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ABBREVIATIONS

A	Ampere
AC	Alternating Current
ATS	Austrian Schilling
°C	Degree Celsius
CO_2	Carbon Dioxide
DC	Direct Current
EEG	Erneuerbare Energien Gesetz
ELWOG	Elektrizitäts- und Wirtschaftsgesetz
EUR	Euro
FY	Fiscal Year
IEA	International Energy Agency
JPY	Japanese Yen
m^2	Square meter
METI	Ministry of Economy, Trade and Industry
mm	Millimeter
MW	Megawatt
PV	Photovoltaic
PVPS	Photovoltaic Power Systems
STC	Standard Test Conditions
USA	United States of America
V	Volt
Vs.	versus
VAT	Value Added Tax
W	Watt

1 INTRODUCTION

Modern day lifestyle has turned energy into a necessity. Hydrocarbons derived from petroleum, natural gas or coal are essential for modern living. Nevertheless, the dominance of hydrocarbons as main fuels has raised concerns. The finite nature of oil, gas and coal has society worrying about the future energy security. The question of how to cope with the increasing global demand for hydrocarbons as developing countries, such as China and India, are growing and becoming wealthier arises. An increasing world population, the enhanced level of development and higher standards of living will impact the future energy requirements. Another concern of the use of hydrocarbons constitutes a vital issue for environmentalists: greenhouse gas emissions and the impacts of their increased production and release into the atmosphere. Greenhouse gas emissions, which are created through the combustion of fossil fuels, are harmful to the environment and to people´s health. In view of the large energy requirements, an awareness of the consequences for the ecosystem and for the quality of life of future generations has now developed. Efforts to spread this awareness and to find ways of dealing with these issues are being made by the media, governments and other institutions. In order not to neglect the impacts of greenhouse gas emissions, the major challenge is finding ways to balance the needs of the society and the damage done to the environment. Energy alternatives to fossil fuels have gained attention as a potential means to achieve a better balance between the two. One of these alternatives, renewable energy, is increasingly receiving attention and is subject to many discussions lately.

Renewable energy is perceived as an option to non-renewable hydrocarbons. As its name says, renewable energy is derived from sources, which are able to replenish, renew themselves. These sources include heat and light from the Sun, wind, organic matter, hydroenergy or geothermal heat, which constitutes the internal heat of the Earth. With the appropriate technology, the energy provided by nature is captured and converted into usable energy. Renewable energy technologies can be divided into three categories, reaching back over a hundred years (IEA 2006: 29):

- First-generation technologies emerged in the industrial revolution at the end of the 19th century and include hydropower, biomass combustion and geothermal power and heat.

- Second-generation technologies include solar heating and cooling, wind power, modern forms of bioenergy and solar photovoltaics. These are now being disseminated as a result of research and development carried through since the 1980s.
- Third-generation technologies are generally at the development stage and include concentrating solar power, ocean energy, enhanced geothermal systems and integrated bioenergy systems.

Solar energy is indirectly responsible for the creation of other renewable energy sources, such as wind and biomass, but the light and heat energy from the Sun can also be directly used. The Sun supplies its energy in the form of radiation. Solar radiation is the most abundant energy source on Earth. Theoretically, only 0.01% of the solar energy would suffice to meet the current global energy demand (DGS 2006: 7). Among the two second-generation technologies, which directly use the thermal or light energy from the Sun, the latter technology represents the one facing the most difficulties. Photovoltaic (PV) systems are able to convert sunlight into electricity. Capturing and converting solar energy seems to be a promising technology and a potentially attractive substitute to conventional electricity. Therefore, the share of PV electricity is rapidly growing worldwide. The majority of the PV systems installed in Europe today are connected to the electricity network. In spite of its growth in recent years, the PV technology is not yet widely deployed. Its share of total electricity production and of the electricity produced from renewables is rather modest.

The situation of PV energy is not very different in Austria than the global scheme. The PV contribution to electricity production is minimal. The reasons for the limited success can be derived from its technical performance relative to the costs of the application. Investing in such a system involves large upfront capital, leading to high unit costs of PV energy. In order to be cost-efficient, the unit cost of producing this type of electricity should be able to compete with the unit cost of conventional energy. As this is generally not the case, this technology and its further dissemination depend on market support mechanisms, such as investment subsidies. These measures have positive effects on the technology and will result in cost reductions over time with increasing deployment. Apart from other factors, such as the the prices of conventional electricity, the costs of generating PV electricity largely determine the profitability of the investment project. The Austrian government has provided subsidies in the past in order to create incentives for the installation of residential grid-connected PV applications. These measures and the development of the global market had certain implications on the Austrian PV market and on the cost-efficiency of domestic PV applications. Therefore, the following questions arise: how has the profitability of grid-connected residential PV energy evolved with time? What have been the main factors leading to this development? Section two of this work introduces the PV technology; a presentation of the leading markets and the Austrian PV market including the support mechanisms in these countries is followed by a study of the development of the costs of photovoltaics; the last section (section five) constitutes the final analysis of the profitability development of residential grid-tied PV electricity in Austria.

The required data for writing this work is based on literature research, analysis of statistical data and e-mail enquiry. The used publications include books, scientific magazines and articles retrieved from Austrian libraries, the Internet or which were handed out to the author personally. Scientific databases, such as ScienceDirect and EconLit, the database of the Austrian National Library and the webpages of the International Energy Agency were used to search for publications on the Internet.

2 THE PV TECHNOLOGY

2.1 Brief History

The physical phenomenon of directly converting sunlight to electricity – called the PV effect was discovered by Alexandre Edmond Becquerel in 1839. An electrochemical experiment with metal plates and diluted acid demonstrated the enhanced production of energy by exposing the combination of the two to sunlight. This discovery represented the origin of the development of solar cells and constituted the beginning of a series of findings about this technology (Schmid 1992: 6).

The PV effect remained to be a laboratory curiosity from 1839 until the 1950s. An accidental discovery by scientists at Bell Laboratories in 1953 revolutionized the solar cell technology. Gerald Pearson, Calvin Fuller and Daryl Chapin had devised a way to control the introduction of impurities needed to transform silicon from a poor to a superior conductor of electricity. After a year of trial-and-error research and development, Bell Laboratories showed the public the first silicon PV cells capable of producing useful amounts of power for electric equipment. Commercial success, however, failed to materialize due to the solar cells´ prohibitive costs.

For the following twenty years the development of photovoltaics was dominated by the United States. The main driving force was providing power for space vehicles. In 1955, the U.S. Government announced its intention to launch a satellite. Since power lines could not be strung out to space, satellites needed a reliable, long-lasting autonomous power source. In 1958, the first satellite equipped with 108 solar cells – Vanguard I – was sent out to space. In the years to follow, the demand for solar cells had rapidly increased, which led to a small industrial production. The consequence was not only improvements in the electrical parameters of the cells, but also a drop in prices. This, in turn, led to a modest use of solar cells in terrestrial applications; albeit space remained the major PV market for over a decade. In the 1960s and early 1970s, the development of solar cells for space was rapid, yet their high price still kept them distant from Earth.

In late 1969, Elliot Berman joined the Exxon laboratory and concentrated on lowering the cost of cells by using lower grade - and therefore cheaper - silicon and less expensive materials for packaging the modules. By decreasing the price from USD 200 to USD 20 per watt (W), solar cells were able to compete with the power equipment needed to generate electricity distant from utility lines.

The breakthrough of photovoltaics can be traced to the oil shock of 1973/74. This historical event had many industrialized nations search for alternatives to scarce and expensive mineral oil. It was the starting point for governments to initiate various solar energy support programs. Newly emerging development institutions in the United States, Europe, and Asia were not only working on the development of solar cells, but also on the systems and system components. These private and public efforts were the main technology drivers. As the price of solar cells has continued to decline, devices run by solar cells have seeped into the suburban and urban landscapes of the developed world. The cost of PV energy was still very high; in order to become more competitive, it had to be reduced by a factor of 1,000. Since then, the price for grid-connected systems has been reduced by a factor 100 (Cleveland 2004: 616, 617, 620; Goetzberger and Hoffmann 2005: 2, 5).

2.2 The Solar Resource

The Sun is approximately 150 million kilometers away from the Earth (Cleveland 2004**:** 669, 670). The intensity of solar radiation outside the atmosphere depends on the distance between the Sun and the Earth. For this reason it varies between 1,325 and 1,412 watt per square meter (W/m^2). The mean value, the so-called solar constant, amounts to 1,367 W/m^2. However, not all of this solar radiation reaches the Earth´s surface. The atmosphere reduces solar radiation through reflection, absorption (by ozone, steam, oxygen or carbon dioxide) and through scattering (by molecules, dust particles or pollution) (DGS 2006: 7). The intensity of solar radiation reaching the surface of the Earth is typically between 900 and 1,000 W/m^2 on a clear sunny day at noon. The total radiation reaching the Earth, also known as the global radiation, is made up of direct and diffuse components (Cleveland 2004**:** 669, 670).

The light striking a PV array does not only come from the direction of the Sun, but from other directions as well. The total solar radiation constitutes the total amount of radiation incident on the array. The beam radiation (also referred to as direct radiation) is the radiation coming from the direction of the Sun; it represents sunlight that has not been scattered by particles in the atmosphere. Diffuse radiation constitutes the opposite: it comprises scattered radiation from all directions except the direction of the Sun. Beam and diffuse radiation from the sky can be reflected onto the PV array by the ground. Ground-reflected radiation constitutes the sunlight that has “bounced off“ the ground (Ross and Royer 1999: 20, 21).

Whether direct or diffuse radiation, the amount of sunlight falling on a given PV array varies greatly from one point in time to another. One can differentiate two main sources of variation:

- Celestial movement: the movement of the Earth with respect to the Sun gives rise to the seasons and the cycle of day and night;
- Atmospheric conditions: Gases and particles in the atmosphere scatter and absorb sunlight.

The insolation on an array does not only vary with time, it varies also with place: it depends on the geographical position, particularly on latitude and on the climate. The difference in radiative energy between the most arid desert regions and central Europe is of a factor of around 2.5. The same solar cell would generate 2.0 to 2.5 times more electricity, at a correspondingly lower cost than in Europe, if it were mounted in a desert area close to the equator (Goetzberger and Hoffmann 2005: 6).

These factors lead to three different annual irradiation levels (Markvart and Castañer 2003: 876):

- High irradiation: approximately 2,200 kWh/m^2, as found in the Sahara or in south-western USA;
- Medium irradiation: around 1,700 kWh/m^2 as found in southern Europe and large parts of the USA;
- Low irradiation: approximately 1,100 kWh/m^2, as found in central Europe. Austria´s average annual irradiation lies between 1,000 and 1,100 kWh/m^2. Nevertheless, it can reach up to 1,400 kWh/m^2 in alpine regions (Wilk 1994: 85).

The amount of sunlight falling on a PV array does not only depend on the strength of the sunlight, but also on the orientation of the array, especially in relation to the position of the

Sun. The location of the Sun is described by its elevation and azimuth at any given place.

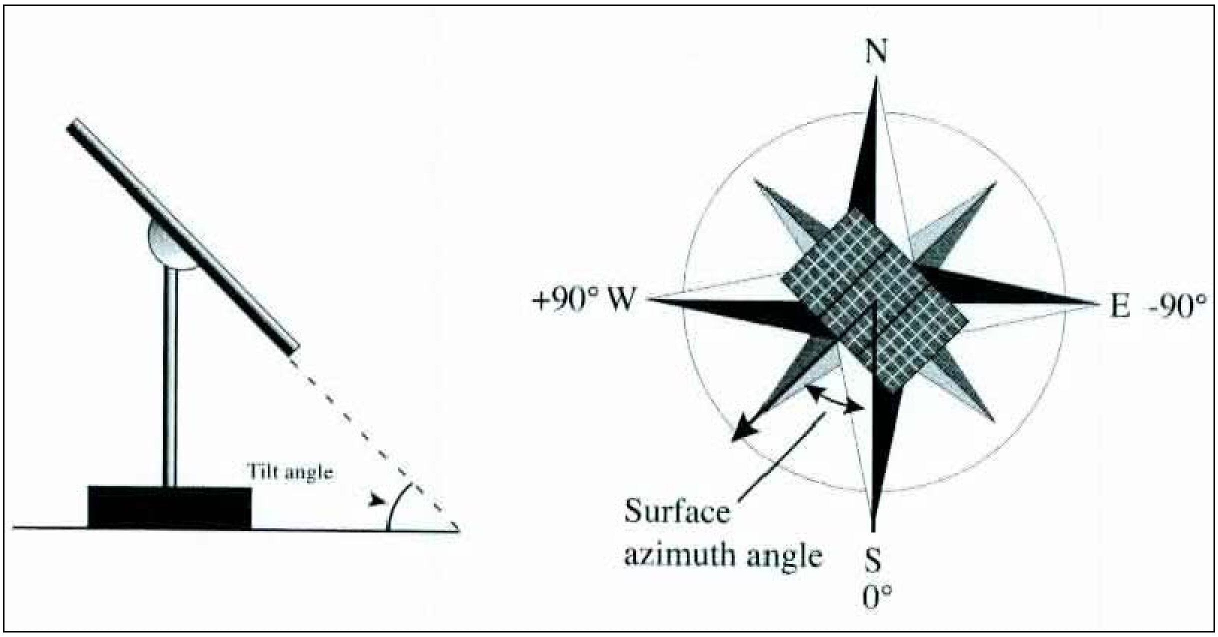

Figure 2.1: Tilt angle and surface azimuth angle

Source: Ross and Royer 1999: 20

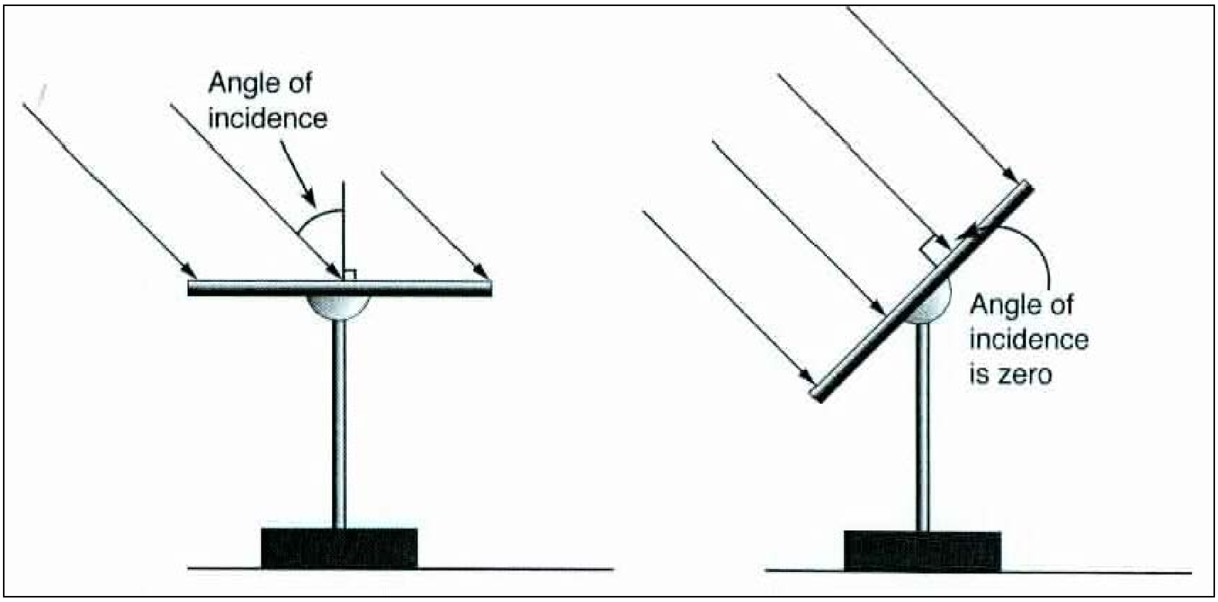

Figure 2.2: Angle of incidence

Source: Ross and Royer 1999: 20

The orientation of the array is described by two angles:

- The tilt angle constitutes the angle formed by the array and the horizontal

- The surface azimuth angle specifies where the array faces, with due south being 0°, due west +90°, and due east -90°.
- Light rays strike the array from different directions as the Sun moves across the sky. This phenomenon is measured by the angle of incidence, which represents the angle formed between the light ray and a line normal to the array. When the Sun´s rays strike the surface of the array squarely, the angle of incidence is 0°; when they fall in a parallel manner onto the surface of the array, the angle of 90° is formed. The angle of incidence should be kept as near to 0° as possible in order to maximize the solar energy collected by an array.

2.3 PV Systems

2.3.1 Components

2.3.1.1 PV Module & Array

The internal electrical field of a single cell is relatively weak. To achieve higher voltages, solar cells are connected in series to form a PV module. These series of cells are very fragile; for this reason, the module has to be constructed in such a way as to protect the cells from the elements of the environment. Solar cells are usually embedded in a soft plastic and glass sandwich creating a weatherproof solar module (Ross and Royer 1999: 15; Krauter 2006: 27).

Most commercial crystalline modules consist of 30 to 36 cells. The number and size of the cells will determine the maximum power produced by the module at a set voltage (Ross and Royer 1999: 15). The module efficiency value is calculated as the output power divided by the total radiation incident on the module. It is generally lower than the efficiency value of a single cell because the entire area of the module is not covered with solar cells (Goetzberger and Hoffmann 2005: 89). Module efficiencies vary from a few percent for thin-film modules to approximately 16 or 17% for monocrystalline silicon solar cells (Cleveland 2004: 43).

As with PV cells, a number of modules can be connected together in series to form a PV array in order to obtain an even higher voltage or current. Due to their modularity, PV systems are able to provide a wide power range, starting from a fraction of a watt (for calculators or watches) to several megawatt (MW) (for centralized power stations). An array consists of a number of electrically connected PV modules, associated cabling and interconnection components, a support structure and, when needed, special devices to protect the array against lightning, reverse flow of current and other electrical hazards. The PV array can be ground-mounted either on a pole or on a frame. It can also be directly installed on buildings using special roof- or wall-mounting structures. PV modules can be integrated into the building´s envelope and act as an environmental barrier while producing electricity at the same time (Ross and Royer 1999:15, 16). Facade-integrated modules have a significantly lower energy yield due to the non-optimal tilt angle: in northern Europe, for instance, the energy yield is reduced by approximately 30-40% (Cleveland 2004: 42).

2.3.1.2 Batteries

Energy storage is a key element in solar energy supply. Under certain conditions, such as darkness at night or during overcast periods, the PV module does not produce power. As electrical output has to be available on demand, PV systems require storage devices. Grid-connected applications feed their excess energy into the local electricity grid. For PV systems which are not connected to the local electricity network, rechargeable batteries constitute the most common energy storage devices (Ross and Royer 1999:16). They are connected between the array and the load and store the produced energy until it is needed. Lead acid batteries are most cost-effective (Cleveland 2004: 44). The importance of the cost-efficiency of these devices may be stressed through the fact that thirty percent of the lifetime costs of solar off-grid systems can be attributed to storage (Bubenzer and Luther 2003: 84).

2.3.1.3 Power-Conditioning Equipment

The electrical output of an array is modified or regulated in such a way as to ensure that it meets the requirements of the rest of the system. The devices which are responsible for doing that are called power-conditioning devices:

- Battery charge regulators: their primary function is to cut off charging current from the array when the battery reaches a certain voltage threshold, indicating that it is fully charged. Other functions of a regulator may include disconnecting the load from the battery when the latter is fully discharged and periodic battery “equalization“, in which a high voltage charge ensures that all cells in the battery are uniformly charged.

- Inverters: these are required in systems which supply power to alternating current (AC) loads. They are used to convert the direct current (DC) output of the array and/or a storage battery to standard AC electricity.
- Power-point conditioners: these are devices, which are able to change the output voltage and current of the PV array to match the requirements of the load (Ross and Royer 1999: 16, 17).

2.3.2 System Types

A PV application consists of the complete set of equipment used to convert sunlight into a useful form of electricity. This includes the array, the conditioning equipment, the cabling, the protective devices and – if needed – the storage system and an auxiliary power supply (Ross and Royer 1999: 17).

PV systems can be divided into grid-connected (also known as grid-tied) and stand-alone (also referred to as autonomous or off-grid) systems:

2.3.2.1 Stand-alone Application

The first commercial applications for terrestrial PV systems were non-domestic stand-alone installations. Stand-alone systems operate independently from the electric utility grid. They provide power for a wide range of applications, such as telecommunication or water pumping. For these type of applications, small amounts of electricity have a high value, making photovoltaics cost-competitive with other small generating sources.

Domestic off-grid systems provide electricity to households and villages which are not connected to the utility electricity network. The produced power can be used for lighting, refrigeration and other low-power loads. These applications have been installed worldwide and represent a cost-effective, economic alternative to extending the electricity distribution network (Ross and Royer 1999: 18; IEA-PVPS 2006: 3).

Besides the general classification as domestic and non-domestic systems, stand-alone PV applications can be subdivided according to whether they have battery storage and auxiliary power supplies:

- Stand-alone with storage: the array powers the load and charges a battery during the day. The battery powers the load when little or no sunlight is available. The main components of these systems are (DGS 2006: 5):

    - Photovoltaic generator (one or several PV modules in parallel arrangement)
    - Charge controller
    - Battery
    - Loads.

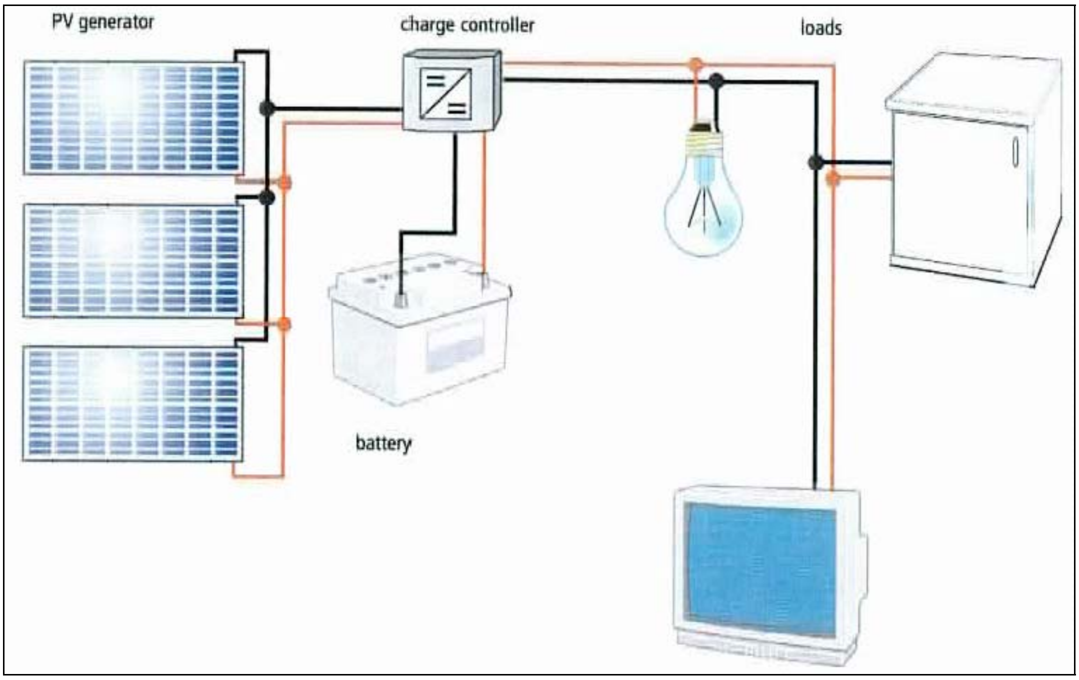

Figure2.3: Components of a PV stand-alone system

Source: DGS 2006: 5

- Stand-alone without storage: this system powers a load which does not require an electric storage system. These systems can be used when their energy production is sufficient in subdued lighting (e.g. calculators), when the operating time of the load is not critical or when it can be matched to available sunlight (e.g., ventilation fans), or when storage is already integrated (e.g. water pumping, where a water tank or reservoir provides storage).
- Stand-alone photovoltaic-hybrid systems: an auxiliary power source augments the energy production of the array. It delivers additional energy during the periods when the average load is larger than the average output of the PV array. A battery usually buffers short-term variations in the available sunlight. A generator powered by a diesel, gas or gasoline engine constitutes the most common auxiliary power source for these type of applications. It powers the load and recharges the battery when the energy in the latter has been used up. The generator, therefore, complements the variable input of the PV system (Ross and Royer 1999: 17, 18).

2.3.2.2 Grid-Tied Application

A PV array can be connected to the electric utility grid through an inverter; the electricity generated by the array is then used by grid-connected loads. It is indistinguishable from the electricity generated by other sources (Ross and Royer 1999: 18). Grid-tied PV systems do not require storage devices, such as batteries. When the output of the PV application is greater than the on-site load demand, the surplus electricity is fed into the electricity network. The PV energy contribution to the grid can be divided in two categories:

- Centralized system: typically constitutes a ground-mounted single large installation – a centralized power station – supplying bulk power which is not associated with any particular electricity customer.
- Distributed system: Various smaller PV systems provide electricity to specific customers instead of supplying bulk power. The arrays are integrated into the premises of the customer, mounted on public or commercial buildings or they may be added to external installations like highway soundbarriers, etc. (Ross and Royer 1999: 18; IEA PVPS 2006: 3).

A grid-connected PV system generally consists of the following main components (DGS 2006: 5):

1. Photovoltaic array (generator)
2. DC switch disconnector
3. DC cabling (optional)
4. inverter
5. AC cabling, AC switch disconnector and energy meter.

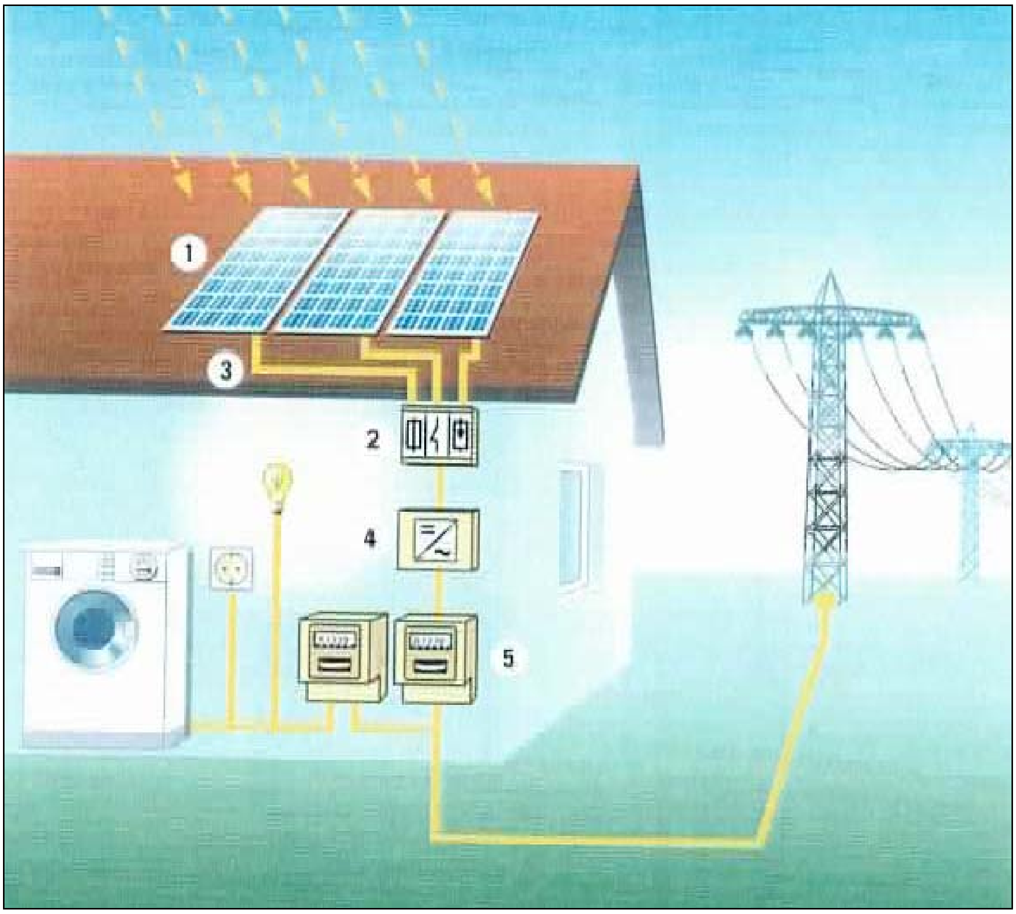

Figure 2.4: Components of a grid-connected PV sytem

Source: DGS 2006: 6

2.4 Characteristics of a Solar Cell

2.4.1 Structure & Function

A conventional crystalline solar cell is composed of two differently doped[1] silicon layers. The layer facing the sunlight is negatively doped with phosphorus; the layer below is positively doped with boron. An electric field is produced at the boundary layer, which leads to the separation of charges (electrons and holes) set free by sunlight. In order to generate electricity from the solar cell, metal contacts have to be attached to its front and rear sides. Irradiance implies charge carrier separation and current current if a load is connected (DGS 2006: 20):

1. Charge separation
2. Recombination
3. Unused photon energy (e.g. transmission)
4. Reflection and shading by front contacts

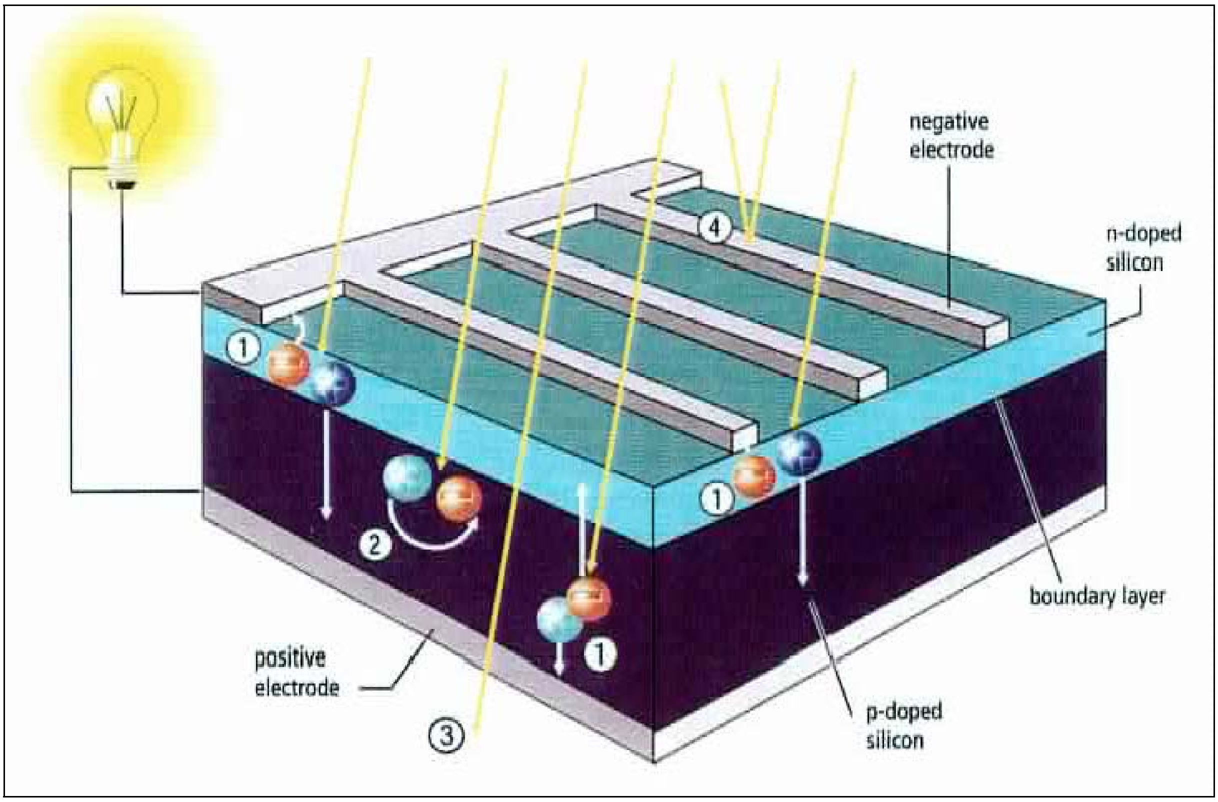

Figure 2.5: Structure and function of a crystalline solar cell

Source: DGS 2006: 20

[1] Doping constitutes adding impurities to a semiconductor in order to change its electrical properties.

The PV conversion efficiency is defined by the ratio of the electrical power output to the irradiated power on a solar cell (Krauter 2006: 24). In practice, this efficiency has not been able to reach its theoretical limit. Physical and technological loss mechanisms restrict the conversion efficiency of today´s crystalline silicon solar cells. As light enters the cell, there are reflection, shadowing and sometimes absorption losses. Recombination losses are due to electrons not reaching the electrical contacts, because the energy of the recombining electron-hole pair is absorbed. Electrical resistance losses in the cell, as well as in its contacts and in the external circuitry can lead to loss in power delivered to an external load. A part of the unused energy is absorbed and transformed into heat. Moreover, a great energy proportion of long- and short-wave radiation cannot be used. Most solar cells rely on a thin layer of antireflection coating to reduce the reflection of light from the front surface of the cell (Bubenzer and Luther 2003: 46; Markvart and Castañer 2003: 78, 107; Cleveland 2004: 49; DGS 2006: 20). Table 2.1 provides an overview of the causes and the extent of loss mechanisms in a PV cell:

100%	**Irradiated Solar Energy**
3%	Loss due to reflection and shading by front contacts
23%	Loss due to insufficient photon energy of long-wave radiation
32%	Loss due to surplus of photon energy of short-wave radiation
8.5%	Loss due to recombination losses
20%	Loss due to electrical gradient in a cell
0.5%	Loss due to serial resistance (electricity heat loss)
13%	***Remaining usable electric energy***

Table 2.1: Loss mechanisms in a PV cell

Source: DGS 2006: 20

2.4.2 PV Cell Performance

The power delivered by a solar cell represents the product of current I and voltage V. When all the possible combinations of voltage and current are graphed for a certain light level, the result constitutes the I-V curve. The latter illustrates the characteristic relationship between current and voltage. The voltage that occurs when the current is zero is known as the open-circuit voltage $V_{OC.}$ It is the highest voltage attainable in a solar cell for a given level of light and temperature. On the other hand, if a cell is short-circuited, the voltage will be zero and the maximum current attainable at this level of light and temperature is called the short-circuit current $I_{SC.}$

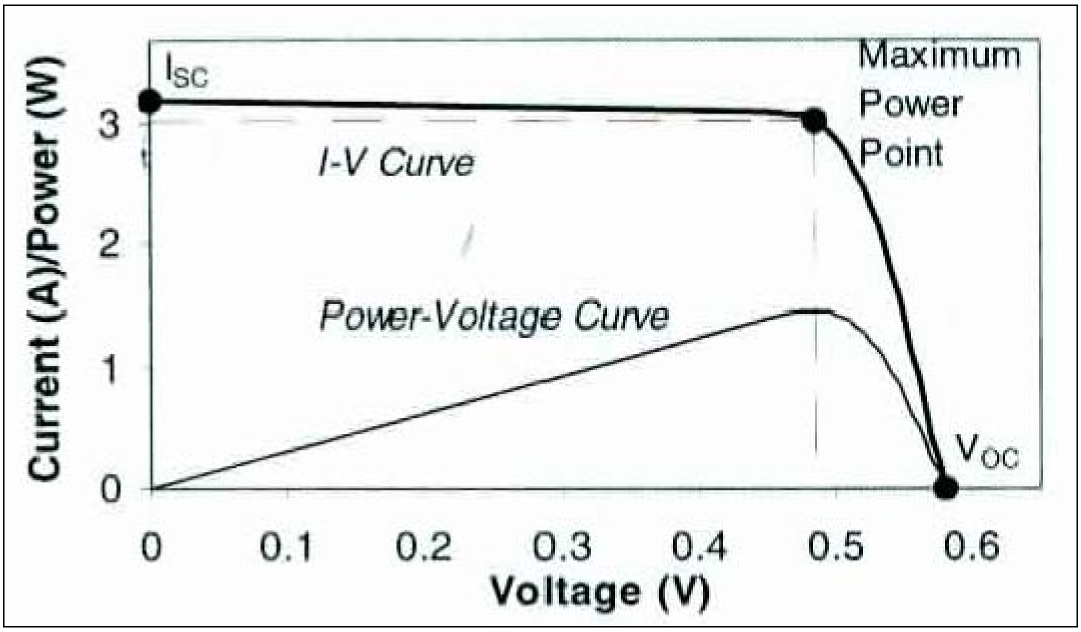

Figure 2.6: Important points on the I-V curve

Source: Ross and Royer 1999: 14

While current and voltage are at a maximum under short-circuit and open-circuit conditions respectively, the power at these points on the I-V curve is zero (Ross and Royer 1999: 13, 14). In between, there is one particular combination of current and voltage for which the power reaches a maximum, the so-called maximum power point (Goetzberger and Hoffmann 2005: 88). In Figure 2.6 the maximum power point occurs at about 3.0 A (ampere) and 0.5 V (volt), generating about 1.5 W.

The I-V curve can be affected by the following factors:

- Light intensity: At lower levels of light the shape of the I-V curve remains almost equal, yet the curve shifts downwards. Therefore, the short-circuit current is proportional to the light level and the the open-circuit voltage only changes slightly.

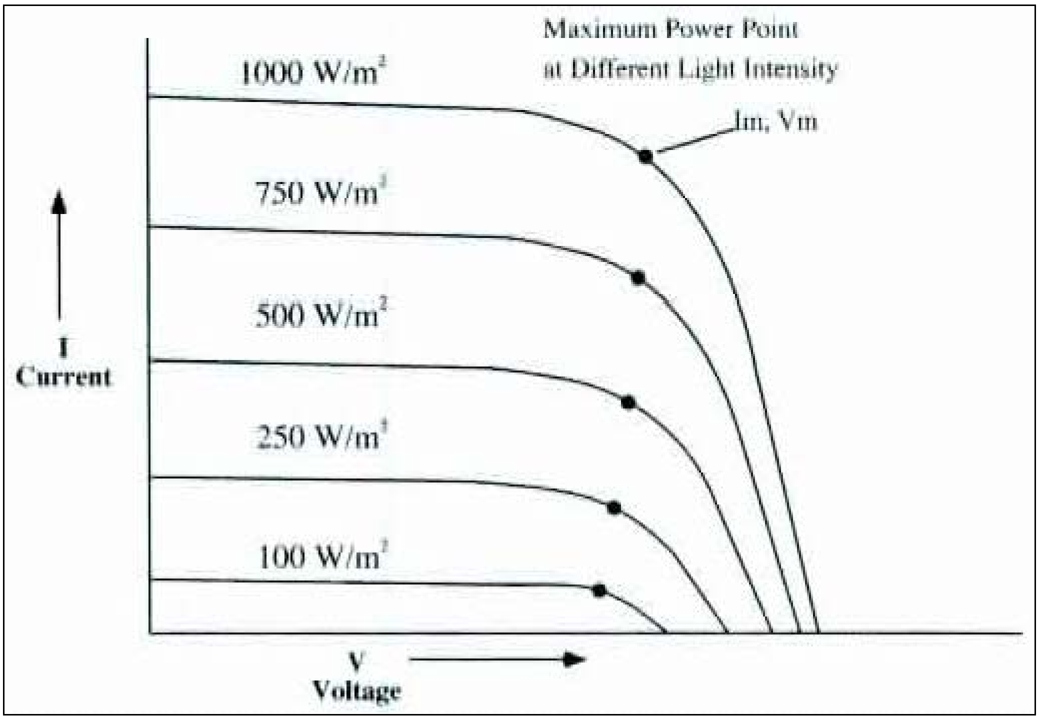

Figure 2.7: The effect of light intensity on the I-V curve

Source: Ross and Royer 1999: 14

- Size of the cell: larger cells are able to capture more sunlight and therefore generate more power. The short-circuit current is proportional to the size of the cell while the open-circuit voltage of the cell is not affected.
- Cell technology: Cells made of different materials or produced in distinct processes differ in their I-V curves. The cell material determines the open-circuit voltage: for crystalline silicon cells, for example, this will be around 0.6 V. The material also affects the cell efficiency. Different materials will be more or less efficient in converting light to electricity.
- Temperature: Lower cell temperatures improve its efficiency and raise the open- circuit voltage. The open-circuit voltage of a silicon cell, for example, will decrease by 2.2 millivolt for every °C (degree Celsius) rise in temperature.

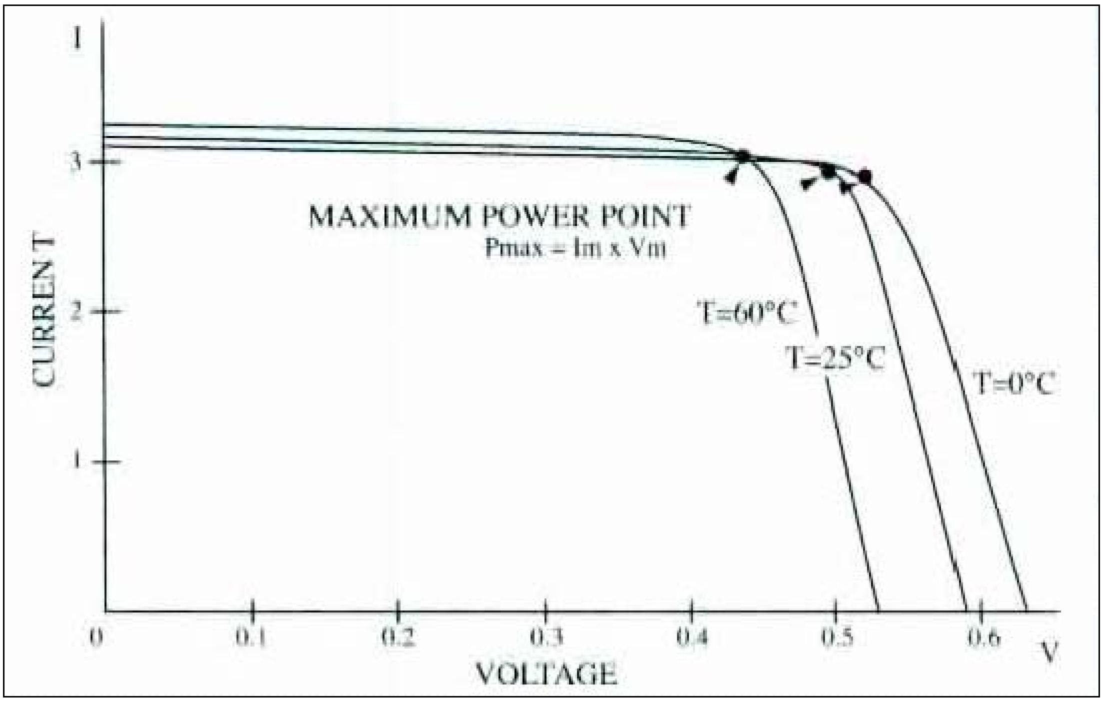

Figure 2.8: Influence of temperature energy production in a cell; the maximum power output rises by 10% when the temperature drops from 25°C to 0°C

Source: Ross and Royer 1999: 14

Because the I-V curve of a PV cell is affected by many factors, a set of standard test conditions (STC) has been defined by international convention to evaluate its performance. At STC, the cell is illuminated by 1,000 W/m^2 of sunlight and has a temperature of 25°C. PV devices are rated in terms of their peak watt output (measured in W_p, which is their maximum power output at STC). Since the cell in Figure 2.6 is at STC, its peak watt output is 1.5 W_p (Ross and Royer 1999: 14, 15).

2.4.3 PV Cell Types

2.4.3.1 Crystalline Silicon Cells

The most important material for crystalline solar cells is silicon. Next to oxygen, it is the second most abundant element on Earth. It is not a pure chemical element but chemically bound in the form of silicon dioxide (DGS 2006: 21). For this reason it has to be reduced to elemental silicon (Bubenzer and Luther 2003: 59). Silicon solar cell research has largely profited from the research carried out for the silicon-based electronics industry. Until 2000, most of the feedstock for the solar cell industry originated from the silicon rejected by the electronics industry. As a result, silicon has dominated the solar cell industry since 1954 (Cleveland 2004: 549) and still continues to do so today. In a survey carried out by the International Energy Agency (IEA), the share of crystalline silicon in the IEA Photovoltaic Power Systems Program (PVPS)[2] reporting countries was 94% in 2005 (IEA PVPS 2006: 16, 19). Crystalline Silicon solar cells have matured, technical improvements and manufacturing scale have contributed to market growth (Cleveland 2004: 556). Today, this technology constitutes a low-risk investment with high demands for return on investments (Jäger-Waldau 2004: 667). Nevertheless, the rising market share of PV led to a scarcity of silicon and has been increasing the price of this raw material in recent years. Generally, the cost of silicon is already high due to its properties as indirect semiconductor. Silicon is not an ideal material for photovoltaic conversion because of its low absorption of solar radiation. Therefore, a thick layer of silicon - approximately 0,1 millimeter (mm) - is required for efficient absorption (Goetzberger and Hoffmann 2005: 3, 57). There are two types of established crystalline solar cells which will be outlined in the following.

2.4.3.1.1 Monocrystalline Silicon Cells

Melted and cooled crude silicon is needed to form a single crystal. The material should be highly purified, yet the process of purification is costly. A wafer, i.e., a slice of silicon, is then cut from the crystal. The wafer is turned into a cell through various processes, such as the creation of the p-n connection and the application of an antireflection layer (BP Solar 2007). Monocrystalline silicon cells are the most efficient among the range of silicon cells. Laboratory cells of this type have reached an efficiency of up to 24.7%. Production cells typically attain efficiencies of 12 to 15%. Nevertheless, elevated temperatures during operation usually lead to reduced output power (Cleveland 2004: 549).

2.4.3.1.2 Polycrystalline Silicon Cells

In the production process of polycrystalline silicon cells, liquid silicon is poured into blocks that are subsequently sawed into plates. During the solidification of the material, crystal structures of varying sizes are formed and defects emerge at its borders. This crystal defect causes the the solar cell to be less efficient. Laboratory cells have reached an efficiency of

[2] Participating countries in the PVPS Program are: Australia, Austria, Canada, Denmark, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States of America.

approximately 18%. Production cells generally attain efficiencies of 13 to 15% (Solarserver 2007). The production of polycrystalline silicon is more cost-efficient than manufacturing monocrystalline silicon. Therefore, more than 50% of the current solar cell production is based on multicrystalline silicon wafers as raw material (Fraunhofer ISE 2006: 48).

2.4.3.2 Thin-Film Cells

The structure of crystalline silicon cells is different from the structure of thin-film cells. Photoactive semiconductors in thin layers are applied on a substrate, such as glass or plastic. Because these materials are highly light absorbant, a layer of less than 0.001 mm is theoretically sufficient for converting sunlight (DGS 2006: 31). Theoretically, they have the potential for cost advantages over traditional wafer-based crystalline silicon because of lower material use, fewer processing steps and simpler device processing and manufacturing technology for large-area modules and arrays (Hamakawa 2004: 15). Nevertheless, thin-film technologies have only played a minor role in PV power generation so far. Actually, potential price advantages for thin-film solar cells, such as reaching lower costs at lower production volumes, are limited due to the improvements in the silicon wafer production technology, such as the reduction of wafer thickness or the economy of scale triggered by a rapid growth of wafer silicon production capacities. Additionally, all thin-film technologies share the common problem of high initial investment costs. This may constitute a considerable entry barrier for new manufacturers (Jäger-Waldau 2004: 669). Amorphous, Copper indium diselenide and cadmium telluride solar cells constitute emerging thin-film technologies.

2.4.3.2.1 Amorphous Silicon Cells

Amorphous silicon does not have a regular crystal structure; it forms an irregular network. The amorphous silicon coating is deposited on a substrate material, such as glass, plastic or metal. Although the production costs are lower due to the low material costs, the disadvantage of amorphous silicon is the low efficiency, which further diminishes within the first six to twelve months of operation (DGS 2006: 32, 33). This is due to light-induced degradation: the efficiency drops when the cell is exposed to light. Stabilized cell efficiencies in the laboratory reach 13% (Goetzberger and Hoffmann 2005: 60). The low performance is the reason for which solar cells from amorphous silicon are mainly used on low-power devices for indoor applications, such as calculators and watches (Bubenzer and Luther 2003: 55).

2.4.3.2.2 Copper Indium Diselenide Cells

Copper indium diselenide (CIS) constitutes the active semiconductor material for these type of solar cells. The CIS compound is also often alloyed with gallium and/or sulphur (CIGS). Unlike amorphous silicon, CIS cells are not susceptible to light-induced degradation. Although they encounter stability problems in hot and humid environments (DGS 2006:34), this should not represent a problem in cold climate countries like Austria. The first commercially available CIGS modules had an efficiency of approximately 10%. Small-area laboratory devices reached cell efficiencies around 18% (Bubenzer and Luther 2003: 57). Such laboratory efficiencies have been difficult to transfer to reliable mass production of large high-efficiency modules. Presently, these PV cells are only produced on a small-scale (Cleveland 2004: 553).

2.4.3.2.3 Cadmium Telluride Cells

Apart from amorphous silicon, cadmium telluride-based thin-film solar cells are closest to commercial readiness. A number of relatively simple, low-cost methods have been applied to manufacture solar cells with efficiencies in the range of 10-16% (Hamakawa 2004: 24). In 2002, these cells represented 0.7% of global cell production and were mostly used for indoor consumer products. However, the toxicity of cadmium and limited global supply of tellurium constitute important challenges for further market growth (Cleveland 2004**:** 553).

2.4.3.3 New Solar Cell Technologies

2.4.3.3.1 Gallium Arsenide

Gallium arsenide is an element from the Groups III and V of the Periodic Table and represents the second most important semiconductor material after crystalline silicon (Bubenzer and Luther 2003: 60). It constitutes an ideal material for solar cell applications due to its high absorption coefficient and its high carrier mobilities. Efficiencies in the range of 25-32% have been achieved for single- and multijunction devices made from gallium arsenide (Hamakawa 2004: 33). Nevertheless, these type of solar cells are expensive. Gallium and indium are not abundant elements, implying high costs and a limited ability to supply a large fraction of the global energy needs in terrestrial applications (Cleveland 2004: 553, 554).

2.4.3.3.2 Dye-sensitized Nanocrystalline Cells

A new kind of solar cell was introduced by the Swiss professor Michael Grätzel in 1991. The semiconductor titanium dioxide represents the basis for the so-called "Grätzel cell". It does not rely on a p-n junction in the semiconductor, but it absorbs light through an organic dye similar to the way plants use chlorophyll to capture energy from sunlight by photosynthesis. The efficiency and the long-term stability of such cells still have to be considerably improved (Bubenzer and Luther 2003: 64). Small laboratory cells have reached an efficiency of 12%. First batch production cells produced by an Australian firm have attained efficiencies of approximately 5%. The advantage of this type of cell is the non-toxic nature of the materials used which are inexpensive to produce. The dye-sensitized titanium dioxide solar cell does offer cost advantages over conventional solid-state PV devices. However, remaining problems need to be solved before it can go into industrial mass production (DGS 2006:36).

2.4.3.3.3 Microcrystalline and Micromorphous Cells

Microcrystalline cells are formed by depositing a high-quality thin-film of gas containing silicon onto an inexpensive substrate (Fraunhofer ISE 2006: 46). This advanced technology has produced maximum stable efficiencies of 8.5%. Higher efficiencies can be achieved by combining microcrystalline and amorphous silicon in so-called tandem cells. The latter can be described as a multijunction approach where different semiconductor materials of different spectral ranges are stacked in order to increase the efficiency over single-junction devices (Hamakawa 2004: 38; Solarserver 2007). When combined, microcrystalline and amorphous silicon form a so-called micromorphous solar cell. This cell is able to use the solar spectrum in a better manner than each semiconductor material could do individually while experiencing less degradation at the same time. Maximum cell efficiencies of 12% have been measured under stable conditions (DGS 2006:36).

2.5 Measures of Efficiency

2.5.1 Technical Performance

The technical efficiency of a PV system has to be separately evaluated for stand-alone applications and grid-tied systems. As stand-alone systems can have different purposes, they may have different performances and designs, therefore, technical efficiencies can only be compared for similar systems. The following normalized performance indicators can be used to compare grid-connected PV systems:

- Final Yield: the final yield of a PV system is used to compare different PV systems at the same operating location. It represents the total output energy or energy yield (in kWh) divided by the nominal power (in kWh/kW_p) of the PV array.
- Performance Ratio: the performance ratio allows a comparison of PV systems at different operation locations. It constitutes the ratio of the actually used energy to the theoretically available total energy. The reference yield represents the indicator for the energy theoretically available from the array. Therefore the performance ratio can be stated as the final yield divided by the reference yield. It is specified in percent and describes the effectiveness of the PV system compared to a system that operates under nominal operation conditions without any losses (Goetzberger and Hoffmann 2005: 147-149).

2.5.2 Energy Payback Time

The overall energy performance of PV systems is determined by accounting all energy flows in the life-cycle of the application. The Energy Payback Time (EPBT) is defined as the ratio of total energy input during the system life-cycle to the annual energy generation during system operation. It indicates the minimum time that is needed to recover the energy input needed for the installation of the PV application. In sunny climates, present-day grid-connected systems have Energy Payback Times of approximately two to three years; in less favorable conditions it increases to around four to six years (Markvart and Castañer 2003: 876). The EPBT also varies with the semiconducting material used in PV cells or modules: Table 2.2 illustrates the differences in the EPBT of PV systems with cells and modules made of different semiconductors when the application is mounted in a low irradiation region like the United Kingdom:

PV System	Energy Payback Time (years)
Monocrystalline Silicon	5.55
Polycrystalline Silicon	5.55
Amorphous Silicon	3.88
CIS (modules only)	3.84

Table 2.2: Energy Payback Time of PV systems (including all components) in the United Kingdom

Source: DGS 2006: 20

Thin-film cells are able to achieve shorter payback periods than crystalline solar cells, but not considerably shorter. Their lower efficiency causes the energetic advantages of the thin-film technology to be partially cancelled out by the higher energy requirements for frames and supports. A PV system will only be energetically feasible if the EPBT is smaller than its entire lifetime which ranges from twenty to thirty years. As we know, the majority of PV cells in today´s systems are made of crystalline silicon. Therefore, an average of five years is required to recover the energy input of a grid-tied application, leaving a net production of energy for at least fifteen years (DGS 2006:348).

3 PV MARKETS & POLICIES

3.1 The Global Market

3.1.1 Demand

3.1.1.1 Global Installed Capacity

As the cost of PV systems had considerably dropped in the 1970s and 1980s, the technology was no longer restricted to space and could be increasingly used in terrestrial applications. Mostly stand-alone systems were initially installed for rural electrification in remote areas. Yet, the number of grid-connected PV systems has rapidly grown since the late 1990s. The cumulative PV power installed in the IEA PVPS reporting countries saw a large increase from 110 Megawatt in 1992 to 3.7 Gigawatt in 2005.

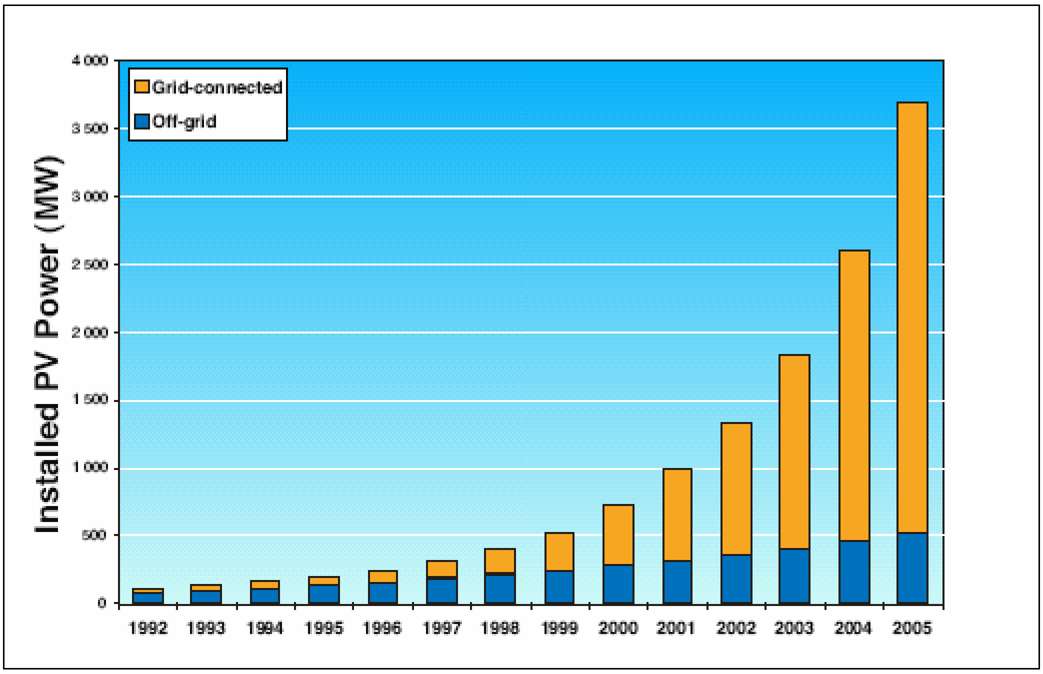

Figure 3.1: Cumulative installed grid-connected and off-grid PV power

Source: IEA PVPS 2006: 4

Figure 3.1 illustrates the cumulative growth of PV capacity since 1992. It shows the development of grid-connected and stand-alone applications and demonstrates the fast growth of grid-tied systems since the turn of the century. The annual growth rate of the cumulative installed capacity in the IEA PVPS countries from 2004 to 2005 alone was 42%. The total annual capacity of PV power installed at the end of 2005 was 1,093 MW. Out of these, merely 5% approximately represented off-grid applications. Today´s dominance of grid-tied systems can be largely attributed to market support mechanisms – dedicated to making them more attractive to consumers – in the leading PV markets. The countries encouraging the dissemination of photovoltaics are Germany, Japan and the USA. Although they do not represent the countries with the largest amounts of irradiation, 85% of the total capacity was installed in Germany and Japan alone (IEA PVPS 2006: 4-6).

3.1.1.2 Germany

3.1.1.2.1 Installed Capacities

The PV contribution to the entire power generated by renewable energy sources represented 2.8% in 2006 (IEA PVPS 2007: 60). After experiencing steady and continuous growth, Germany´s PV industry has been booming since 2004. In 2005, Germany reached the highest levels of cumulative and annual installed capacity for the first time. The cumulative PV power installed had increased from 6 MW in 1992 to 1,429 MW in 2005. The annual installed capacity grew from 5 MW in 1995 to 635 MW in 2005. The PV boom in Germany is reflected through annual growth rates of 137% and 75% in the years 2004 and 2005 (IEA PVPS 2006: 4-6). Nevertheless, market approximations for the year 2006 indicate a stagnation of the PV market.

3.1.1.2.2 Market Incentives

The acceleration of the demand for grid-connected PV applications since 2004 was a consequence of the German "Renewable Energy Sources Act" – "*Erneuerbare-Energien-Gesetz*" (EEG) which was amended in that same year. This new legal framework constituted the main market driving force, as it introduced guaranteed feed-in tariffs[3] which were above market price. The first EEG came into force in April 2000 and was amended in 2004. New grid-connected PV projects are granted fixed tariffs for twenty years which decrease each year at 5% (IEA PVPS 2007: 61; Lopez-Polo et al. 2006). The guaranteed rates for 2006 are listed in Table 3.1:

[3] This policy obliges utilities to purchase renewable energy at a minimum price.

Capacity (kW_p)	*Feed-in Tariff (EUR/kWh)*
Rooftop Systems	
<30 kW_p >30 kW_p > 100 kW_p	0,518 0,493 0,487
Facade Systems	
<30 kW_p >30 kW_p >100 kW_p	0,568 0,543 0,537
Ground-mounted Systems	
No limitation	0,406

Table 3.1: German feed-in tariffs in 2006

Source: Lopez-Polo et al. 2006

The applied feed-in tariff depends on the type of application (rooftop, facade or open space) as well as on the capacity: the subsidy falls with increasing power output. The feed-in tariff for rooftop systems smaller than 30 kW_p was 0.574 EUR/kWh in 2004. Due to the legal framework set by the EEG, the feed-in tariff was reduced to 0.545 EUR/kWh in 2005 and reached the above-mentioned 0.518 EUR/kWh in 2006.

The high demand for PV electricity in Germany can also be attributed to further incentive and dissemination programs: the "100,000 Rooftops Solar Electricity Program" and "Solar Power Generation – *Solarstrom Erzeugen*". The 100,000 Rooftop Program was initiated in 1999 and ended in 2003. It provided soft loans[4] (Lopez-Polo et al. 2006) for 65,700 grid-connected applications with a total granted capacity of 345.5 MW. In 2005, the 100,000 Rooftop Program was replaced by a different soft loan program – the Solar Power Generation Program – leading to an additional volume of 237.4 MW in its first year of adoption (IEA PVPS 2007: 61).

3.1.1.3 Japan

3.1.1.3.1 Installed Capacities

In 2005, Japan had been overtaken for the first time in terms of cumulative installed power

[4] Soft loans are ten-year credits granted by the federal development bank at 0% interest.

and presently constitutes the second largest PV market. The capacity increased from 19 MW in 1992 to 1,422 MW in 2005. Annual installations grew from 12 MW in 1995 to 290 MW in 2005, implying an annual average increase of 40%. The annual growth of 6% in 2005, which was considerably lower than in previous years, can be attributed to the end of the Japanese "Residential PV System Dissemination Program"(IEA PVPS 2006: 4-6).

3.1.1.3.2 Market Incentives

The Japanese government is very active in supporting its PV market; encouraging renewable energy is part of their National Energy Strategy. The Ministry of Economy, Trade and Industry (METI) has implemented various research and development initiatives, demonstration and dissemination programs for the further deployment of PV systems (IEA PVPS 2007: 68). The driving forces of the Japanese market have been the "Residential PV System Dissemination Program" and the "70,000 Rooftops Program".

The "Residential PV System Dissemination Program" supported investments in PV applications on the basis of their power output. It was the successor of the "Residential PV System Monitor Program" initiated in the fiscal year (FY) 1994. The latter program subsidized 50% of installation costs until FY 1997 (Hamakawa 2004: 15). Approximately 250,000 PV systems reaching a total capacity of 950 MW had been installed between 1994 and the end of the program in October 2005. These two initiatives significantly helped in developing and expanding the grid-connected residential PV market in Japan (IEA PVPS 2006: 9; IEA PVPS 2007: 70).

Another major initiative – the "70,000 Roofs Program" – was started by the government in 1994 and ended in 2003. Its main goal was to install 70,000 residential systems of 3-4 kW through subsidies of 50% on the installation costs. Although the capital subsidy had been gradually reduced to 10% towards the end of the program, a total of approximately 144,000 PV rooftop systems had been installed. The cumulative installed capacity increased from 1.86 MW in 1994 to 161.8 MW in 2003 (Fawer-Wasser 2003: 23).

Japan does not have a feed-in tariff like Germany; their metering system is called net-metering. The rate for the producer of PV energy is identical to the retail price of electricity. Japan´s net-metering system exists since 1992 and today the rate lies between 0.2 and 0.3 EUR/kWh (Talavera et al. 2006: 3101). In practice, the consumer has a standard electric meter, which can run forwards and backwards. The meter runs backward when PV power is fed into the grid. It registers the net excess generated electricity (IEA PVPS 2002: 19).

3.1.1.4 The United States

3.1.1.4.1 Installed Capacities

While photovoltaics have been growing rapidly worldwide, the United States has lost the leading position in the market it held in the 1980s and early1990s. Being the country with the largest installed capacity in 1992, it only came in third position in the year 2005. The cumulative PV power installed increased from 43.5 MW in 1992 to 479 MW in 2005. The annual installed capacity saw a continuous rise from 9 MW in 1995 to 103 MW in 2005, with an annual average increase of 29% (IEA PVPS 2006: 5).

3.1.1.4.2 Market Incentives

The implementation of specific incentive programs for grid-connected applications led to an increase in their installation. Grid-tied systems had overtaken off-grid systems in terms of cumulative installed capacity in 2005. Unlike Germany and Japan, the commercial market constitutes the driving force of PV deployment. In the United States, initiatives are generally implemented on a regional/state level rather than on a federal basis. As a consequence, the states which offered attractive programs to consumers managed to establish themselves as market leaders. The state of California has moved to the forefront of the renewable energy development. It represents the largest PV market with 73% of grid-tied applications in the USA in 2006 (SEIA 2007).

California´s recent deployment programs include the "California Solar Initiative" and the new "Million Solar Roofs" Program. The California Solar Initiative constitutes the largest state solar incentive program in the United States so far. This project, established by the Public Utilities Commission in 2005-2006, was implemented to increase the solar capacity installed on Californias rooftops by 3,000 MW until the year 2017. The initiative uses performance-based incentives for residential and commercial systems larger than 100 kW. Smaller systems are based on "expected performance-based buydowns", meaning each systems' estimated future performance. This type of funding represents a different approach: The main criteria is not the installed capacity, but the maximization of energy output. The focus has shifted from the system size to the design and the construction of the application (IEA PVPS 2007: 104).

The “Million Solar Roofs“ Program was initiated by the California Energy Commission in 2006 and will go on for ten years. It was created to complement the California Solar Initiative and to bring about lower system costs through decreasing the subsidy every year. This would turn photovoltaics into a cost-effective technology without governmental funding (IEA PVPS 2006: 11).

The United States uses the net metering system like Japan. California allows PV surplus energy to be sold at 0.31 USD/kWh during the summer peak hours and at about 0.9 USD/kWh during off-peak periods (Talavera et al. 2006: 3101).

3.1.2 Supply

3.1.2.1 PV Cell Production Development

The USA were leading the worldwide PV cell production industry at the beginning of the1980s, but had lost a large share of the market to Japan towards the end of the decade. Today, the market is dominated by Japanese firms and, within Europe, Germany has come up as a strong force. This can be seen in Figure 3.2, which illustrates the development of international cell production.

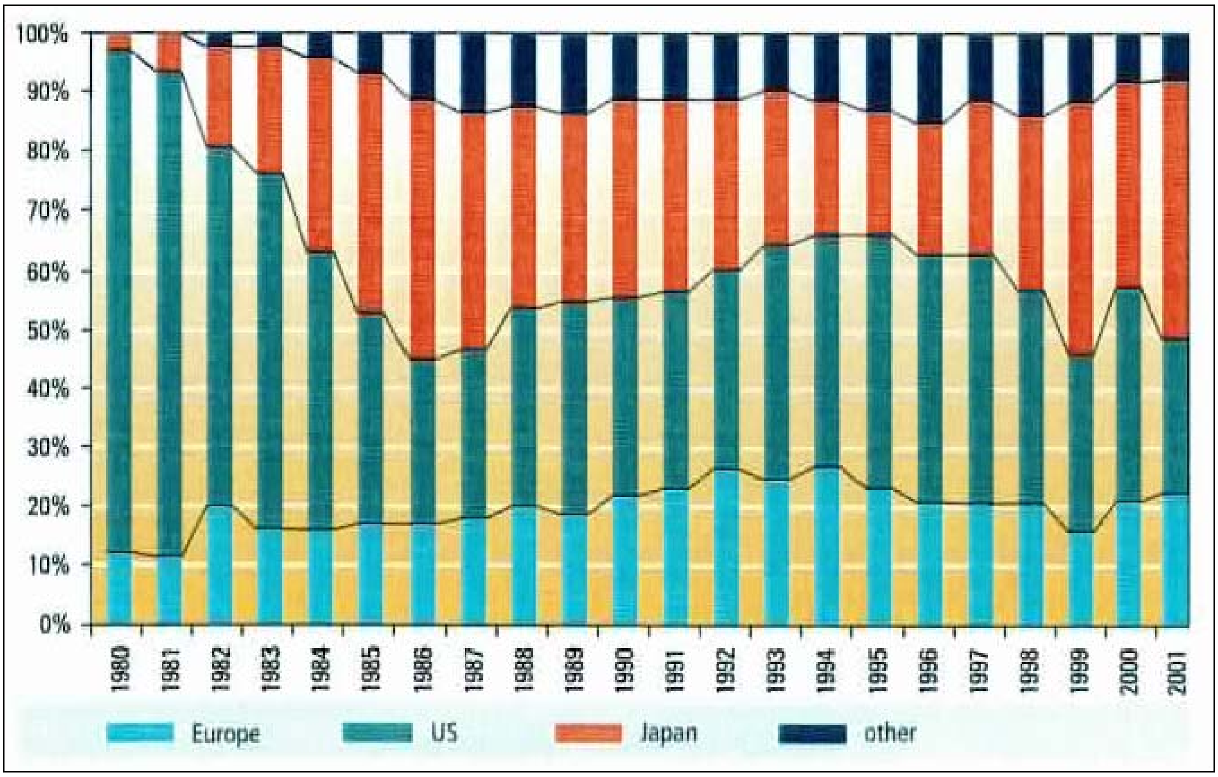

Figure 3.2: Regional solar cell production

Source: Räuber and Warmuth 2002 cited by: DGS 2006: 345

3.1.2.2 PV Cell Production Today

In 2005, the total PV cell production volume in the IEA PVPS countries was reported to be 1,500 MW; this corresponds to a 35% increase compared to 2004. Gobal cell production can be approximated to 1,730 MW when the production of the countries outside the PVPS reporting countries (the biggest producer of the latter being China with 150 MW) is added.
Japan was the leading producer of PV cells in 2005 with 55 % of the total production in the IEA PVPS countries. Germany was in second position with 23%. In the United States, the third largest producing country, the output of crystalline silicon cells declined in 2005 while the output from thin-film technologies had increased.

The ten largest PV manufacturers held 84% of the world market, whereas the rest was shared by over twenty different companies. Figure 3.3 depicts the shares of these large companies in PV cell production in the year 2005.

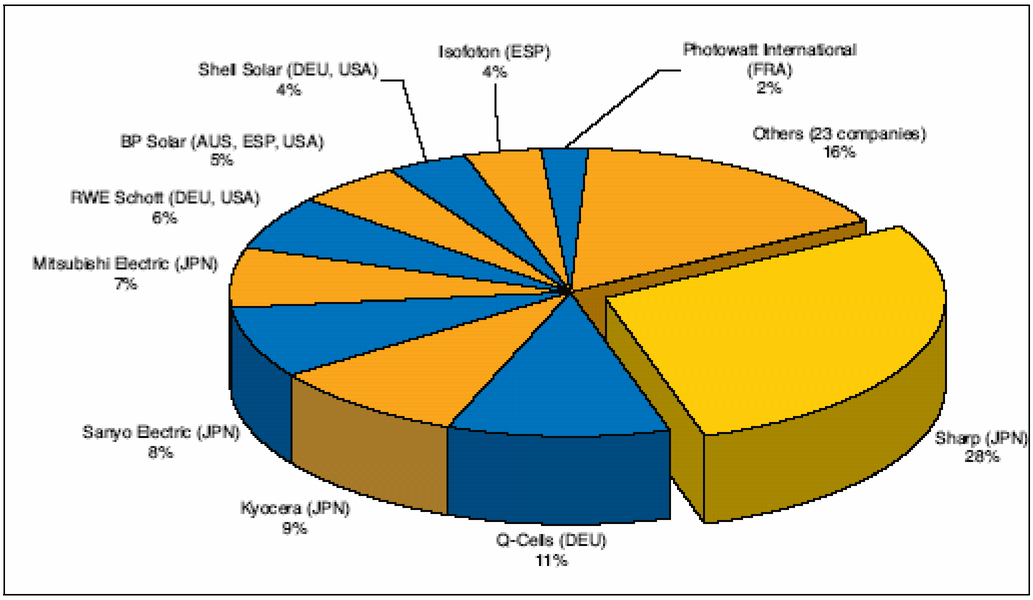

Figure 3.3: Share of PV cell production by company in 2005

Source: IEA PVPS 2006:17

The Japanese Sharp Corporation dominated the PV market with its share of 28%. The second largest company – Q-Cells from Germany – held 11% and was able to overtake Kyocera from Japan with its 9% market share. Sanyo Electric being in fourth position and ahead of Mitsubishi Electric constitutes a new development.

The rapid expansion of grid-connected PV systems in recent years increases the importance of the market for balance-of-system components[5]. In 2005, most of the balance-of-system components were produced for the residential PV market. The typical system capacity varied from 2 to 10 kW. In Europe, the large manufacturing companies were situated in Germany, Austria, Switzerland, Denmark and the Netherlands. The German company SMA Technology AG represented the market leader. Manufacturing activities outside of Europe took place in Japan, the United States, Canada and Korea. In these countries, the leading companies producing inverters for grid-connected applications were Sharp, Sanyo Denki and Xantrex (IEA PVPS 2006:15-17).

[5] Balance-of-system components include all the components of a PV system with the exception of the modules (i.e. the inverter, support frames, wiring, etc.).

3.2 The Austrian Market

3.2.1 Legal Framework

The Austrian electricity market saw many new developments in 1999: it was the year in which the market was liberalized and in which the Austrian Electricity Act – the "*Elektrizitätswirtschafts- und -organisationsgesetz (ElWOG)*" – came into force. The latter stated minimum feed-in tariffs for the electricity produced from renewable energy within each Austrian province in order to stimulate the renewables market. The Austrian *ElWOG* law was amended in the year 2000: it obliged distribution system operators to purchase a minimum share of electricity originating from renewable energy sources. A grid operator has to prove that its renewable electricity

- from 1st october 2001 represented at least 1%
- from 1st october 2003 represented at least 2%
- from 1st october 2005 represented at least 3%
- from 1st october 2007 represented at least 4%

of the total electricity supplied to consumers. The specifications of setting the minimum feed-in tariff for renewable energy – including PV electricity – to achieve these quotas was part of the authority of the *Landeshauptmann*[6] of each Austrian province (Haas 2002: 117, 120, 121, 124).

The first attempt to implement regulations on a national scale was the introduction of the "*Ökostromgesetz*" – the Green Electricity Act – in 2003, which was based on the EU directive from September 2001 in support of the dissemination of renewable energy (IEA 2004: 151). It had set the following target: By 2010, 10% of demanded public national electricity should be supplied by electricity generated from new renewable energy sources (excluding hydropower) (IEA PVPS 2007: 39). The new law which went into effect on january 1st 2003 applied the same feed-in tariff scheme to all grid-connected PV applications in Austria. These systems are

[6] The *Landeshauptmann* constitutes the highest ranking, the presiding member of a provincial government.

grouped in three control areas ("*Regelzonen*"). Within each control area, one company ("*Öko-Bilanzgruppenverantwortlicher*") is obliged to compensate the supplied PV energy at the rate defined within the new framework over a period of thirteen years. The feed-in tariff was set to 0.6 EUR/kWh for systems with an installed capacity larger than 20 kW_p and 0.47 EUR/kWh for smaller applications. The obligation to compensate PV electricity at these prices was set to a limit – a cap – of 15 MW (Faninger 2007: 13, 14, 34).

With the beginning of the Green Electricity Act, regional market incentives provided by federal states, communities or local utilities had ceased. Due to the limited availability of subsidized feed-in tariffs, the provinces of Upper Austria, Lower Austria and Vienna re-established regional market incentives to avoid a collapse of the local PV market (IEA PVPS 2006: 7). The cap of 15 MW for PV electricity within the national framework prevented the further development of the market needed to reach the desired 10% target for 2010. As a consequence, the "Green Electricity Act" was revised in October 2006. The new rules were applied to grid-tied applications which obtained all necessary permits for their installation after December the 31st 2004. The new guaranteed long-term feed-in tariffs for PV electricity in Austria are listed in Table 3.2:

System Capacity	**2007 (2006) Feed-inTariffs**
kW_p	EURCent/kWh
≤ 5	46 (49)
5-10	40 (42)
> 10	30 (32)

Table 3.2: Feed-in tariffs for PV electricity from the revised Green Electricity Act

Source: Faninger 2007: 34

The above-stated tariffs will be guaranteed to 100% for the first ten years, to 75% for the eleventh year, and to 50% in the twelfth year (Faninger 2007: p34). A decrement factor to reduce the size-specific maximum tariffs each year has been implemented. The reduction from 2006 to 2007 varied between 5 and 6.5% (IEA PVPS 2007: 39). Should the guaranteed tariff within the eleventh and twelfth year be smaller than the market price, the producer of the PV electricity has the right to be paid the market price. The market price for renewable energy constitutes the compensation for PV electricity from non-subsidized applications. In the third quarter of 2007, this market price was 0.05 EUR/kWh (E-Control 2007).

In comparison to the Austrian support model, the German policy framework for the dissemination of grid-connected PV systems can be qualified as more favorable to investors. Not only are the German feed-in tariffs higher than the ones offered in Austria, but the number of years in which guaranteed rates will be paid to the PV electricity producer is also larger in Germany than in Austria (twenty years vs. twelve years).

3.2.2 Installed Capacity

The development of Austria´s PV market started off with small stand-alone systems in the 1980s, mainly for domestic use in alpine regions without grid-connection or for emergency communication systems and parking meters in non-remote areas. The first grid-tied applications were installed in the late 1980s; the 30 kW system on the Loser summit in Upper Austria constitutes a well-known example: located in the alps, it could take advantage of clearer skies, snow reflection and improved cooling of the panels in winter which resulted in relatively high levels of irradiation (Bergauer-Culver and Jäger 1998: 324).

The government had been initiating support measures since the 1990s to promote the dissemination of small residential grid-connected systems, yet the market grew slowly and only started to pick up towards the end of the 20th century. Austria´s PV home market is still very small today. Only 0.25% of the electricity produced from renewable energy sources in 2006 originated from PV applications (Faninger 2007: 31).

Figure 3.4 illustrates the cumulative growth of PV capacity from grid-tied and stand-alone applications since 1992:

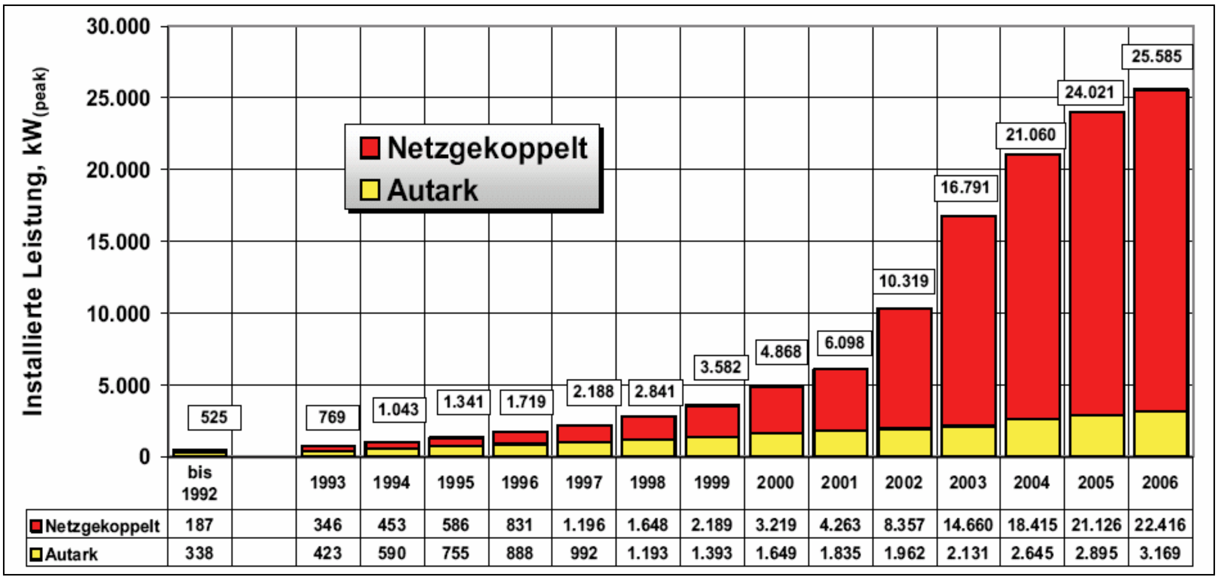

Figure 3.4: Market development from 1992 to 2006 (cumulative installed capacity)

Source: Faninger 2007: 27

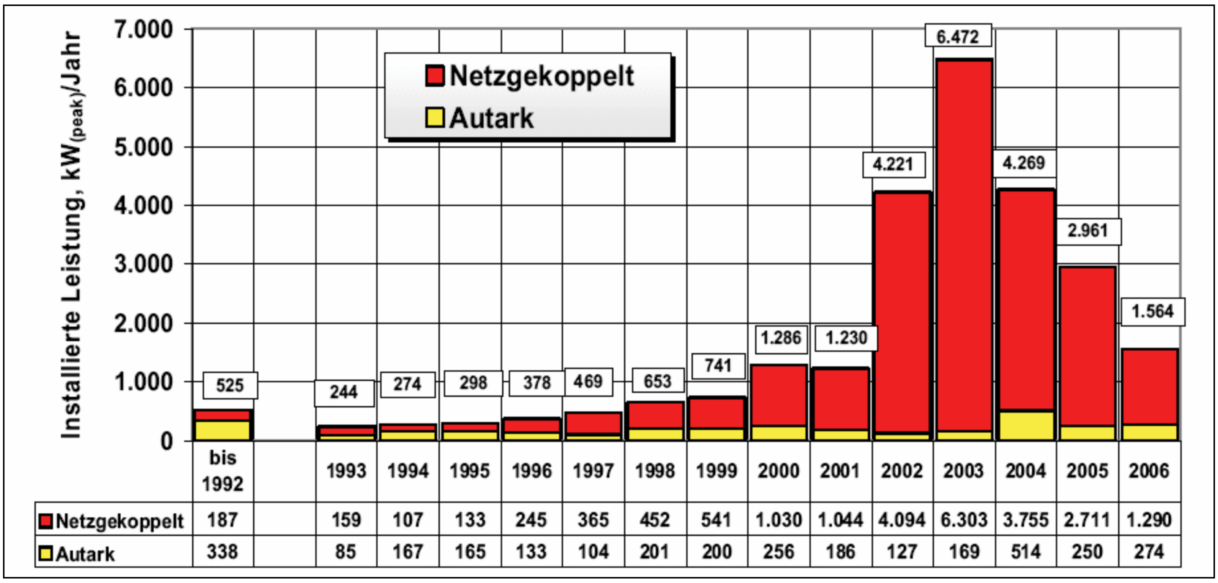

Figure 3.5: Market development from 1992 to 2006 (annual installed capacity)

Source: Faninger 2007: 27

The cumulative installed PV power increased from 769 kW_p in 1993 to 25,585 kW_p in 2006. Austria has known a stronger growth in PV power generation, mainly for grid-connected systems, since 2002-2003. In 2006, merely 12,4% of the cumulative installed capacity represented stand-alone applications and 87.6% constituted grid-tied PV systems. Figure 3.5 depicts the annual installed capacity over the same time period. This figure gives us a clearer image about the specific years of important growth. As with the developments on the global

market, increases in capacity can be attributed to the dissemination of grid-connected PV systems. Austria´s annual PV power installed power increased from 244 kW_p in 1993 to 1,664 kW_p in 2006. The years 2002 and 2003 represented the years of highest growth in the annual PV power capacity installed in Austria. After moderate, yet steady increases until 2000, the capacity rose by approximately 343% from 2001 to 2002. This large increase was due to a special feed-in tariff offered in the federal state of Vorarlberg. The largest installed capacity was reached in 2003, with 6,472 kW_p, when the Austrian "Green Electricity Act" came into force (Faninger 2007: 26-28). It provided guaranteed feed-in tariffs (0.6 EUR/kWh for systems ≤ 20 kW_p and 0.4 EUR/kWh for larger applications) which were fixed by the Federal Ministry of Economics and financed by a supplementary charge on the net-price combined with a fixed price purchase obligation for electricity dealers (IEA PVPS 2007: 39).
The upper limit of subsidized compensation – the cap set to 15 MW – was reached at the end of the same year. This was the main reason for the continuously decreasing rates of annual installed capacities within the following years. The installed PV power fell by approximately 47% from 2005 to 2006. It is worth mentioning that the decline was only observed for grid-tied applications. The cap on subsidized feed-in tariffs led to a rise in stand-alone capacity, especially in 2004. Nevertheless, on the whole on-grid applications dominated the PV market. Figure 3.6 shows the installed capacity from grid-tied applications in MW in the nine federal states in 2006:

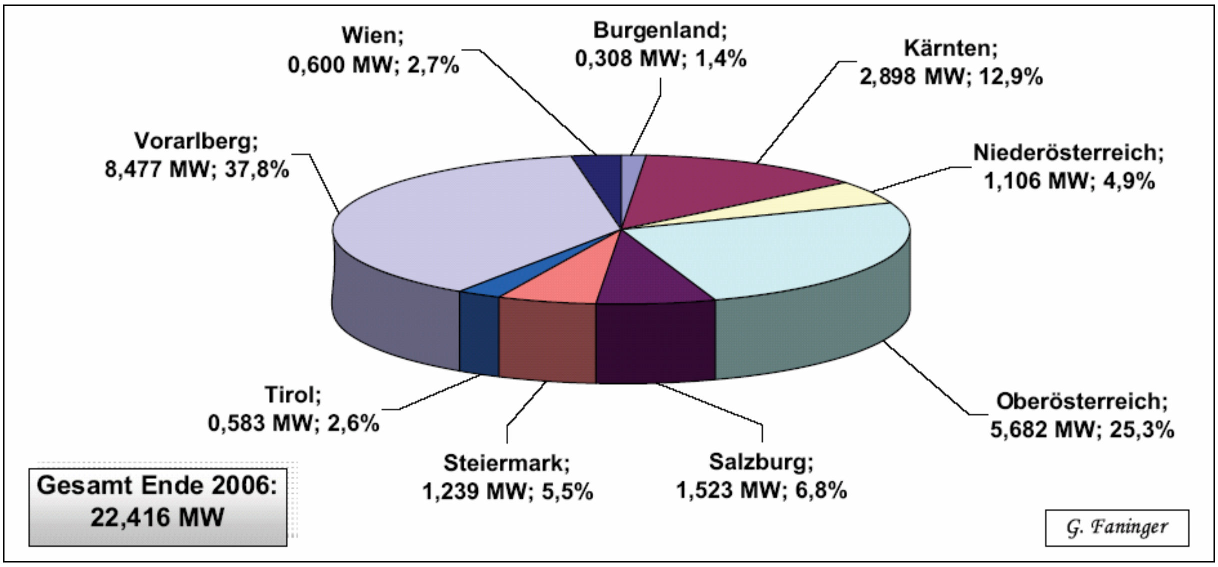

Figure 3.6: Grid-connected installed capacity in the Austrian provinces at the end of 2006

Source: Faninger 2007: 28

In terms of installed PV power supplied by grid-connected systems, the leading provinces in Austria were Vorarlberg, Upper Austria and Carinthia. Among these, Vorarlberg had the largest share of 37.8% which amounts to a capacity of 8.5 MW. Upper Austria was in first position until 2004 – when it held 81.7% – due to additional rebates offered by the federal government within their own Green Electricity Program. But the above-mentioned preferential feed-in tariff in Vorarlberg led to the fact, that Upper Austria lost its leading position the following year (Faninger 2007: 26-28).

3.2.3 PV Production

Since 2005, Austria witnessed a large increase in the production and in the export of PV modules, whereas the performance of its home market weakened. This can be observed in Table 3.3. During the year 2006, total PV module production reached 39.5 MW, approximately 10 MW of module power was imported and 46.7 MW were exported. The largest share of Austria´s module production was exported to Germany. The strong growth of Germany´s PV market had a positive effect on the Austrian the market and, therefore, led to the expansion of the Austrian PV industry (Faninger 2007: 34):

The Austrian PV Market: 2003 - 2006				
Production, Imports, Exports and Home Market				
kW_p				
	2003	**2004**	**2005**	**2006**
Production	242	3.242	17.700	39.500
Imports	2.056	2.894	6.250	9.992
Exports	0	4.933	20.989	46.705
Home Market	2.298	1.203	2.961	1.564
Sales	2.298	6.136	23.950	48.269
Sales: Home Market and Exports				

Table 3.3: The PV Market in Austria: 2003 to 2006

Source: Faninger 2007: 17

In 2006, there were five companies involved in the small- and medium-sized production of PV cells and modules in Austria: SOLON-Hilber Technology (a subsidiary of the German manufacturer SOLON), Ertex Solar (a subsidiary of Ertl Glass), KIOTO Photovoltaics GmbH (formerly known as RKG Photovoltaik and affiliated to GREENoneTEC, Europe's market leader for solar thermal collectors), SED (the company focuses on the production of PV-roof tiles) and PVT Austria (the first manufacturer of PV modules in Austria, starting its production in 2002).

Besides producing PV cells and modules, Austrian companies also manufacture balance-of-system components. This industry has traditionally played a bigger role in Austria; it can be considered as one of the largest inverter producing countries in Europe today. The inverter industry today is profiting from the increasing international demand more than ever. The most important manufacturing companies are: FRONIUS INTERNATIONAL GmbH (Austria's largest producer of inverters, and second largest in Europe) and SIEMENS AG AUSTRIA (the company started its large-scale manufacturing only in 2002) (IEA PVPS 2007: 40-41).

3.3 Advantages & Disadvantages of PV

The outline of the global PV market showed the strong growth of the PV industry in recent years. Nevertheless, this global market growth was mainly restricted to the three largest markets, Germany in particular. Presently, one could say that the PV technology is caught in a Catch-22 situation: the PV technology is not widely used because of its high cost and the high cost is due to the low level of adoption (Sandén 2005: 138). At this point, it might be useful to highlight some of the important reasons for the present market situation. The PV market will only be able to grow if it can create more demand. The pros and cons of investing in a grid-connected PV system have to be analyzed and the demand-side barriers which hinder further market growth should be removed in order to uncover the full potential of the technology. The important advantages and disadvantages of photovoltaics from an investors perspective are stated as follows (IEA PVPS 2002a: 19, 22):

3.3.1 Advantages

The main advantages are:

- The electricity is produced from an inexhaustible energy source with low environmental impact. The reduction of greenhouse gas emissions is not only beneficial to the user of the system, but to the entire society.
- The cost of one unit of PV energy is derived from the investment costs of the system and there are no fuel costs. Therefore, PV electricity costs are stable, they are independent from fluctuations and price increases of fossil fuels.
- A PV system is flexible and adaptable to individual needs due to its modular design.

3.3.2 Disadvantages

The disadvantages an investor would face can be divided in three categories:

A) <u>Technology barriers</u>:

- The fluctuation of solar radiation causes intermittency in the PV energy production.
- The low system efficiency reduces the overall technical performance and the reliability of the application.

B) <u>Marketplace barriers</u>:

- The cost of generating PV electricity are very high and the prices for conventional energy are low.
- The production of solar electricity does not match the energy consumption pattern. The mismatch between supply and demand can be observed on a seasonal and on a daily level. Most of the electricity is generated in summer and at noon. Therefore, the majority of solar energy is fed into the grid at low market prices. This problem is enhanced by the fact that the summer constitutes the main holiday season of the year, when the demand for electricity is lowest.

- Generally, the public lacks information and understanding about the PV market. As the latter is not transparent, it is difficult for potential investors to have access to the necessary information. This increases their transaction costs.
- For new energy technologies that have not yet established themselves, it is difficult and more expensive to obtain financing opportunities.

C) Other barriers:

- There is a lack of subsidies and market support measures which could buy down the cost of PV applications to a competitive level.
- If support mechanisms are implemented, they are usually not established on a consistent, long-term basis. In most countries the policy situation can be defined as unstable.

4 THE COST

4.1 PV vs. Other Renewables

With the exception of a few countries, such as Germany, where the PV industry has boomed, the success of photovoltaics can be described as limited. This is mainly due to the very large cost of this solar technology. The costs are also relatively high compared to other electricity production technologies. Figure 4.1 shows the cost range of electricity produced from renewable resources[7]:

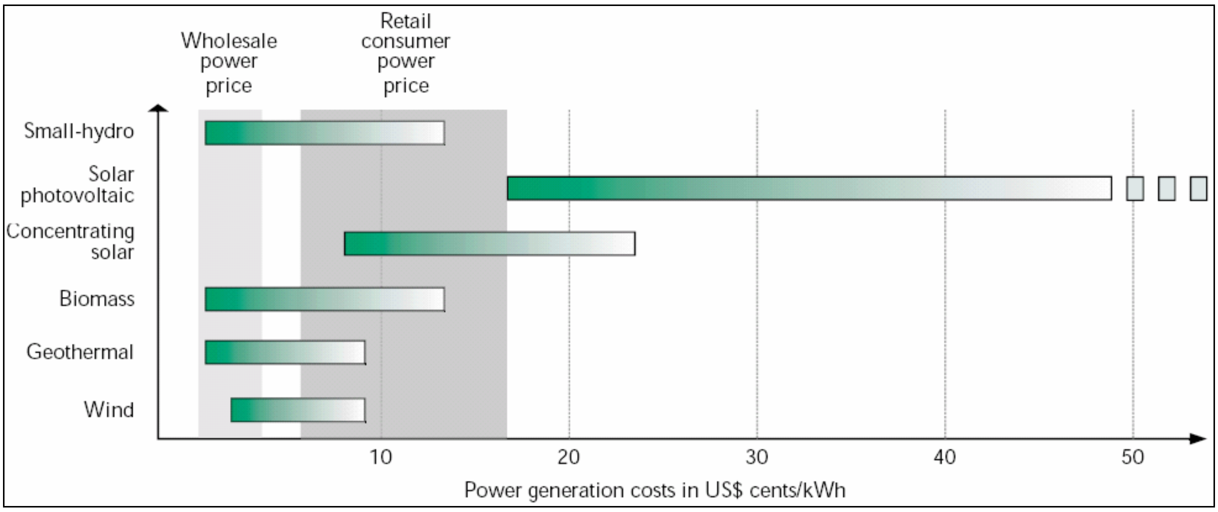

Figure 4.1: Cost competitiveness of selected renewable power technologies

Source: NET Ltd. Switzerland cited by: IEA 2004: 62

Solar technologies are generally more expensive than other renewable energy technologies, such as wind energy, biomass, small-hydropower and geothermal energy. Among solar energy technologies, the electricity produced by means of photovoltaics is by far the most expensive. The generation costs of PV energy exceed the unit costs of all other renewable energy technologies by more than 50%. This difference in costs is partly due to the high cost of silicon and the PV cell production process[8].

[7] Cost calculations are based on a discount rate of 6% and an amortization period of 15-25 years
[8] see chapter 2.4.3.1

Only off-grid systems in remote areas where grid-extension or any other alternative would incur higher costs than the solar application can be considered cost-effective. While the profitability situation for stand-alone systems seems to be unproblematic, the future challenge will be to reduce the costs of grid-connected PV systems and increase their ability to compete with relatively cheap grid electricity or with other renewable energy technologies. Therefore, the focus of this work will be on grid-connected photovoltaics.

4.2 Elements of PV Costs

The costs of PV systems vary widely and depend on the system´s size and location, the type of customer, the grid connection and technical specifications (IEA 2006a: 223). The cost of complete grid-connected systems consists of the costs of the following elements:

- PV modules
- inverter
- planning and installation (electric installation material, mounting and support frames)
- operation and maintenance
- insurance
- capital costs.

As previously mentioned, the solar modules are usually the biggest expenditure, especially for grid-tied systems which don´t require other components that add to the cost of autonomous systems[9]. The solar cells account for half of the module cost. For grid-connected systems, planning and installing is the second largest expenditure. The third largest cost factor is the inverter. In present-day grid-connected applications in Austria, the solar modules account for approximately 60% of the total investment cost; the costs of planning and installing the PV application take up 30% and around 10% are invested in the inverter. In the twenty to thirty

[9] Stand-alone applications will have additional costs, especially for batteries and power-conditioning devices, as these have to be replaced every five to ten years.

years of the system lifetime, 1% to 3% of the investment costs have to be added to the total expenses as running costs. The latter constitute the cost of maintaining the PV arrays, such as cleaning them, insurance costs, etc. (IEA 2006a: 223, 224; ÖKL 2007: 7).

4.3 Historical Cost Development

4.3.1 System Costs

We know that cost reductions are essential to increase the competitiveness of photovoltaics. So far, the costs of PV systems have fallen by more than 60% since the beginning of the 1980s (DGS 2006: 341). Nevertheless, the speed of the witnessed cost reductions has reduced since the mid 1990s. This can be observed in Figure 4.2 which shows the development of PV system costs in the three largest PV markets: Germany, Japan and the USA.

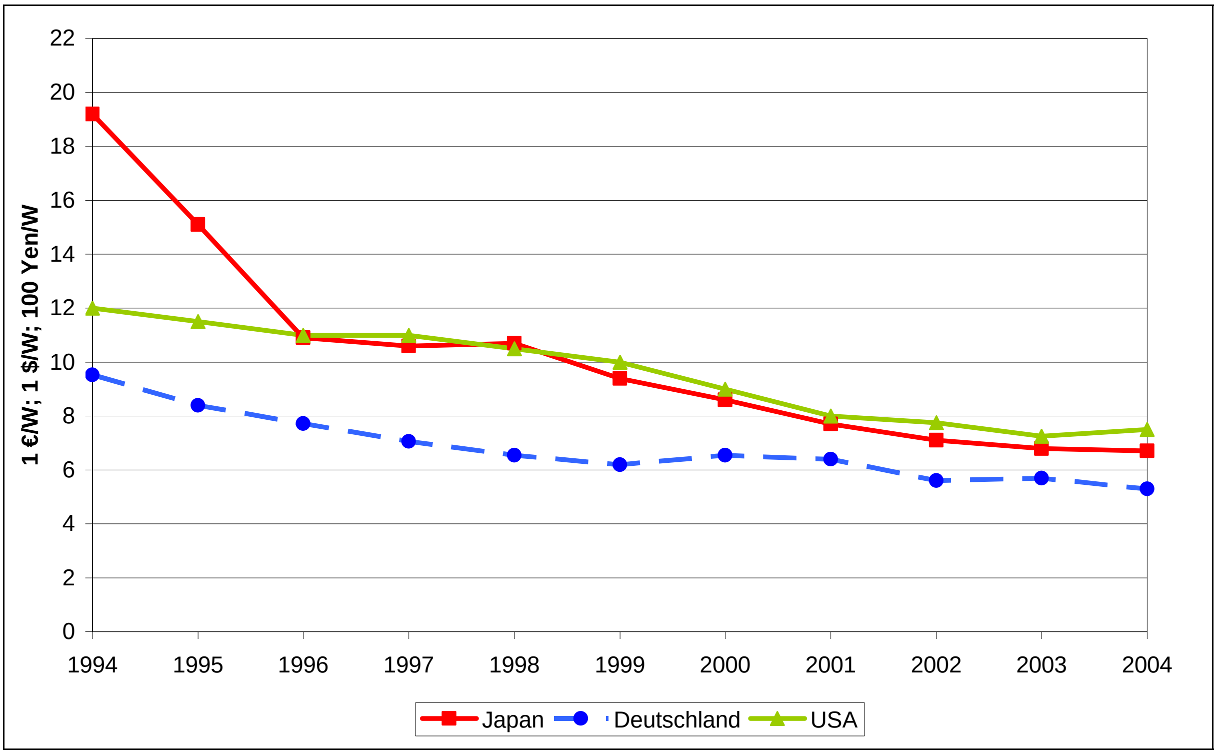

Figure 4.2: Historical development of PV system cost from 1994 to 2004

Source: Suna et al. 2006

All three countries saw a more or less continuous decline in cost. Especially in Japan, system costs fell rapidly until 1996. Japan started off with 19,200 JPY/W in 1994 and reached a value of approximately 6,700 JPY/W in 2004. This equals a decrease of 65% during the entire decade and an annual average of around 10% (Suna et al.). Yet in the year 2005, Japan, Germany and the state of California in the USA witnessed an increase in cost for the residential PV sector. This phenomenon may have been the result of the respective deployment strategies followed by these countries. The amendment of the EEG in Germany, for instance, and the large increase in demand had caused a rise in global module prices and in the installation costs of PV applications (Lopez-Polo et al. 2006).

4.3.2 Cost Distribution

When observing the costs of PV systems, it also interesting to follow the development of their constituents. Not only system prices on the whole, also the distribution of the cost has evolved over time. The prices of components have fallen differently than others. PV market support mechanisms may have led to quicker investment cost reductions for certain components. Figure 4.3 shows the evolution in the cost distribution since the 1990s and over a decade in Central Europe, Japan and the United States:

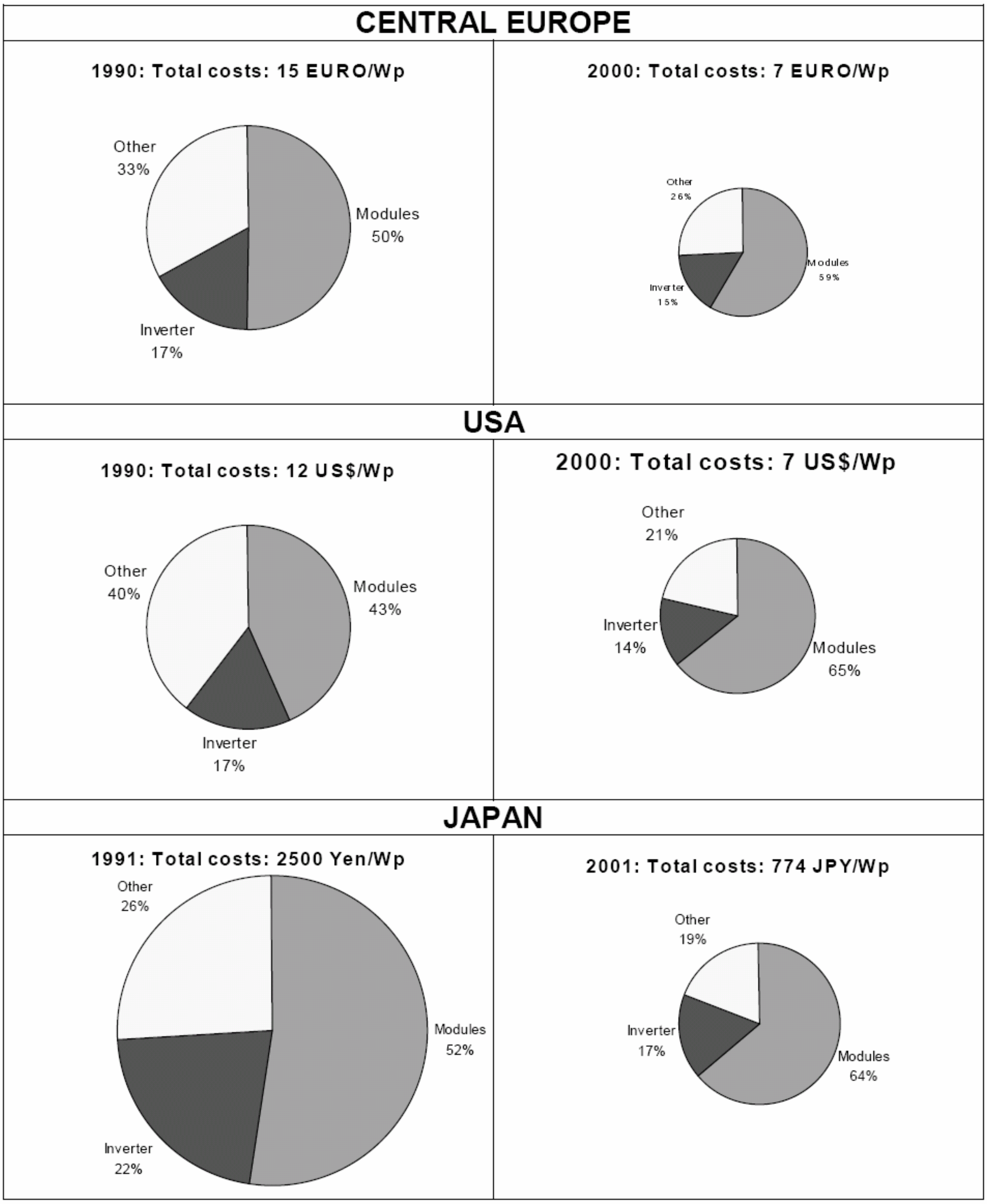

Figure 4.3: Shares of modules, inverters and other components to PV system prices in Central Europe, the USA and Japan (excluding VAT)

Source: IEA 2002a: 34

While the total cost per W_p has been reduced by more than 50% in Central Europe and over 40% in the United States, the decrease was almost 70% in Japan. Figure 4.3 clearly illustrates the cost reductions that have been achieved for inverters and other non-module costs in relative terms. In the USA, all non-module costs represented 57% of the total system price in 1990. Within one decade, these costs had reduced their share within total expenses and reached a level of 35%. All three examples demonstrate the fact that PV modules have even more so become the major cost factor with relative shares of approximately 60%.

4.4 The Experience Curve

Cost reductions which have been achieved in the PV technology of one country will have a positive impact on the costs in other countries (Neuhoff 2005: 105). Nevertheless, from chapter 4.3.1 we know that prices for entire PV systems are not uniform and that they vary internationally. This is due to the fact that module prices are generally determined by international and global market laws, whereas installation costs are mostly determined by the local market (Lopez-Polo et al. 2006). We have previously observed a relative increase of module costs for PV applications over time. Yet, in absolute terms, these costs have fallen. Developments in the prices of PV modules – which are uniformally determined – affect the international market. Therefore, it may seem interesting to analyze their development over time and the reasons for cost declines.

Crystalline silicon module prices have decreased from 51 USD/W_P since the start of commercial manufacture of solar cells in 1976, to approximately 3.5 USD/W_P in 1998 (Ayres et al. 1998; Thomas et al. 1999; cited by: Harmon 2000: 6). Prior to commercialization, in 1968, laboratory-based PV module prices were set at approximately 90 USD/W_P (Maycock et al. 1975; cited by: Harmon 2000: 6). A reduction in cost can be used as a measure of technological improvement and “learning“ or “experience“. This can be done by plotting PV module costs on a “learning curve“ or “experience curve“. Experience curves describe how unit costs decline with cumulative production by defining a certain correlation between the two. The main parameter in this model is the so-called learning index *b*. *Cost(x)* is the unit cost as a function of output, *x* the cumulative unit production over time, and $Cost_0$ represents the cost of the first unit produced. The curve can be expressed by the following function (Harmon 2000: 7,8):

$$\text{Cost}(x) = \text{Cost}_0 * x^{b} \qquad (1)$$

The experience index is used to calculate the "learning rate". The latter can be defined as the cost reduction for each time the cumulative production is doubled. The learning rate *LR* is expressed as:

$$LR = 1 - 2^{b} \quad (2)$$

A learning rate of 30% means that a certain technology has known a 30% cost decrease for each cumulative doubling of production. The experience curve within the timeframe from 1968 to 1998 can be seen in Figure 4.4. Between 1968 and 1998, the average price of PV modules – as a function of cumulative module shipments – indicates a learning rate of 20.2%:

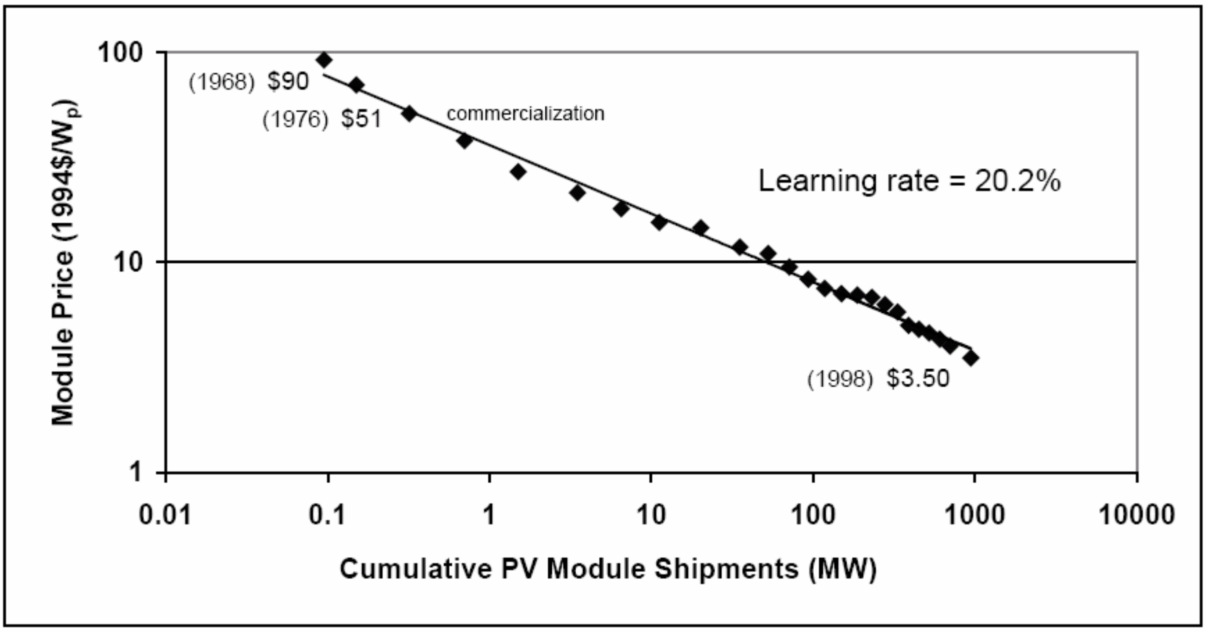

Figure 4.4: Experience curve of PV modules from 1968 to 1998

Source: Maycock et al. 1975; Ayres et al. 1998; Thomas et al. 1999; Watanabe 1999 ; NREL 1999 cited by : Harmon 2000: 10

Experience curves depict production cost declines through adoption and diffusion of a technology. An economic virtuous cycle is created when a technology is disseminated: a number of positive feedback mechanisms will increase its utility and decrease its cost: the gain in experience can be the seen as the result of technological evolution through production- and/or product-related improvements. The production process can be optimized through economies of scale and learning-by-doing effects which both occur with increasing cumulative production. Economies of scope can also be realized with growth if by-products of the PV technology establish themselves in a market and reduce the net cost of producing the main product. The product itself can also be refined as to increase its performance-to-cost ratio and to better meet the needs of users and producers (Sandén 2005: 139). From 1968 to 1998, a combination of these technology-related factors led to an average learning rate of approximately 20% in the manufacturing of PV modules for each doubling of market deployment.

4.5 Limits to Cost Reductions

We have seen a continuous decline in PV system costs in Figure 4.2 until the year 2004. This can be explained with the theory of the experience curve where the diffusion of the PV technology led to an economic virtuous cycle and resulted cost decreases. Nevertheless, the system costs again rose the following year, in 2005. This increase in global costs is consistent with market theory which states that prices rise if demand for new emerging technologies increases. With the implementation of market support measures, such as the EEG in Germany, global demand had rapidly increased to a level leading to price increases in PV modules and therefore in system prices. Figure 4.5 shows these price fluctuations as short-term phenomena:

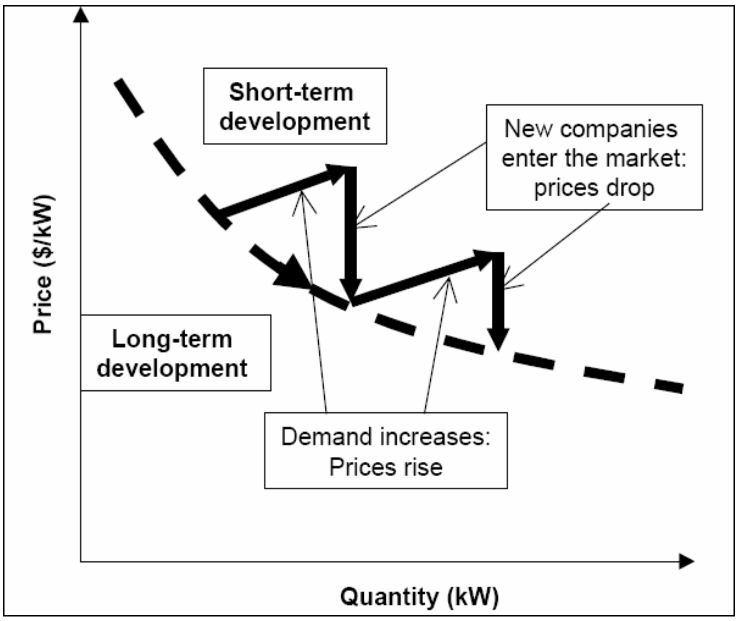

Figure 4.5: Short-term versus long-term development of prices for PV systems in the early market introduction phase

Source: IEA PVPS 2002a: 31

The PV industry can be considered as an imperfect market, where prices increase in the short-term. As a consequence, new companies enter the market and the latter becomes increasingly competitive, which leads to prices reductions. The long-term development will be a price decline until a perfectly competitive market has been attained. In the long-run the development of PV prices will follow the learning and experience theory. Therefore, the long-term supply curve can be seen as a learning curve, where the prices will decrease until a perfect competitive market has been reached. Once this market state has been attained, no further price decreases can be expected if the demand continues to increase (IEA PVPS 2002a: 31,32).

4.6 Opportunity Costs

Under these previously outlined circumstances, where the costs of a grid-connected PV application are relatively high, potential users would only invest in this system out of pure commitment to reducing greenhouse gas emissions. The latter seems to be at the center of the investors' interests, not financial profit making. Yet, other renewable energy options could do just the same: fulfilling the need to decrease CO_2 emissions. Knowing how expensive the PV technology is, they could possibly do it at a lower cost. When making an investment decision, one issue which has to be considered are the opportunity costs of the envisaged undertaking. Opportunity costs are defined as the return that could have been earned on the next best alternative, given the aims of the investor. They represent the economic cost of an action measured in terms of the benefit foregone by not pursuing the best alternative course of action (Oxford Reference Online 2007). Investing in a grid-connected PV system creates opportunity costs. The opportunity costs of installing a PV application comprise all the benefits and losses from installing a PV system and not pursuing another project. They include the capital and the workforce brought into the project – which could have been used differently – as well as external effects that could have been prevented had another project been chosen. As one can see, this definition of opportunity costs is wide and includes various things, some of which are difficult to quantify. Nevertheless, some of the opportunity costs of installing a PV system – concerning the use of more promising renewables for decentral, residential energy production – will be outlined in the following.

4.6.1 Wind Energy

The wind also represents a resource from which renewable energy in the form of electricity can be produced. In order to do this, wind turbines are mounted on a tower to capture the winds' energy with their propeller-like blades. Two or three blades are usually mounted on a shaft to form a rotor (NREL 2007). A wind turbine obtains its power input by converting the force of the wind into a turning force acting on rotor blades. The rotor, which is connected to a generator, converts the rotational energy into electrical energy. The amount of energy that the wind transfers to the rotor depends on the density of the air, the rotor area and the wind speed (Windpower 2007). Wind turbines can be connected to an electricity grid or they can be used as stand-alone applications, in which case a backup power – as with PV systems – is needed. Modern wind turbines have a lifetime of approximately twenty years.

The efficiency of a turbine is determined by the design of the rotor blade. In practice, the maximum efficiency obtainable at optimal rotation speed is near 35% (Green Spec 2007). The wind resource is more abundant in Austria than solar irradiation and a wind application generally produces a larger annual electricity output than PV systems do. For small-scale individual use, the energy output is smaller compared to wind plants. Lower average wind speeds increase electricity costs, yet the investment costs are lower than the expenses for PV applications. The intermittent nature of wind energy constitutes the biggest challenge: the reliability of the grid is affected when the wind provides too much or too little power (IEA 2004: 84). Therefore, the appropriate site for a wind turbine has to be carefully chosen through measurement of wind speeds which increases the overall cost of the project. Taking the differences in sites, capital costs and wind speed into account, the variation in the cost of wind is relatively high in different countries and locations and ranges from 0,03 USD/kWh at favorable sites to 0,20 USD/kWh at rather unfavorable sites (IEA 2006a: 127). Nevertheless, these generation costs are considerably lower than the ones for PV electricity. This is clearly shown in Figure 4.1. In Austria, the wind energy from a system installed in 2007 is compensated at 0,0755 EUR/kWh if it is fed into the grid (0,0765 EUR/kWh for a system installed in 2006) (E-Control 2007). These feed-in tariffs just about help a wind energy producer to break-even. Nevertheless, if reducing greenhouse gas emissions is the main goal, investing in wind energy would be more cost-effective than investing in a grid-connected PV application.

4.6.2 Biomass Energy

The term biomass covers a wide range of products, by-products and waste streams derived from forestry and agriculture, as well as from municipal and industrial waste streams (IEA 2006: 38). Biomass resources can be combusted to produce electricity, heat, or both (combined heat and power). Combustion is a frequently applied process because of its low cost and high reliability. During combustion, the biomass first loses its moisture at temperatures up to 100°C; as the dried particle heats up, gases containing hydrocarbons, carbon monoxide, methane and other gaseous components are released. The remaining char oxidizes and ash remains at the end (IEA Bioenergy 2007).

Biomass constitutes an important fuel for heating systems where sufficient resources are available at a low cost. As approximately 40% of Austria´s area is covered with woods, residues from wood processing are abundant and available at a relatively low cost. Therefore, domestic heating with wood represents the largest share of bioenergy in Austria. In the residential sector, small-scale systems for biomass combustion for space heating are widespread, although the number of traditional wood stoves is decreasing. New, improved services have been developed, including new boiler technologies (fully automatic installations), new fuel types, such as pellets, and new supply strategies (e.g. contracting projects for micro networks and heat supply schemes for individual buildings on the basis of woodchips from forestry). Several different concepts are available for domestic heating: improved tiled stoves, advanced logwood boilers, woodchip boilers, pellet boilers and pellet stoves (Energytech 2007). The smaller the combustion plant, the greater the need for quality and homogeneity of the fuel. In Austria, the demand for wood pellets has increased in the last couple of years as they possess these qualities. Compared to other wood fuels, the main advantage of pellets is the low moisture content and their increased density. Modern pellet boilers have efficiency ratings of 80% to 90% and hardly produce ash (IEA Bioenergy 2007). Combined heat and power applications are reliable and have an overall efficiency of up to 60% (IEA 2006: 45).

The cost of biomass conversion varies according to a range of factors, such as the types of biomass, the conversion process and the scale of operation. Therefore, it is difficult to generalize the costs of bioenergy. The relative high cost for the pelleting process increases the price of the end product. In 2005, prices of wood pellets ranged from 151 to 225 EUR/ton, depending on the purchase quantity (Kalt 2005: 66, 69).

A study on renewable energy in Austrian households showed that CO_2 emmissions from individual domestic biomass heating applications are very low, almost insignificant. In addition, they have the lowest total costs in comparison to other heating options including PV. Since the majority of the annually consumed energy, around 55% in Austria (Haas et al. 2001: 15, 20), is used for space heating, the demand for heat is greater than the demand for electrical energy. Therefore, a larger share of the consumed energy can be covered with biomass combustion for heating (or combined heat and power) than with renewable technologies producing electricity only. The used biomass is local and does not have to imported like the silicon for PV modules. Unlike sunshine, the resource is not available for free when using biomass. Nevertheless, the latter does not know daily and seasonal fluctuations in supply, as solar radiation does.

4.6.3 Solar Heating

Solar heating covers a broad spectrum of technologies, such as solar water heating and active solar space heating (and cooling) for instance. Small-scale, low temperature solar thermal systems can supply heat for residential hot water which can be used in the household or for heating swimming pools. Active solar technologies use solar collectors to heat a fluid, usually water. The main collector technologies include unglazed, glazed flat-plate and evacuated-tubes collectors. A flat-plate collector runs plastic or copper tubing through an insulated, weather-proofed box. Evacuated-tube collectors are made up of rows of parallel, transparent glass tubes. The main advantage of vacuum tubes is the lower heat loss due to the vacuum. As with PV, the solar resource is intermittent, therefore, most systems in industrialized countries use a back-up, either biomass (pellets), fossil fuels or electricity (IEA 2006b: 10, 11).

The efficiency of a solar collector depends on the application, particularly on storage and back-up systems. Annually averaged collector efficiencies of 40-55% for domestic hot water can outperform the efficiencies of PV modules. Hot water use can be considered more or less constant throughout the year. A solar hot water system will reduce the need for conventional water heating by about 70% and can reduce fuel use by 10-30%. In 2006, the investment costs of a solar hot water system ranged from 3,100 EUR to 7,500 EUR. The average price of one kWh of solar-heated water is about 0.19 USD/kWh[10]. The learning curve of solar hot water systems in Austria and Germany shows that each doubling of the market since 1996 led to a 20% reduction in the installed cost. For domestic hot water, the energy payback time is often less than one year (IEA 2006a: 142, 143, 374, 375).

The same kind of solar collectors, which are used for domestic hot water can also be used for heating houses and other types of buildings. “Combi-systems” provide both, space and water heating and prove to be more efficient and profitable. A thermal collector can be designed for winter heating and cooling in summer as well, which would reduce the energy cost per unit and provide additional comfort. Annual utilization efficiencies of 20-25% have been achieved in combined systems. Between 10 and 60% of the combined hot water and heating demand can be met with these applications, depending on the size of the collectors and of the installed storage tanks (IEA 2006b: 10, 11). As we know that the majority of the annually consumed energy is used for space heating, more fuel costs can be saved in this way than with a simple solar hot water system. This is especially true in times of increasing oil and gas prices. The mismatch between the supply of solar energy and the actual need for space heating lead to an increase the total cost of the application due to energy storage. The investment cost of a combined system with space and water heating reached 17,300 USD in 2006. The average price of one kWh of solar-heated water is about 0.37 USD/kWh[11]. Out of the total investment cost for both types of applications, hot water and combi-system, the collector set represents approximately 60% of total investment costs and the mounting expenses generally accounts for around 20%. Nevertheless, the latter expenses can be saved when the application is mounted without professional assistance[12]. Furthermore, some countries, such as Austria and Germany offer subsidies which further reduce the investment costs.

The above-mentioned solar thermal technologies constitute a mature technology and their achieved standard is high. In terms of technical performance and reliability, they can be

[10] For systems with an average lifetime of twenty years and which are financed at 4% interest without subsidies.
[11] For systems with an average lifetime of twenty years and which are financed at 4% interest without subsidies.
[12] The cost of mounting such applications can be reduced by purchasing “do-it-yourself“ systems which are then installed by the user.

considered more advanced than the PV technology. The efficiencies of these domestic solar thermal applications are higher than the ones attained in PV systems. Despite their high upfront capital costs, solar thermal systems can be considered more cost-efficient, as more energy is needed for water and space heating than for electricity only. The fact that the input cost of PV modules, i.e. the price of silicon, has increased in the last couple of years, not only favors solar thermal applications, but all the above-mentioned renewable energy technologies, making them even more attractive.

5 PROFITABILITY DEVELOPMENT IN AUSTRIA

5.1 Parameters

5.1.1 Investment Costs

In chapter 4.2, we have seen that the investment costs of a grid-connected PV system include the costs of the solar modules, the inverter, planning, and the installation itself (electric installation material, mounting and support frames). These expenditures depend on the capacity of the system, on the mounting expenses and on the module efficiency. In Austria, the investment costs of present-day grid-tied applications amount to:

- The specific net investment costs for the solar modules are between 3,000 and 4,500 EUR/kW$_p$.
- In Austria, the specific net investment costs for an inverter vary with the installed power of the system. For a small grid-tied system, they will range from 500 EUR to over 700 EUR.
- The specific investment cost for the installation amounts to approximately 1,700 EUR/kW$_p$ for the network connection, and 250 EUR to 300 EUR for the mounting itself.

The total specific investment costs (including VAT) for grid-connected applications amount to a maximum of 7,600 EUR/kW$_p$. The costs decrease with increasing capacity, nevertheless, systems up to 20 kW$_p$ still cost over 6,000 EUR/kW$_p$ (ÖKL 2007: 7).

The first efforts in Austria to support and promote grid-connected PV systems were made in the 1990s, by granting capital subsidies or compensating the PV power producer with a higher tariff than the market price. The goal was to create incentives for the dissemination of this technology and thereby achieve cost reductions. These subsidies were intended to increase the sales and incur market learning and experience; this would in turn decrease the costs and the need to subsidize photovoltaics. In 1992, the Austrian Ministry of Economic Affairs launched the Solar Energy Program for decentralized PV systems which subsidized around 100 small residential grid-connected applications. The program ended in 1994-1995, and led to approximately 200 kW of newly installed capacity. Market growth after these years can be attributed to the voluntary agreement between Austrian utilities and the Ministry of Economic Affairs. Starting in 1994, an agreement between the Ministry of Economic Affairs and the Association of Electric Utilities guaranteed a 100% bonus of the market price of PV power over a period of three years. These higher buy-back rates were paid until the end of 1999 (IEA 2004:135, 141, 142). The effect of these initiatives can be seen in Figure 5.1, which illustrates the development of the investment costs (including VAT) from 1991 to 2000 for PV systems with an installed capacity of 1 kW_p[13]:

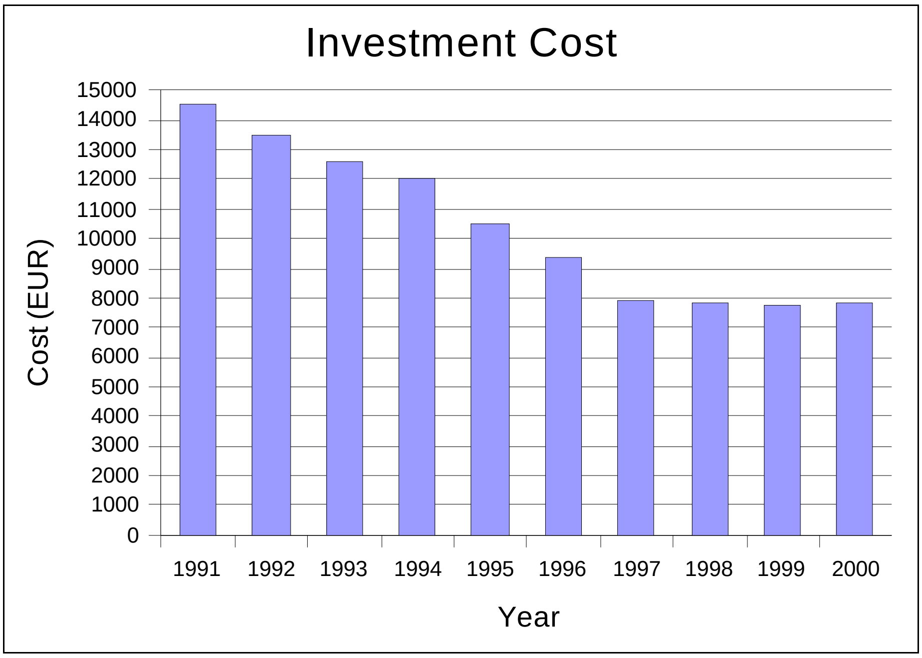

Figure 5.1: Investment costs for grid-tied PV systems (including VAT) with a capacity of 1 kW_p from 1991 to 2000

Adapted from: Wilk 2001

The efforts by the Austrian government to further deploy decentralized PV systems indeed helped to reduce the investment costs of PV systems. The latter fell by almost 50% over a decade. Although market growth was slow during the 1990s[14], these initiatives were able to increase the diffusion of grid-connected systems to a certain level, which led to learning and economies of scale, thereby reducing the costs. At the beginning of the decade and during the Solar Energy Program the investment costs fell continuously until 1997. The voluntary

[13] See Appendix (Table 7.1) for original data.

[14] See chapter 3.2.2

agreement between the utilities and the Ministry of Foreign Affairs may have not been able to achieve the same effects as the Solar Energy Program because the applied feed-in tariffs were not cost-covering. The investment costs have remained relatively constant since the year 2000. The fact, that the investment costs of a 1 kW_p residential grid-connected PV system is presently 7,600 EUR, shows that no considerable cost reductions were achievable in Austria, despite the strong market growth in the years 2002 and 2003. This strong increase in sales through the implementation of the Green Electricity Act in Austria and the increasing level of global demand were not able to reduce the cost of PV. One factor, which could have played a major role and that could have partly offset possible cost reductions is the limited availability of silicon, which led to supply shortages in recent years and drove up the input cost of the technology.

5.1.2 Profitability Ratio

The profitability of grid-connected PV systems is determined through their cost, their energy output and the electricity rates. The electricity prices can be defined as the feed-in tariff paid by the utility, should the power produced by the application be fed into the electricity grid. The feed-in tariffs for PV power in Vienna, for instance, varied from 0.04 EUR/kWh to 0.11 EUR/kWh (Hauer 2007) between 1991 and 2002 and from 0.02 EUR/kWh to 0.06 EUR/kWh between 2003 and quarter three of 2007 (E-Control 2007). Therefore, the maximum compensation for an annual production of 950 kWh from a 1 kW_p system was approximately 105 EUR per year. The investment costs of PV systems are extremely high in relation to the feed-in tariff paid by utilities in Austria. Facing such a low compensation, investors in PV systems would not have any incentive to sell their entire electricity production to the utility; they would rather consume the energy in their own households and only feed the surplus electricity into the grid. This also explains the limited success of the voluntary agreement compared to the effects of the Solar Energy Program.

The cost-efficiency of PV systems for power producers consuming their solar energy themselves, can be determined through the household electricity prices. The ratio *PR* reflects the profitability of PV electricity in the residential sector, where:

$$PR = \frac{\text{household electricity price/kWh}}{\text{cost of PV electricity/kWh}} \quad (3)$$

and PR = 1 indicates cost-efficiency. In the following, three different scenarios will be compared: the profitability ratios will be computed and the development of the latter will be analyzed for three systems with a capacity of 1 kW_p. The first PV application was installed in 1992, the second in 2000 and the third in 2006. The household prices and the cost of PV electricity from 1992 until 2006 need to be assessed prior to the ratio calculation.

5.1.2.1 Household Electricity Prices

In order to exclude any inflation-based effects, normalized prices for conventional household electricity have been calculated in the analysis. The prices are expressed in EUR of 2006[15]. From 1992 to 2006, these electricity prices (including VAT and additional charges) were (IEA 2002: 86; IEA 2007: 85):

[15] See Appendix for nominal prices (Table 7.2) and the Austrian Consumer Price Index (Table 7.3) which constitute the basis for the calculation of the inflation-adjusted prices.
The nominal household electricity prices are based on an annual consumption of 3,500 kWh (including 1,300 kWh night-time consumption) and on the average values of Upper Austria, Tyrol, Vienna since the year 1999.

Year	Household Electricity Prices (EUR/kWh)
1992	0,1792
1993	0,1749
1994	0,1698
1995	0,1688
1996	0,1760
1997	0,1748
1998	0,1743
1999	0,1449
2000	0,1431
2001	0,1447
2002	0,1481
2003	0,1428
2004	0,1477
2005	0,1422
2006	0,1390

Table 5.1: Household electricity prices (including VAT and additional charges) expressed in EUR 2006

The Austrian electricity industry was fully nationalized until 1999, when the Electricity Act *(ElWOG)* came into force and paved the way to a liberalized market. This liberalization and the cease of monopoly pricing led to a considerable drop in household electricity prices in 1999.

5.1.2.2 Cost of PV Electricity

The cost of producing one unit of PV electricity is called the power generation cost or power production cost. For a grid-tied system, the main factor determining the production costs of the generated electricity are the investment costs, since the running costs, such as maintenance and insurance payments, are very low and additional fuels are not necessary. The power generation costs allow a comparison of the PV system to other energy systems and the determination of a cost-covering compensation for the electricity fed into the grid. The power production costs depend on the insolation at the system site, on the interest rate and on the lifetime of the PV application. Their calculation is based on the overall costs that are incurred over the lifetime of the system and includes the interest on capital by using the annuity method which converts the initial investment costs into capital costs (DGS 2006: 339).

In the following calculations $Cost_{PG}$ represent the power generation costs, and $Cost_{INV}$ the investment costs according to chapter 5.1.1. $Cost_{OP}$ stands for the operating costs, and a for the annuity factor. An interest rate of i = 4% and an amortization period of t = 20 years will be applied for computing the power generation costs at different points in time, the latter being the years 1992, 2000 and 2006. The grid-tied PV system mounted on an Austrian rooftop produces an annual energy output of E_a = 950 kWh. The costs of the generated PV electricity can be expressed through the following equations:

$$Cost_{PG} = [(Cost_{INV} * a) + Cost_{OP}] / E_a \quad (4)$$

where

$$a = i * (1 + i)^t / [(1 + i)^t - 1] \quad (5)$$

The annuity factor a according to equation (5) is:

$a = 0,04 * (1 + 0,04)^{20} / [(1 + 0,04)^{20} - 1] = 0.0736$

Due to the absence of data on the specific values for these years, the operating costs of the system installed in 1992 and 2000 have been approximated to 1.5 % of the investment cost. A value of 101 EUR was applied to the application installed in the year 2006 (ÖKL 2007: 9).

According to equation (4) the generation costs of PV power in 1992, 2000, and 2006 were:

- 1992: $Cost_{PG}$ = (13.517 * 0,0736 + 203) / 950 = 1.2604 EUR/kWh
- 2000: $Cost_{PG}$ = (7.849 * 0,0736 + 118) / 950 = 0.7318 EUR/kWh
- 2006: $Cost_{PG}$ = (7.600 * 0,0736 + 101) / 950 = 0.6950 EUR/kWh

The resulting PV power production cost have declined over time, although the difference between 0.7318 EUR/kWh in 2000 and 0.6950 EUR/kWh in 2006 is not very large. The reduction of the above-stated PV power production costs reflect the achieved technological improvements during this timeframe and also the pace, at which these developments took place. The rate, at which the generation costs dropped, was considerably higher from 1992 to 2000 than between 2000 and 2006: – 42 % compared to – 5 %. The product- and production-related improvements that were made during this first period have also shown in the PV power generation costs.

5.2 Result

Since the household electricity prices and the PV power generation costs in the residential sector have been computed, the profitability ratios according to equation (3) can be calculated. The results, the profitablity ratios from the three systems installed in 1992, 2000, and 2006 with a capacity of 1 kW_p are shown in Table 5.2:

Year	***1992 System***	***2000 System***	***2006 System***
1992	0.1422		
1993	0.1388		
1994	0.1347		
1995	0.1340		
1996	0.1396		
1997	0.1387		
1998	0.1383		
1999	0.1149		
2000	0.1135	0.1955	
2001	0.1148	0.1977	
2002	0.1175	0.2023	
2003	0.1133	0.1951	
2004	0.1172	0.2018	
2005	0.1128	0.1943	
2006	0.1103	0.1899	0.2000

Table 5.2: Profitability ratios for the 1 kW_p systems installed in the years 1992, 2000 and 2006

When looking at the numbers in Table 5.2, and if a ratio of PR = 1 is supposed to indicate cost-efficiency, the results clearly show how far they are from the threshold of profitability. The PV system installed in 2000 achieved the highest profitability ratio overall with PR = 0.2023 in the year 2002.

The following figure will help to visualize and further interpret the results:

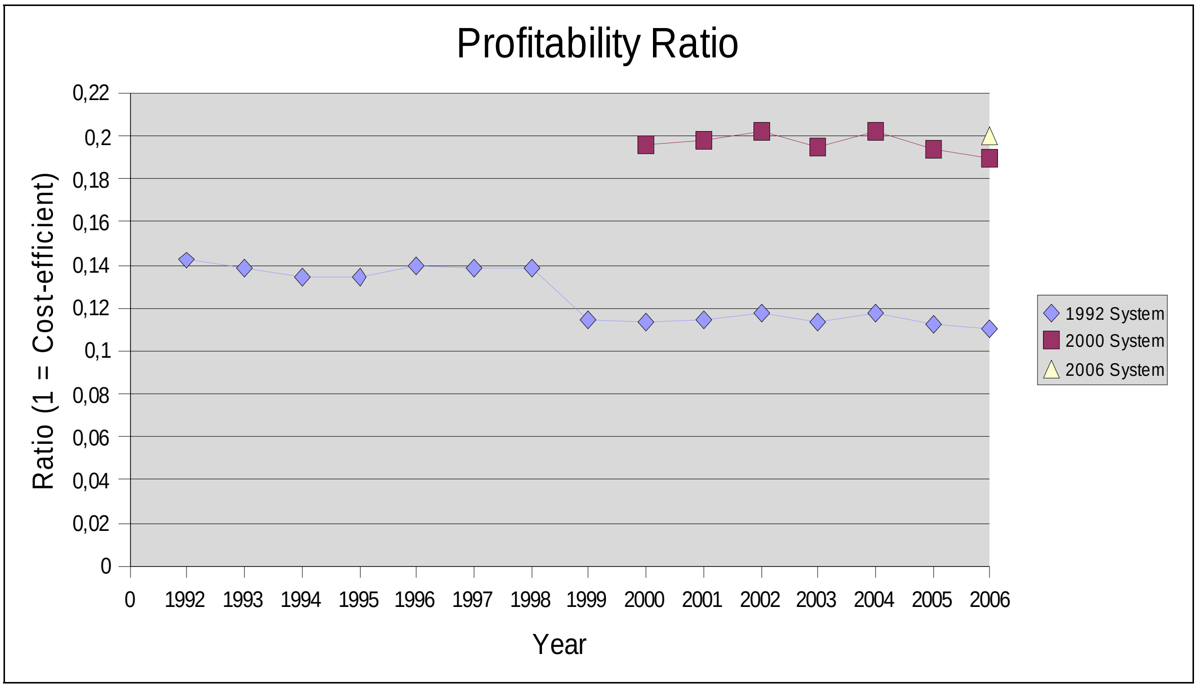

Figure 5.2: Profitability ratios for the PV systems installed in the years 1992, 2000 and 2006

The shape of the curve, the development of the profitability ratio is influenced by the development of the household electricity price on the one hand, and by the cost of PV on the other hand. These are the two variables increasing or reducing the cost-efficiency of the technology. The higher the household electricity price and the lower the cost of grid-connected photovoltaics, the better will be the ratio.

The development of the household electricity prices and its effects over the entire period – from 1992 to 2006 – can be followed best when observing the development of the curve from the PV system installed in 1992. Table 5.1 shows that the highest price level was reached in the years before the Austrian electricity market was liberalized. The fact, that a higher electricity price positively affects the profitability of PV, can be seen in Figure 5.2. With a profitability ratio of PR = 0.1422, the figure shows that this system was most cost-efficient in

1992, the year in which the level of electricity prices was highest. It seems surprising that the first year of operation was the year in which the application was most profitable and that its cost-efficiency had generally decreased over time after that. The lowest profitability ratio reached by the system was in 2006 with a profitability ratio of PR = 0.1103. The influence of the electricity price on the profitability of PV is demonstrated by the large drop in cost-efficiency during the year in which the electricity market was fully liberalized and in which the price decreased more than in other years. The ability of the electricity consumers to freely choose their electricity provider and the more competitive price level prevented a more favorable outcome for the PV technology. After the privatization of the electricity market, the level of cost-efficiency remained relatively stable and did not show large fluctuations. Nevertheless, the profitability ratio at the end of the period was lower than its value in 1999. With an operational lifetime of twenty years, it is presumable, that the PV application would not become much more profitable within the remaining years to follow, if household electricity prices remained at the level at which they have been since 1999. It seems impossible for this PV system to ever reach the level of cost-efficiency in its remaining operational lifetime. For this to materialize, electricity prices would have to skyrocket and reach a level which is unlikely to become reality.

The profitability of PV systems is also determined by the power generation costs. The three PV applications which were installed at different points in time have different power production costs. These generation costs and their development over time are reflected in the "jump" of each system to a higher level of efficiency in Figure 5.2. The higher the achieved cost reductions over time – through improvements in the PV technology – the bigger the leap towards an increased cost-efficiency. Product- and production-related improvements reduce the power production costs and increase the profitability of PV electricity. The biggest leap was realized from the application installed in the year 1992 to the one installed in 2000, where the decrease in PV power generation costs was strongest. The profitability ratio in the year 2000 was PR = 0.1135 for the system installed in 1992 compared to PR = 0.1955 for the newly installed application, constituting a leap of 0.0820. Between 2000 and the year 2006, the investment costs of PV systems did not decrease significantly. We know that the efforts of the Austrian government with the implementation of the Green Electricity Act did lead to market growth, yet these efforts were not able to significantly reduce the cost of grid-connected PV power. Towards the end of this period, the global market was suffering from rising module prices caused by the sudden increase in demand[16] and the consequent silicon shortage. These global events may have had an impact on the Austrian PV market: the price development on the international market could be responsible for partly preventing or offsetting cost declines which had been achieved through market support measures in Austria. The effect of the relatively small cost reductions achieved between 2000 and 2006 is depicted in Figure 5.2: the system installed in 2006 reached a profitability ratio of PR = 0.2000 and the ratio of the application installed in 2000 was PR = 0.1899 in the same year. Admittedly, the timeframe from 1992 to the year 2000 is longer than the one from 2000 to 2006. Nevertheless, the technology-induced leap from the second application to the third was considerably smaller than the jump from the first to the second system. In 2006, the difference of 0.0101 between the last two applications installed was considerably lower than the difference of 0.0820 between the first two systems installed in the year 2000.

The highest profitability ratio achieved overall - considering all three applications over the entire period - was with the PV system installed in 2000 with a PR = 0.2023 in the year 2002. During this year, household electricity prices were at their highest level between 1999 and 2006, the period in which the prices were generally low. The impact of a relatively high electricity price combined with the achieved cost reductions until the year 2000 is clearly reflected in the profitability ratio of the system installed in 2000 during the year 2002. The consecutive drop in real electricity prices in 2005 and 2006 reduced the cost-efficiency of the same system and made the latter reach its lowest profitability ratios during these two years. This again underlines the importance of both factors acting at the same time: the fall in the cost-effectiveness demonstrates that only the combination of reduced power generation costs together with higher electricity prices can act in favor of grid-connected PV electricity production.

This analysis has proven that, although efforts were made by the Austrian government to disseminate grid-connected PV electricity, the results were nevertheless moderate. So far, the cost-efficiency of this technology could not be raised up to a level, at which one could consider it competitive. The profitability of photovoltaics had actually slowed towards the end of the observed period.

[16] See chapter 4.3.1

6 CONCLUSION

Austria is part of the countries with low annual irradiation; sunlight does not constitute the most abundant resource in this country. Domestic use of grid-connected PV systems for producing electricity in Austria has not been profitable in the past and is still far away from being cost-effective today. Installing a grid-tied PV system creates significant opportunity costs; if the reduction of greenhouse gas emissions constitutes the main objective for investing in such a system, other renewable energy options might be more cost-efficient in doing so. Since the majority of the energy consumed in Austrian households is required for space heating, renewable energy technologies providing heat and electricity will be more profitable.

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The profitability of photovoltaics depends on the costs of PV electricity on the one hand and on the prices of conventional electricity on the other hand. As the costs of producing PV electricity are prohibitively high, long-term commitment in the form of government policies and market incentives are required in order to induce market learning and experience. The objective is achieving learning effects through technology-related improvements to reduce the cost of photovoltaics and to help resolve the chicken-and-egg dilemma of the technology. Germany and Japan can be stated as best practice examples in terms of creating a favorable policy environment. Their market support measures in the past have significantly contributed to global cost reductions. In Austria, the continuous efforts of the provincial governments in the 1990s to encourage the dissemination of residential grid-tied PV systems had indeed led to a cost decline and to an improvement in their profitability level. Unfortunately, Austria had lost the continuity within its policies with the implementation of the Green Electricity Act. The unfavorable combination of inconsistent market initiatives in Austria together with global cost increases prevented a better outcome for the cost-efficiency of PV electricity.

The shortage of silicon which has raised the cost of photovoltaics in recent years will most probably not constitute a short-term problem, but it will affect global module prices on a long-term basis. This indicates the need to turn to thin-film solar cells and new types of feedstock with lower material use. These technologies have yet to be further developed and elaborated, which involves time and high investments in research and development. This implies that there are not many cost reductions achievable for PV systems in the future and that an increase in their profitability could only be attained through higher prices for conventional electricity.

In the profitability analysis, household electricity prices during the observed period of time had the overall tendency to fall. The main drawback in their development was the liberalization of the Austrian electricity market. The consequent downward shift in prices - which was good news for households depending on conventional electricity only - caused a decrease in the cost-efficiency of PV electricity. The cost development of conventional electricity and its effect on PV profitability would have been different had the market not been privatized. This price fall increases the importance of the future development of conventional electricity prices as we have presumed that further reductions in the cost of photovoltaics are unlikely. A rise in PV profitability can only be achieved through increases in the prices for conventional electricity. In the present energy market situation, they will eventually rise in the long-term; nevertheless, it would probably take decades for them to reach the level of PV power generation costs.

One way of speeding up the process of rising electricity prices would be to internalize negative externalities. External costs could be calculated into the price of conventional electricity by introducing taxes on carbon emissions for instance. Although reducing greenhouse gas emissions constitutes the primary objective of such a system, it could have additional positive side-effects: the implementation of carbon taxes would include the cost of pollution into the prices of conventional electricity and provide a means for considerably improving the profitability of PV power. This would dramatically change the stand of PV electricity and revolutionize the energy industry. At present, carbon taxation remains a highly controversial issue among scientists and politicians due to its complexity and the difficulties encountered in quantifying externalities. Austria has not yet implemented a tax on carbon emissions, nevertheless, it is not averse to this subject and considering the options.

7 APPENDIX

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7.2 Data Tables

The data for the figures and calculations in chapter 5 are given in the following tables:

Table 7.1: Development of total investment costs for small grid-connected PV systems (including VAT)

Source: Province of Upper Austria and Utility of Upper Austria cited by: Wilk 2001.

Year	***ATS/ W_p***
1991	200
1992	186
1993	173
1994	166
1995	144
1996	129
1997	109
1998	108
1999	107
2000	108

Table 7.2: Nominal electricity prices for households (including VAT and additional charges)

Source: IEA 2002, IEA 2007

Year	***EUR/kWh***
1992	0.1366
1993	0.1381
1994	0.1381
1995	0,1404
1996	0.1491
1997	0.1500
1998	0.1509
1999	0.1262
2000	0.1275
2001	0.1324
2002	0.1379
2003	0.1348
2004	0.1423
2005	0.1402
2006	0.1390

Table 7.3: Consumer Price Index (Annual averages for Austria – Basis: 1986 = 100)
Source: Statistik Austria 2007

Year	***Index (1986 = 100)***
1992	117.7
1993	121.9
1994	125.6
1995	128.4
1996	130.8
1997	132.5
1998	133.7
1999	134.5
2000	137.6
2001	141.3
2002	143.8
2003	145.8
2004	148.8
2005	152.2
2006	154.4

7.3 Abstract

The dominance of hydrocarbons as main fuel in our present society has raised concerns. An increasing world population, the enhanced level of development and higher standards of living will impact the future energy requirements. Greenhouse gas emissions constitute another concern of the use of hydrocarbons. Renewable technologies, such as solar energy, are perceived as an option to non-renewable hydrocarbons. Solar photovoltaic energy seems to be a promising substitute to conventional electricity. In spite of its growth in recent years, the photovoltaic technology is not widely deployed. The reasons for the limited success can be derived from its technical performance in relation to the costs of the application. The photovoltaic market depends on support mechanisms for cost reductions. The Austrian government had provided subsidies in the past in order to create incentives for the installation of residential grid-connected photovoltaic applications. These measures and the development of the global market have had certain implications on the Austrian photovoltaic market and on the cost-efficiency of domestic photovoltaic applications. Therefore, the following questions arise: how has the profitability of grid-connected residential photovoltaic energy evolved with time? What have been the main factors leading to this development? Section two of this work introduces the PV technology; a presentation of the leading markets and the Austrian photovoltaic market together with the support mechanisms in these countries is followed by a study of the development of the costs of photovoltaics; the last section constitutes the final analysis of the profitability development of residential grid-tied photovoltaic electricity in Austria.

The analysis showed that developments on the global market and that the Austrian efforts to disseminate the residential grid-tied photovoltaic technology during the observed time period could not raise the cost-efficiency of this technology to a level, at which one could consider it competitive. Domestic use of grid-connected PV systems for producing electricity in Austria has not been profitable in the past and is still far away from being cost-effective today.

7.4 Zusammenfassung

In unserem modernen Leben sind Öl, Gas oder Kohle unabdingbar geworden. Jedoch bereitet die große Abhängigkeit von diesen Rohstoffen den Menschen Sorgen. Die wachsende Weltbevölkerung, die rasante Entwicklung und der weltweite Anstieg der Lebensqualität werden sich auf den zukünftigen Energiebedarf auswirken. Weiters bereiten die Schadstoffemissionen eine weitere Quelle der Verunsicherung. Erneuerbare Energieformen, wie die Solarenergie, werden als Chance für die Zukunft wahrgenommen. Die Photovoltaik wird als vielversprechender Ersatz zur Elektrizität aus fossilen Brennstoffen gehandelt. Trotz ihres Wachstums in den letzten Jahren ist diese Technologie noch nicht weit verbreitet. Die Gründe dafür liegen in der Relation der Leistung im Vergleich zu den Kosten. Kostensenkungen können nur mithilfe von Subventionen erzielt werden. Österreich hat den verstärkten Einsatz von netzgekoppelten Photovoltaikanlagen in der Vergangenheit bereits gefördert. Diese Fördermaßnahmen und die Entwicklungen am weltweiten Photovoltaikmarkt haben sich auf den österreichischen Markt und auf die Rentabilität solcher Anlagen ausgewirkt. Daher stellen sich die folgenden Fragen: wie hat sich die Profitabilität von kleinen dezentralen netzgekoppelten Photovoltaikanlagen über die Zeit entwickelt? Welche Ursachen führten zu dieser Entwicklung? Das Kapitel zwei dieser Arbeit stellt eine Einführung in die Technologie dar; im Anschluss an die Vorstellung der weltweit führenden Märkte und des österreichischen Marktes inklusive der jeweiligen Fördermaßnahmen, folgt ein Blick auf die Entwicklung der Kosten. Der fünfte Abschnitt beschäftigt sich mit der Analyse der Entwicklung der Profitabilität von kleinen dezentralen Photovoltaikanlagen in Österreich.

Diese Arbeit zeigt, dass die Entwicklungen auf dem globalen Markt und die österreichischen Initiativen zur Förderung und zur Verbreitung kleiner dezentraler Photovoltaikanlagen während des untersuchten Zeitraumes nicht imstande waren, die Kosten dieser Technologie insoweit zu senken, dass diese profitabel werden. Der Einsatz kleiner dezentraler Photovoltaikanlagen war bisher für die Stromerzeugung in Haushalten nicht kosteneffizient und ist noch weit enfernt von der Schwelle der Profitabilität.

7.5 Curriculum Vitae

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Specialization: Energy and Environmental Management (Master Thesis, Prof. Wirl)
International Management (KFK Exam, Prof. Windsperger)

1999 - 2000 **Study of Law, University of Vienna, Austria**

1986 - 1999 **French Baccalauréat and Austrian Matura, Lycee Francais de Vienne, Vienna, Austria**
Specialization: Economics and Social Studies (last two years of school education)

Professional Experience

2003 to present

Project Management, Alumni Association of the University of Vienna, Austria
Part time assignment: research, translation, event management for the UNIUN [UNIversitätsabsolventen gründen UNternehmen] qualification program; focus of the program: conveying the needed soft-skills and sustainability-skills for Entrepreneurship.

July 2005

Accountancy, MED-PLAN Steuerberatung, Wirtschaftstreuhand G.m.b.H., Vienna

Part time assignment: book-keeping assignments for clients, such as medical doctors

July – August 2003

Marketing, TRUST CONSULT Unternehmensberatung Ges.m.b.H., Vienna

Internship: assistant to marketing manager, research, database management (CRM tool), diverse marketing activities

Short Term Assignments and other Work

2006 to present	**Voluntary work:** Translation and writing of reports; administrative work NGO "Entwicklungshilfeklub", Vienna, Austria focus of the NGO: international development aid
2004 and 2006	**Short term assignments:** Conference Assistancy 21st- 22nd October 2004: 12th Conference of EUROCHAMBRES in Vienna 20th- 21st February 2006: European Conference on Security Research in Vienna
1995 – 2007	**Tutoring of high school students** in a various subjects, such as Mathematics, History and the French language