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Photovoltaic
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1 Why Photovoltaic (PV)?

“The current situation of the environment and the energy demand urgently needs drastic political, economical and technical decisions in order to face a situation that could quickly become hopeless.
Amongst the wide range of sources of renewable electricity, which itself only represents part of renewable energy sources, Photovoltaic (PV) takes a very particular place for three main reasons:

- One of its main characteristic is totally harmfulness operation for the immediate environment: no noise, no movement, no smoke, no dust, no waste, not any kind of physical risk
- Although the cost of PV power is expected to compete with conventional sources within a few years thanks to technical improvements and to mass production, the current prices are still higher than most of other renewable sources, making it more precious
- Because of its own physical properties, it is due to get a more and more large place in the daily and ordinary landscape of any part of population, as well in rural areas as in the heart of urban one.

Thus, PV, as the most popular technology, is an exemplary renewable energy from a technical point of view and for educational purposes.”
(Source: European Demonstration Project Hip-Hip.)

The Phenomena - Photovoltaic means conversion of sun rays direct into electricity. The potential for this electricity generation is nearly unlimited, since the source of energy is the sun. By using roofs or facades you need no additional space. Physically, electricity from Photovoltaic cells is high performed energy, because solar electricity can be converted into chemical, thermal and mechanical energy.

Photo-Effect - 1839, the so called "photo-electric-effect" was discovered by the French scientist E. A. Bequerel. Photons from the sun cause specific energy levels in semiconductors, which generate electric voltage. After connecting the contacts electric current flows within the semiconductor.
In general all existing chemical elements can be divided into 3 groups:

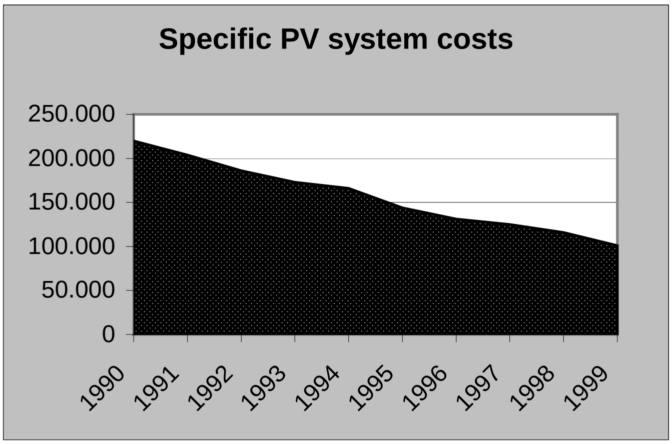
1. Isolators are characterised by fixed atoms and are not conductive.
2. Metals have free movable electrons within the crystal structure and are very conductive.
3. Semiconductors are laying between isolators and metals.

Silicon is a semiconductor with 4 free electrons at the outmost energy level. The free electrons are responsible for the binding to the neighbouring elements. Additional energy crack the bindings; at the position of a lost electron there is a defect electron (positive charge).

2 Photovoltaic market in Austria

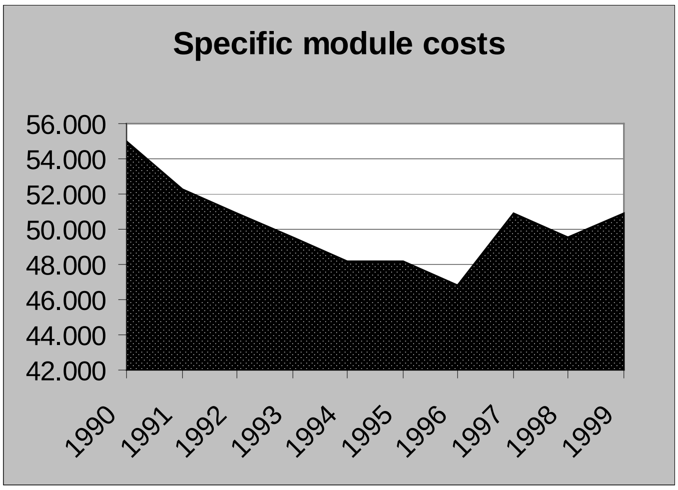
2.1. Austrian cost development

According to Austrian PV association and DI H. Wilk (Austrian PV-Expert and National ExCO-Member within the IEA PV-Power Systems-Programme) the investment costs of small residential PV systems in Austria have significantly decreased from 1990 to 1998. In the early nineties the system cost reduction was similar to the module price decreasing.



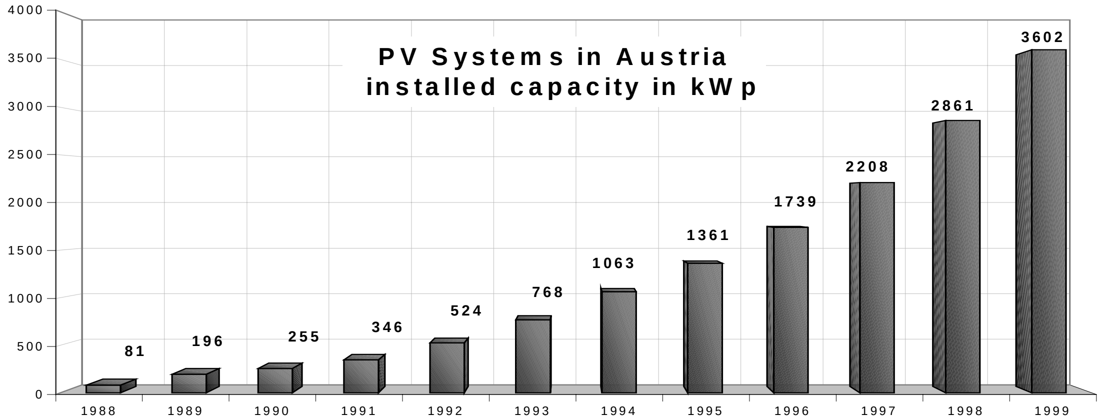
Total PV System costs (per kWp) from 1990 until 1999 (Source: Austrian PV association)

Since 1995 the decrease of the module cost stopped. The large world-wide demand of PV modules finally caused an increase of the prices. The main cause of this market situation was the implementation of promotion programmes in Germany, Japan, the Netherlands and in the United States. One result of these programmes is the move from a supply pushed market toward a more demand and service oriented market. This development went hand in hand with price reductions of components and with a shortening of the system assembling time. Both effects yield to yearly cost reductions of around 10%.



World-wide module costs (per kWp) from 1990 until 1999 (Source: DI H. Wilk)

Beside the international PV leading countries the installed Austrian capacity is small. The following diagram shows the market development during the last years. The cumulated capacity is continuously growing with around 25% per year. Regional and national financial incentives and distributed information are the major reasons for this continuos growth. But the development is only linear and not a dynamic increase.



Installed PV capacity in Austria 1988-1999 (Source: Prof. G. Faninger)

2.2. Promotion incentives

There is a wide range of incentives to promote Photovoltaic systems within Austria and its regions. The most significant subsidised programme for increasing the market penetration PV systems was the **"Austrian 200kWp Rooftop Programme "** in the nineties.

The Austrian Ministry for Economic Affairs and the Union of Austrian Utilities decided to install 200 kWp grid connected rooftop PV systems in Austria similar to the German 1000 roofs programme started in May 1992. Within this program 110 small residential grid connected PV power systems were installed until 1994. The average capacity of the plants is about 2.28 kWp. A team of experts from government and union of Austrian Utilities elected out of hundreds of PV projects the best to be subsidised. The plants were selected for getting experiences about how PV systems are working at rather distinct places e.g. like in altitudes of about 2,000 meters above sea level as well as in valleys. About 58% of the investment cost of around 170.000.- ATS/kWp were subsidised by authorities and electrical utilities. (R. Haas et al., 1999).

The major targets of the 200 kWp Rooftop program were:

- Collecting comprehensive operation data as a basis for further R&D activities on various components of PV systems,
- testing and assessing the long-term performance of small decentralised PV systems,
- investigating the maintenance efforts for small PV systems,
- optimising the system design of grid-connected systems and
- acceleration of the market penetration of PV.

In Austrian regions

Promotion incentives are very different between Austrian regions, but nevertheless insufficient concerning existing PV investment costs. The following table shows Feed-in Tariffs and investigation support for PV systems depending on different regions in Austria [1 ATS/kWh = 0,07 Euro/kWh].

<table>
<tr><th>Region</th><th>Feed-In S-HT(€/MWh)</th><th>Feed-In W-HT(€/MWh)</th><th>Investment support</th><th>Max. Subsidy (€)</th></tr>
<tr><td>Burgenland</td><td colspan="2">140</td><td>30%</td><td>1,400 €</td></tr>
<tr><td>Carinthia</td><td colspan="2">700 (till 10kW)
545 (>10kW)</td><td>--</td><td>--</td></tr>
<tr><td>Lower Austria</td><td colspan="2">129</td><td>30%</td><td>2,200 €</td></tr>
<tr><td>Upper Austria</td><td>88</td><td>149</td><td>37%</td><td>3,500 €/kWp</td></tr>
<tr><td>Salzburg</td><td>83 (till 2kW)
37</td><td>83 (till 2kW)
52</td><td>--</td><td></td></tr>
<tr><td>Styria</td><td colspan="2">363</td><td>--</td><td>--</td></tr>
<tr><td>Tyrol</td><td colspan="2">276 (till 10kW)</td><td></td><td></td></tr>
<tr><td>Vorarlberg</td><td colspan="2">111</td><td>37%</td><td>2,450 €/kWp</td></tr>
<tr><td>Vienna</td><td colspan="2">111</td><td>50%</td><td>3,500 €/kWp</td></tr>
</table>

Legend: **S-HT**: High Tariff during daytime in summer, **W-LT**: High Tariff during daytime in winter

Tab.: Regional Feed-In Tariffs and investment support (Source: Austrian PV association)

2.3. Optimised dynamic subsidy strategies

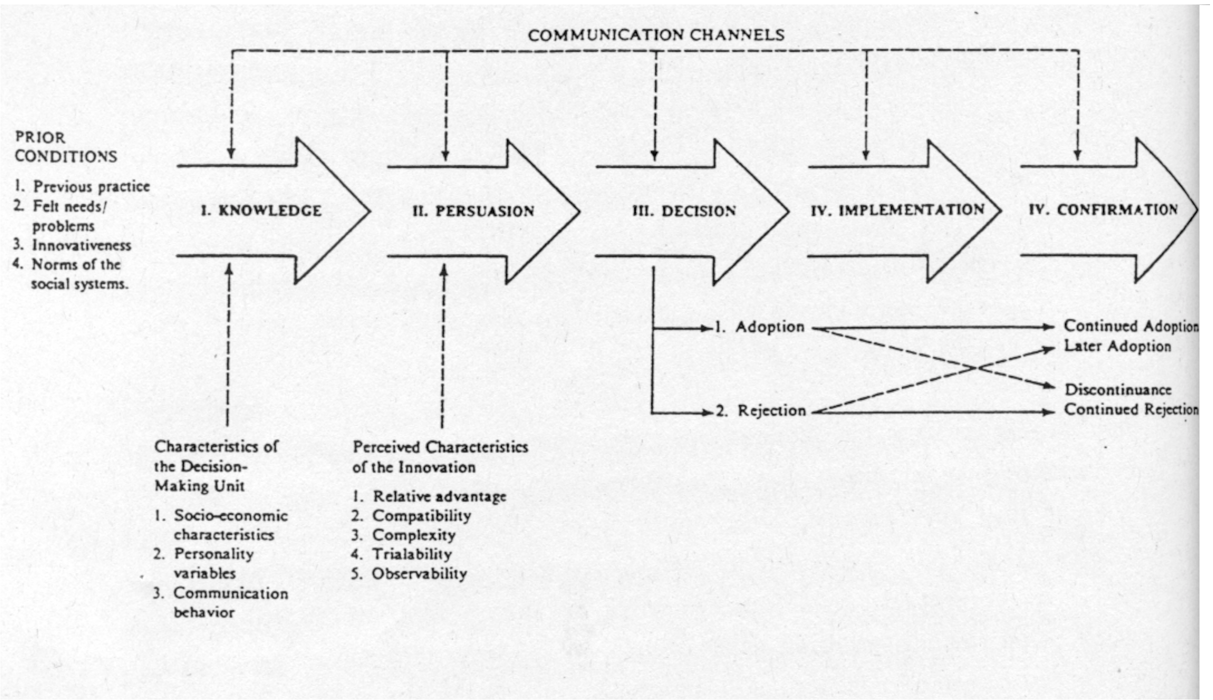
“For developing optimal subsidy strategies for PV systems different parameters like the price trend of PV systems and the willingness-to-pay of potential consumers play an important role.“ is a quotation of a diploma from A. Studentschnig (Technical University in Vienna) in 1997. “The optimal control theory is used to take into account dynamic parameters and to create dynamic models. Producing electricity with PV systems is compared with the expenditure for subsidies. It turns out that a subsidy strategy can be donated as optimal if available funds are granted as soon as possible.“

The actual situation in Germany reflects this thesis. The 100.000 Roof programme combined with higher feed-in tariffs follows the results of the investigated dynamic model. The budget of the 100.000 Roof programme had to be increased only three months after starting. The yearly fund reduction of 5% might be a good average value to follow the conclusion of A. Studentschnig’s diploma. Generally can be said:

> *The subsidies can be decreased after a preparation period impressed on dissemination activities and price reductions followed by the dynamic growing PV market.*

2.4. Sociological aspects

For promoting the development and distribution of PV plants on the market an accompanying scientific programme was installed to analyse sociological aspects within the Austrian 200 kWp Rooftop programme. The Group of Adapted Technology (GRAT) and the Institute of Economical Energy (IEW) of the Technical University of Vienna worked out sociological aspects of the Austrian 200 kWp Rooftop program (R. Haas et al., 1999). The investigations followed the “Innovation – Decision – Process” of the American Rogers concerning the question: “What are the driving forces and market preparation steps to disseminate innovative technologies.”



Willingness-To-Pay decision process (Source: Rogers)

Interviews - Detailed information were collected from three interviewed groups:

- Participants in the program (so called innovators),
- PV retail companies (so called diffusion agents) and
- informed persons, who are considered to be next adopters of PV systems.

Analysing and interpreting the data of the interviews with the participants are summarised in following results:

1. The major motives to invest in a PV system are the same for both, program participants and informed persons: Environmental protection, alternative to nuclear power and technical interest. In addition to those reasons for investment motives the presence of public subsidies for PV systems is also of principal relevance.
2. The investment in a PV system is the last part of energy saving investments chain for both, program participants and informed persons. Hence, subsidies

for PV are not in direct competition with subsidies for other energy saving measures (e.g. insulation of outdoor walls or retrofit of windows). Moreover, PV triggers electricity conservation, whereas building retrofits merely save space heating energy demand.

3. The purchase of a PV system leads to different changes in consumer behaviour. Consumers with low initial consumption increased their electricity demand slightly, consumers with high initial electricity Demand saved electrical energy.
4. The incentives in the program were not optimally designed. With the same amount of total subsidies, it would have been possible to promote more PV systems. Informed persons have a rather willingness to invest in PV systems. Yet, they claim rebates to put this willingness to pay into practice.
5. The key factors for further dissemination of PV systems are subsidies, rebates or full cost rates, reduction of the investment costs, increase in reliability, well aimed distribution of information and enhancement of environmental awareness.

3 Photovoltaic Components

Solar Heat (Solar Thermal Collectors) and electricity (Photovoltaik) production are often mixed. Generally can be stated:

- Photovoltaics is a semiconductor technology that converts light energy into direct-current electricity, with no moving parts. In its current form Photovoltaics has been developed in 1953-1954, for the aim of power supply of satellites in space since 1958; remote telecommunications, cathodic protection, and signaling systems since the mid-1960s; remote residential and commercial systems since the 1970s; and utility-intertied residential and commercial systems since the 1980s.

- Solar (thermal) collectors are heat exchangers, which convert the sun rays on a black absorber plate into heat. The heat is removed from the absorber by fluid filled pipes integrated into the plate. Afterwards, the heated fluid is used for space heating and hot water preparation.

Solar cells

Mono crystalline silicon

Sliced from single-crystal boules of grown silicon, these wafers/cells are now cut as thin as 200 microns. Research cells have reached nearly 24-percent efficiency, with commercial modules of single-crystal cells exceeding 15-percent.

Poly crystalline silicon

Sliced from blocks of cast silicon, these wafers/cells are both less expensive to manufacture and less efficient than single-crystal silicon cells. Research cells approach 18-percent efficiency, and commercial modules approach 14-percent efficiency.

Gallium Arsenide (GaAs)

A III-V semiconductor material from which high-efficiency photovoltaic cells are made, often used in concentrator systems and space power systems. Research cell efficiencies greater than 25 percent under 1-sun conditions, and nearly 28 percent under concentrated sunlight. Multijunction cells based on GaAs and related III-V alloys have exceeded 30-percent efficiency.

Integrated Thin Film Technology

Copper Indium Diselenide (CuInSe2, or CIS)
A thin-film polycrystalline material, which has reached a research efficiency of 17.7%, delivers the highest completed module efficiency for full sized power modules, reaching over 11 percent.

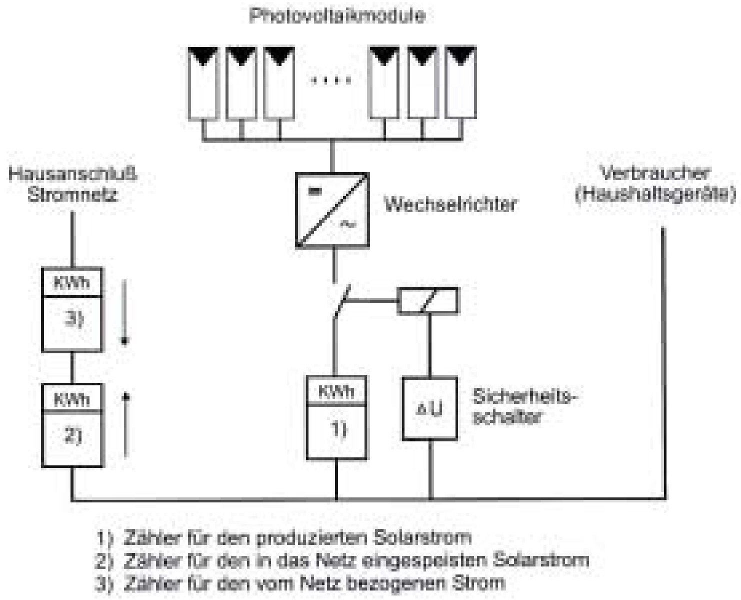
Amorphous Silicon (a-Si)
Used mostly in consumer products for solar watches and calculators, a-Si technology is also used in building-integrated systems, replacing tinted glass with semi-transparent modules. The primary issue with a-Si technology remains the low efficiency and associated greater requirement for space and higher array installed cost and weight

Cadmium Telluride (CdTe)
A thin-film polycrystalline material, deposited by electrodeposition, spraying, and high-rate evaporation. Small laboratory devices reached 16% efficiency, with commercial-sized modules (7200-cm2) measured at 8.34% (NREL-measured total-area) efficiency and production modules at approximately 7 percent.

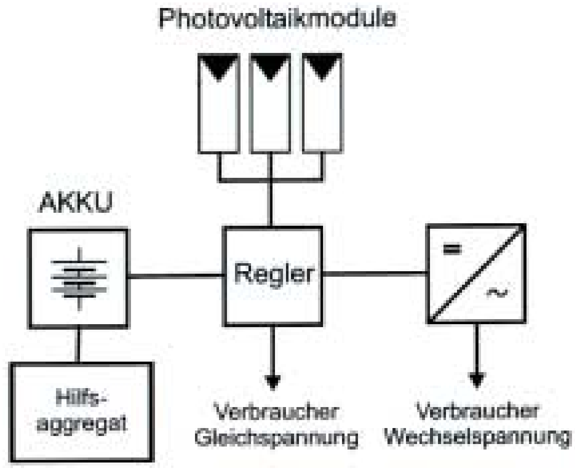
4 Applications

The two types of applications are:

- Grid connected systems (GCS) which feed directly into the public grid.



- Stand alone system (SAS), which do not possess a coupling with the electricity grid.



4.1. Grid connected systems

In areas with an existing utility grid it normally makes no sense to operate the PV System as stand alone system. Avoiding the costs for the batteries it is more easy to connect the system with the grid by means of an DC/AC inverter. Beside the conversion into AC, the inverter is responsible for the maximum power tracking (MPP-Tracking). MPP-Tracking means to optimise the electrical performance automatically. Aspects of reliability, safety and electromagnetic compatibility are further features which an inverter must comply with. Investigations regarding the effect of lightning and other effects which may influence the power grid are just under intensive research.

Installing a Photovoltaic-System on and integrating into a multi-family house arises immediately the question about the optimal building integration. Nowadays Photovoltaic modules are more and more often integrated into the roof, serving as part of the roof or used as entire roof area. Sometimes PV -elements are even made like roof tiles. Most of these innovative PV systems are installed in the highly industrialised countries such as Germany, the USA and Japan as well as Austria. Competitions and impulse programs e.g. the " house of the future " of the Austrian Ministry of Traffic Innovation and Technology further pushes the development of such innovative solar technologies.

Building and facade integration of PV modules depends substantially on the co-financing by supporting measures of national or European programs. Target of these programs is to integrate the solar cells in the same way like other standard elements into the building envelope. New, coloured and individually formed cells offer new possibilities for architects. Information campaigns and competitions are the instruments for a successful dissemination. A CDROM of the IEA task VII - " Photovoltaic power of system into the Built Environment " shows impressively examples of modern solar architecture.

This IEA task has also established a Website (www.demosite.ch) designed, on different versions the fixings, to which roof and front integration and free standing carriers are demonstrated.
Shown are:

- Innovative module attachment and interconnecting concepts
- Facade components on base of usual market standardmodule
- Integration of PV components into the building cover
- Roof integration
- Solar roofing tile or. - items
- Glass A packagings
- Shading items
- Amorphous solar cells, AC of modules...

PV-Noise barriers

Stricter official regulations, laws for newly built traffic routes, increased feed-in tariffs for the grid connected solar electricity are the main reason for the establishment of PV noise barriers. Switzerland and Germany are outriders of this market tendency, which now also in Austria finds rising interest. To the "16th European test specifications conference in Glasgow" in May 2000, the market potentials of this technology for six countries of Europe were presented / 9 /
on the basis of the different concepts and architectures implemented in demonstration projects like

1. installed PV modules or PV roof-elements on existing walls
2. the vertical simple or Bifacial-construction,
3. the horizontal Zigzag construction and
4. the cassette form

There are high potentials for a wide dissemination of PV noise barriers in Germany, the Netherlands and Switzerland. Austria has good market potentials as well, where increased feed-in remuneration - e.g. in Carinthia and Styria - are paid.

4.2. Stand Alone Systems

Photovoltaic-Moduls, battery and load automatic controllers are the basic elements for a current supply off the utility grids. On alpine huts and holiday houses, they are often the most economic solution. In this applications PV systems have much advantages in contrast to the noise- and emission-rich Diesel generator. The system voltage of an island system is usually 12 V of DC voltage, with larger systems in addition, 24 or 48 V. For 12 V of voltage, in addition, for the other voltage levels a variety of devices can be bought. (lamps, radios, refrigerators, vacuum cleaners, television sets, pumps...). For operating devices with other voltages, it is necessary to use a dc static converter. If one wants to use devices, which are intended for the link at 220 V alternating current (the usual current supply in households), then the application of an inverter is inevitable. The efficiency of such a system is slightly less. However, it can be used with 230V devices in Stand Alone systems from time to time.

5 Batteries

With the use of renewable energies (wind, photovoltaic) for sites which are isolated from the energy network, electricity production profiles do not fit with consumption profiles. To meet consumers power needs, it is necessary to store the energy. Lead-acid batteries, which are most often used for this storage, represent today more than 90% of the industrial or domestic installed batteries and their market share will be still significant in the next 25 years. Often battery lifetime in the field is considerably less than the manufacturer's claimed lifetime, because of energy management shortfalls. Classical methods of battery management, which are based on voltage threshold control, are not able to avoid :

- stratification of electrolyte, because of incomplete charges ,
- sulfation hardening, which builds up during periods of insufficient electricity production.

Premature failures of lead-acid batteries are principally linked to these two processes. The battery management is then a key point in such systems.
An EDF (Electricité de France) patent disseminated within the European demonstration project MULTIBAT will solve this problem and will significantly extend the lead-acid batteries.

6 Demo Project Stüdlhütte

Planning aspects of the Alpine hut: The substantial criteria for planning the best utilisation of the Energy resources of such a remote Alpine hut of 2800m attitude is t**he Rational Use of Energy and the effective Use of Renewables under given economical conditions**. The starting point for the application of Renewable Energy at the Stüdlhütte was the evaluation and selection of the construction and the isolation material. The requirements of the hut and restaurant owner led to the decision of a hybrid system, because this system represented the best solution for supplying Energy, when it is needed. The Energy planner of the hut took into their consideration the remote aspects of the Stüdlhütte by developing and installing the hybrid system. Mountain huts offer the possibility of proving with model-like projects the optimised integration of Renewable energy. The application system as pilot object, which works continuously under extreme positions of high mountains might easily realisable at valley sites under normal conditions.

For the calculation of the hybrid systems the planner can normally assess to reliable Data of the weather services. In remote areas like the Alps the climate Data must be referred through faraway-assessable weather stations. High Alpine experiences and the knowledge in the winter of occurring snow reflections are essential for planning. The sizing of the system for measured irradiation yields until 1700 W/m². The selection of durable components is necessary because of the extreme climate conditions.

The operational start: Up to the beginning of the test operation at 12th of September,1995 the helicopter transported around 28 tons technical equipment to the Stüdlhuette. The extreme snowing and the storms delayed the planned start of operation. The helicopter could not fly and the material cableway could not drive because of the high snow level. Due to the described weather conditions the installed Photovoltaic (PV) systems inclusive the Battery Back-up started to operate in the second half of September. For ensuring the equalising charge of the batteries and for covering the peak loads an additional District heating power station was installed in October 1995, which operates with pure vegetable oil. The power station produces 6 kW electrical and 11 kW thermal power and works perfectly in the winter season with minus 20 degrees.

The existing facilities integrated in the Stüdlhütte

- Photovoltaic system (3,4 kWp: Approx. 31.5 m² 32 modules of 108 Wp installed on the roof of the hut and 2 Siemens inverters of 1500W and 600W/230V~),
- Battery back-up (capacity 2x2.000Ah/24V) with integrated control unit,
- District heating power station (6 kW electrical and 11 kW thermal power operating with pure vegetable oil),
- Electricity installation,
- Solar thermal system for heating,
- Drinking water sterilisation, ...

The PV system with the two vented lead acid battery supply 73% of the consumed hut electricity. The discharging of the batteries is controlled through the integrated unit, which triggers the start up of the district heating power station.

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