be connected to the local electricity network as well as a back-up battery. Any excess solar electricity produced after the battery has been charged is then sold to the network. It is ideal for use in areas of unreliable power supply.

Off-Grid

Completely independent of the grid, the system is directly connected to a battery, which stores the electricity generated and acts as the main power supply. An inverter can be used to provide AC power, enabling the use of normal appliances without grid-connected power.

Hybrid System

This is a solar system that can be combined with another source of power – a biomass generator, a wind turbine or diesel generator – to ensure a consistent supply of electricity. A hybrid system can be grid connected, stand alone or grid support.

The Benefits of Solar Power

Photovoltaic power systems offer many unique benefits above and beyond simple energy delivery. This is why comparisons with conventional electricity generation – and more particularly comparison with the unit energy costs of conventional energy generation – are not always valid. If the amenity value of the energy service that PV provides, or other non-energy benefits, could be appropriately costed, it is clear that the overall economics of PV generation would be dramatically improved in numerous applications, even in some grid-connection situations.

• Space-saving installation

PV is a simple, low risk technology which can be installed virtually anywhere there is available light. This means there is a huge potential for the use of roofs or facades on public, private and industrial buildings. PV modules can be used as part of a building's envelope, providing protection from wind and rain or serving to shade the interior. During their operation such systems can also help reduce buildings' heating loads or assist in ventilation through convection. Other places where PV can be installed include the sound barriers along communication links such as motorways. To satisfy a significant part of the electricity needs of the industrialised world there is therefore no need to exploit otherwise undisturbed areas. In the UK, for example, it has been estimated that the country's total electricity demand could be satisfied by solar arrays using only 3% of the land area.

CLIMATE CHANGE AND FUEL CHOICES

Carbon dioxide is responsible for about 50% of the man-made greenhouse effect, making it the most important contributor to climate change. It is produced mainly by the burning of fossil fuels. Coal, oil and natural gas all produce carbon dioxide and other polluting gases. Nuclear power produces very little CO_2, but has other major pollution problems associated with its operation and waste products.

The consequences of climate change already apparent today include:

The proportion of CO_2 in the atmosphere has risen by 30% since industrialisation began.

- The number of natural disasters has trebled since the 1960s. The resulting economic damage has increased by a factor of 8.5.
- The seven warmest years over the last 130 were recorded during the past 11 years.
- The mass of glaciers has been halved since industrialisation began.
- Rainfall in temperate and northern latitudes has increased by 5% since 1950. Average wind speed has also increased significantly.
- Sea level has risen by 10-20 centimetres in the last 100 years, 9-12 cm of this in the last 50 years.

Because of the time lapse between emissions and their effects, the full consequences of developing climate change have still to emerge over the coming decades, bringing increased danger to the stability of the world's economy and lifestyle.

To effectively stem the greenhouse effect, emissions of CO_2 must therefore be greatly reduced. Scientists believe that only a quarter of the energy reserves which can be developed commercially today ought to be allowed to be burned if ecosystems are not to go beyond the point at which they are able to adapt.

Improving the electricity network

For power companies and their customers, PV has the advantage of providing relatively quick and modular deployment. This can offset investment in major new plant and help to strengthen the electricity network, particularly at the end of the distribution line. Since power is generated close to the point of use, such distributed generators reduce transmission losses, can improve service reliability for customers and help limit maximum demand.

• Protecting the environment

Solar power involves none of the polluting emissions or environmental safety concerns associated with conventional generation technologies. There is no pollution in the form of exhaust fumes or noise during operation. Decommissioning a system is unproblematic.

Most importantly, in terms of the wider environment, there are no emissions of carbon dioxide – the main gas responsible for global climate change *(see box "Climate Change and Fuel Choices")* – during the operation of a PV system. Although indirect emissions of CO_2 occur at other stages of the manufacture, these are significantly lower than the avoided emissions.

Solar power can therefore make a substantial contribution towards international commitments to reduce the steady increase in the level of greenhouse gases and their contribution to climate change *(see box "The Climate Change Imperative").*

Enabling economic development

PV offers important social benefits in terms of job creation, energy independence and rural development. Significantly, much of the employment creation is at the installation point (installers and service engineers), giving a boost to local economies.

Solar power can be easily installed in remote and rural areas, places which may not be targeted for grid connection for many years. This can help reduce urban migration through the provision of essential services. Installation of transmission and distribution lines are avoided and remote communities can reduce reliance on energy imports.

Energy payback

A popular belief still persists that PV systems cannot 'pay back' their energy investment within the expected lifetime of a typical system – about 20-25 years. This is because the energy used, especially during the production of solar cells, is seen to far outweigh the electricity eventually generated.

Data from recent studies demonstrate, however, that present-day systems already have an energy payback time – the time taken for power generation to compensate for the energy used in production – well below their expected lifetime (three to seven years for crystalline silicon modules, depending on the solar irradiation, the cell material and the frame) For thin film modules the energy payback time is already below two years for areas such as Mediterranean countries. With increased efficiency in the production of cells it is feasible that the energy payback time for grid-connected PV will decrease to two years or less for crystaline silicon modules and to one year or less for frameless thin film modules.

One way in which efficiency will be increased is through the production of solar-grade silicon specifically designed for the PV market, as opposed to the high quality silicon from the electronics industry currently employed.

THE CLIMATE CHANGE IMPERATIVE

The growing threat of global climate change resulting from the build-up of greenhouse gases in the earth's atmosphere has forced national and international bodies into action. Starting from the Rio Earth Summit in 1992 a series of targets have been set both for reducing greenhouse gas emissions and increasing the take-up of renewable energy, including solar power.

- The 1997 **Kyoto Protocol**, brokered by the United Nations, committed the world's developed countries to reduce their emissions of greenhouse gases by an average of 5% from their 1990 level. Despite continuing negotiations over the details of Kyoto, many nations have taken up this challenge.
- The **European Union** has set a target to double the proportion of energy in the 12 member states provided from renewable sources. The aim is for 12%renewable energy by 2010. This includes a specific target to achieve 3 Gigawatt peak of PV capacity.
- **The EU** also has a target for 1 million solar roofs as part of its renewable energy "Campaign for Take-Off". Other countries around the world have similar targets for large numbers of grid-integrated PV systems *(see Part Three: The Solar Race).*