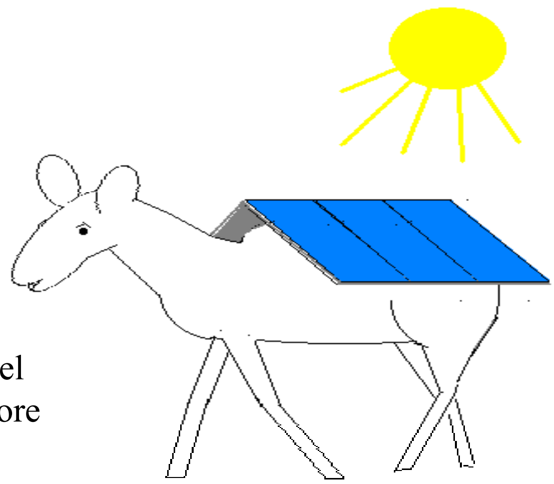
SIXTH INTERNATIONAL SUMMER SCHOOL
SOLAR ENERGY 2000

Workshop 4

PHOTOVOLTAICS

Wolfhart Bucher et al.

PV - Peak Vision



From the Back of a Camel
you can definitely see more
than from the ground.

But how to find a Camel?
And make shure not to
follow a Fata Morgana!

Documentation of the Results of Workshop IV:

Photovoltaics

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Photovoltaic Cells – the silent Energy Source

Wolfhart Bucher, DLR

Despite of many fluctuations in the energy demand and price figures energy statistics of the last decades of the 20th century illustrate an obvious trend: PV module production increased nearly steadily from below 1 MW per year in the early 70-ties to more than 200 MW last year. Summarising the production figures in this period leads to an installed capacity of solar systems utilising PV conversion, which exceeds 1 GW. Exact figures would be difficult to compile, since there are no reliable statistics about decommissioned systems and the fraction of replacement needed for older plants. Anyway, the figure is quite impressive, even if still very low in comparison to the world-wide energy demand and to the electricity generation capacity based on conventional energy sources.

Even if all predictions and trend extrapolations show a strong growth (Table 1), there is still need for further development and for market promotion measures. Improvement of PV-cells and other system components is valuable to increase the cost-benefit ratio of PV-systems, financing and marketing routines could make the technology available and attractive to a broader audience, and the demonstration of the various applications will contribute to the public awareness about the advantages of the method. From a technical point of view as well the approach to provide basic energy needs for regions with no access to other resources is an interesting topic as the utilisation of PV in grid-connected mode as a means to save fossil energy.

A few years ago in the general opinion high priority was devoted to PV-applications as a means to build up electricity infrastructures in the Third World or in regions with weak supply. Now expectations rise that Building Integrated PV (BIPV) in the industrialised countries will become a significant factor in the grid-coupled electricity production infrastructure. One important reason for this change of minds is certainly the still high costs of energy from PV devices. Without additional financial support only a few people in developing countries can afford the expensive equipment. This hampers the dissemination of the technology. In contrary, the scientific community in the industrialised countries and especially in Europe is regarding alternative energy concepts as a means to cope with the promised reductions in CO_2 emissions – costs playing not so an important role, since many governments grant tax incentives and subsidies, acting under the pressure of agreements to limit the emission levels.

Table 1: PV - Market Statistics and Forecasts until 2010 [MW production/year]

Application, Market: <TBODY>	**1990**	**1993**	**1996**	**1997**	**1998**	**1999**	**2000**	**2005**	**2010**
Consumer Products	16	18	22	26	30	35	40	70	100
off-grid Residential	3	5	8	9	10	13	15	30	50
off-grid Rural	6	8	15	19	24	31	35	80	200
Communication; Signal	14	16	23	28	31	35	40	60	200
Commercial and Hybrid	7	10	12	16	20	25	10	60	150
grid-conn. Residential	1	2	7	27	36	60	110	300	800
Power Plants (>100 kW)	1	2	2	2	2	2	5	50	200
Total [MW/year]	**48**	**61**	**89**	**127**	**153**	**201**	**255**	650	1700
Profitable PV-Price [$/W ex fact.**]**	**>5,50**	**5,00**	**4,75**	**4,25**	**<4,00**	**3,75**	**3,5**	2,0	1,50
System Costs (installed) [$/W]	**15...19**	**14...18**	**12...16**	**10...15**	**9...13**	**8...12**	**7...12**	4 ... 8	3 ... 6</TBODY>

Source: P.D. Maycock; Ren. ENERGY World, Jul-Aug 2000
(data partially adapted and enhanced)

Nevertheless, in comparison to conventional electricity costs from the mains energy from PV is still quite expensive. The actual figures depend not only on the system prices and the economy of scale, also the ambient conditions and the seasonal irradiance parameters influence the outcome. Table 2 shows some data from a recent study, in part modified according to latest test results from large-scale field measurements.

Table 2: Economic Analysis of grid-connected PV-Systems

	USA			**Japan**		Germany	
Location	California	Virginia	California	-	-	-	-
Annuity	regular	regular	low	low	low	regular	low
(Year)	(1999)	(1999)	(1999)	(1999)	(2005)	(1999)	(1999)
Installed Costs [$/W$_p$]	7,-	7,-	7,-	8,-	5,-	9,-	9,-
Ann. Peak Hours (estim.) *1)	*1200*	*1050*	*1200*	*800*	*800*	*750*	*750*
Capital Recov. Factor	13%	13%	5%	8%	8%	8%	~7%
Subsidies [$/W$_p$]	-	-	3,-$ & Tax	-	-	-	-
Electr. Costs [$/kWh] *1)	*0,75*	*0,87*	*0,24*	*0,61*	*0,50*	*0,96*	*0,83*
Grid electr. Price [$/kWh]	0,14	0,08	0,14	0,27	0,27	0,22	0,5 *2)

Source: P.D. Maycock; Renewable ENERGY World, Jul-Aug 2000
Remarks: *1) Annual peak hours and cost figures modified!
*2) 0,5 $/kWh acc. to actual German 'solar electricity' regulations (2000)

Using only the data in the lower part of Table 2 for an economic assessment is somewhat misleading: grid electricity prices may be a "reliable" basis for judgement in the industrialised regions, but they show only part of the picture. For conventionally generated electricity at remote locations costs of more than 0,5 $/kWh are common. With regard to the definitely better irradiance conditions in the developing countries it can easily be deduced that putting these costs in relationship to the costs of electricity from a solar system will result in very similar figures. At least for systems of small or moderate size even advantages for solar solutions exist, and it is expected that this situation will still improve as economy of scale effects become true.

Besides looking at the costs there are some other perspectives influencing the choice between the energy concepts. Solar systems are certainly superior with respect to environmental aspects: They do not pose any pollution hazards (as is the case, when fossil fuels are transported over large distances, or when used lubricants or other waste materials are dumped in an often fragile environment). Moreover, the energy required to transport fuels to remote locations is often not counted for when the specific energy consumption is assessed.

On the other hand, very divergent records have been published about the reliability of solar systems. Obviously the technology is mature and capable to cope with tough conditions and requirements, but also frequent reports tell us that there is still an unsatisfactory state of development with regard to the balance-of-system components (batteries, controllers) and auxiliary equipment, and that not in any case the lay-out of the system and the choice of gear was done properly. This makes the need apparent for additional endeavour to improve the technical hardware as to enhance the awareness of the people involved about the important topics.

The workshop activities in the framework of the Summer School 2000 can in part be seen as a contribution to the tasks mentioned above – or even as proof about the level of understanding and knowledge reached in an important field of solar energy utilisation.

Design Considerations of Photovoltaic Systems

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Introduction

Optimal results from solar devices can only be derived, if the design takes into account the variability of the solar resource as well as the demand, which is mainly defined by the users' needs. For photovoltaic appliances lay-out routines have been developed, which – if applied properly – lead to an adequate system performance. In the following paper the basic considerations and the physical properties controlling the design process are presented.
Since PV devices preferably yield electric energy (concentrating PV with forced heat rejection being the exception) the topic is concentrating on electric energy output, even if similar approaches also apply to most other solar appliances.

1. Basic System Parameters of PV cells

The basic element of any PV system is the photovoltaic cell, usually with an area close to or larger than 10 cm x 10 cm. The thickness of the cell can vary widely (0,01 – 0,4 mm), depending on the cell type, material, and manufacturing processes. The bulk of cells from the market is made from Silicon, generating a voltage of approximately 0,5 volts and a current, which depends on the irradiation and the geometry of the cell. By connecting these cells in series and parallel it is possible to build up panels, and from panels finally modules fitting the desired voltage level and capable to deliver the nominal power can be manufactured.

The most typical voltage levels in small PV-systems are 12V and 24V, but depending on the application the system voltage can even be higher (e.g. 144V). One has to remember - though - that by increasing the voltage level safety issues may become increasingly important.

The power of commercial PV-systems typically ranges from a couple of watts to some kilowatts, stand-alone concepts for industrial applications and for small enterprise nay have even larger output. Since PV-systems are modular, no upper limits for the power rating exist, but even in grid connection arrays beyond 1 MW output have not been realised so far.

Practical limits exist for the balance-of-system components (regulators, transformers, controls, etc.). Since for safety reasons moderate voltage levels are preferred, the nominal current in existing systems can easily reach some 100 amperes to kilo-amperes. So in any case the optimal lay-out necessitates some considerations, especially, since all other system components including batteries, charge controllers (regulators) or inverters, metering and cabling have to be adapted to these levels as well.

2. Available solar energy

Beyond the earth's atmosphere the intensity of solar radiation amounts to 1353 W/m^2. This so called Solar Constant is more or less invariable. On the surface of the earth however the insolation varies with time and place: The earth's orbit around the sun causes the seasonal variation between winter and summer and the rotation of the globe results in days and nights, the duration depending on season and latitude. In addition to these predictable deviations the weather conditions are constantly changing – subjecting the actual solar irradiance level to stochastic rules.

To cope with such unpredictable conditions the "available" solar energy at a specific location is usually approximated by monthly average values. Such data can be derived from long-term measurements and are available as insolation figures on a horizontal surface. In Austria for example this is in December approximately 40 kWh/m^2, whereas in July it is as high as 150 kWh/m^2. Per year this leads to about 1000 kWh/m^2 in lowlands and up to 1400 kWh/m^2 in Alpine regions in Austria. Since with increasing latitude the radiation impinging on a horizontal plane is reduced, it is common to modify the inclination angle of any solar devices. Accordingly, in the Northern hemisphere it is optimal to tilt the solar modules to the south to face the suns path over the sky. The optimal fixed tilt angle, which produces greatest yearly solar output, depends on the latitude and is 30° in Austria. In addition to choosing optimal alignment of the PV-panels, one also has to avoid any shading of the panels as much as feasible (see also the following paper on "grid-connected PV").

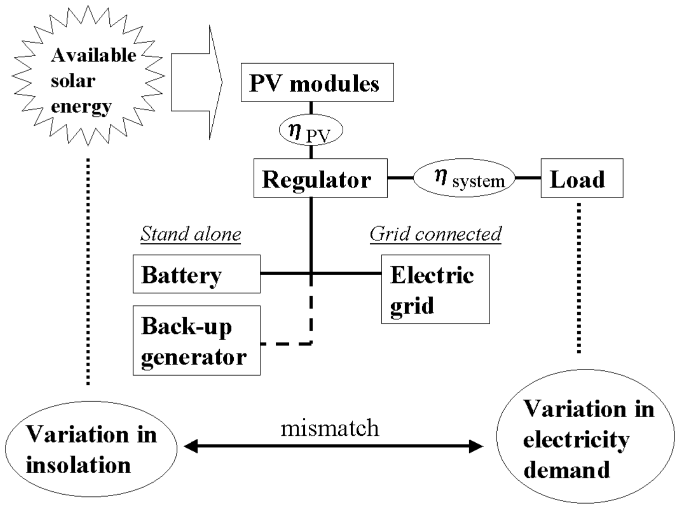

Figure 1. Design factors of PV-system

3. User's needs

The electric energy required depends in general on the application: operating telecommunication links necessitates fairly constant power throughout the year, whilst lighting system in mobile homes and in sail boat are in use only short periods of time every now and then. The load profile of the system intended to be electrified by photovoltaic therefore determines the optimally sizing of the system components. The lay-out is usually performed taking all appliances (e.g. for small household systems), estimating their respective time of use on a daily basis and multiplying this figure with the (nominal) power of the appliance. Summing up every device yields the user's load profile and electricity demand (kWh/d).

The ratio of electric energy produced by the photovoltaic system to the total electric energy consumed by the system is called solar fraction. For small stand alone systems in remote areas, it may be preferable to have solar fraction of 100% in order to eliminate the need of delivering additional energy for the system at potentially high costs. On the other hand in grid connected household systems the solar fraction is usually much lower as the capacity of the PV–system may be considered only as sort of extra "green" energy from a certain number of modules.

The desired solar fraction together with the user's electricity demand and the system efficiency determines the average amount of electricity to be delivered from the PV-system; as a consequence: this energy demand determines – with respect to the available solar energy and PV-module efficiency - the total PV-panel area needed.

$$\text{PV electricity needed (kWh/d)} = \frac{\text{energy demand (kWh/d)} \cdot \text{solar fraction (\%)}}{\text{system efficiency (\%)}}$$

$$\text{PV area needed (m}^2) = \frac{\text{PV electricity needed (kWh/d)}}{\text{available solar energy (kWh/d/m}^2) \cdot \text{module efficiency (\%) /100}}$$

Costs of PV-modules usually are proportional to the active surface area of the modules. To eliminate differences in module efficiency it is common to use a standardised nominal PV output power, which is defined by the so called Peak Power (W_p), which is measured under Standard Test Conditions (STC), i.e. at a solar intensity of 1000 W/m^2 and at 25°C ambient temperature. So the higher the solar irradiance, the smaller a PV area and number of modules is sufficient to satisfy a certain demand of electricity: Smaller PV arrays also mean lower investment costs for the PV unit.

3. Energy storage

The variable solar insolation and the load profile in general do not correspond. Lighting is for example needed practically only when the sun is not shining. This means that PV electricity cannot be generated at the time of maximal demand. The same goes for seasonal variations: In summer time there is a lot of sunshine while the need for lighting is practically reduced to only some late hours, while in winter time the situation is quite opposite: the already small amount of solar energy has to be collected during the short daylight hours.
Another example is a PV-system in a week-end cottage, where there is use of energy only during weekends, while solar energy will be collected during the whole week.

To deal with this mismatch between supply and demand an energy storage or backup electricity generator is needed. In the case of stand alone systems usually conventional batteries are used to store the energy, the performance of the accumulator being optimised with regard to the system conditions. When a backup generator is installed, usually diesel generators present the favourable solution. One potentially advantageous storage system is the electrolyser – hydrogen storage – fuel cell–system, where electrical energy can be stored as chemical energy and converted back to electricity.

In the case of grid connected systems energy storage is not needed, because electricity can be supplied to or obtained from the grid depending on the situation. The electric grid can thus be viewed as a kind of energy storage, where stored energy is energy not produced by some other generator.

The system autonomy is usually measured by number of days that the system can operate without PV generation. For grid connected systems this is really not a question, but for stand alone systems higher autonomy means bigger battery capacity, where no other sort of backup energy is available. The number of days of autonomy together with daily energy demand and maximum depth of discharge of the batteries determine the battery capacity.

$$\text{battery capacity (kWh)} = \frac{\text{days of autonomy (d)} \cdot \text{max. daily el. demand (kWh/d)}}{\text{max. depth of discharge (\%) / 100}}$$

Sizing PV arrays and battery banks goes hand in hand. The area of the PV panels has to be sufficiently large to collect the amount of energy needed in a certain period of system operation (week, month or year), and the battery capacity has to be high enough to compensate for the mismatch between alternating irradiation and energy demand and to cover all losses.

Even though photovoltaics is flexible and adaptive way of electricity generation in both residential and industrial applications, it may not always be economically reasonable to choose PV. The available solar energy at the location in question together with the system costs determine the price of PV electricity. Usually PV projects are economically compared with other forms of energy generation. This will be subsequently examined as a case-study of two almost equal PV-systems in totally different solar conditions.

Stand Alone PV System: Case Studies

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1. INTRODUCTION

In regions, where access to a public electric grid is not available, Stand Alone Systems (SAS) present a viable solution. PV supported SAS are common with or without battery storage, frequently even combinations with batteries and other power sources are used (the so called back up systems in most cases include diesel generators, which are the preferred supplement to the PV array, thus making up hybrid energy systems). Very familiar examples of systems without battery storage are the applications for water pumping, where the water reservoir can serve as energy storage. Nevertheless, the standard configuration for most SAS applications is utilising electro-chemical storage.
Depending on the load connected to the SAS either direct current (DC) or alternating current (AC) electrical circuits can be set up, AC systems (mostly with battery) being common for higher power applications. The introduction of an inverter in AC systems between the DC circuit connecting the PV modules (batteries) and the load contributes to somewhat higher investment costs. Thus, simple and low power concepts usually stick to DC circuitry.

2. GENERAL APPLICATIONS

SAS are mostly used in remote locations with no access to the utility grid. Even in the developed countries such districts are found, be it in the mountainous regions, along the sea shore, or in recreational places far from the grid. The main areas of SAS application there are water pumping, telecommunication transmitters, etc. Such applications mostly replace diesel generators thereby reducing emission and noise pollution. Small SAS appliances, like car park-meters, can even be commercially attractive in very short distances from the grid. The same is true for emergency telephones along motor ways.
In developing countries a high proportion of the population has no access at all to electricity. Rural health stations, schools, community centres etc. are the principal areas where SAS are being utilised, for the likewise important private sector the so called Solar Home Systems (SHS) are available. Water pumping in villages is another important application.
Experiences from some countries can be mentioned here. A survey carried out by IAE [1] reported the experiences of 21 developing countries. According to the survey India, Thailand, South Africa, Brazil, and Kenya have the highest numbers of installed PV power. Many of the implementation projects in developing countries are often funded by international agencies in co-operation with governments. However, Kenya, Dominican Republic and Namibia have successfully and autonomously developed commercial PV industry infrastructure without foreign aid. Recent SAS projects in Brazil provide power for lighting, video equipment and satellite dishes for local community centres and schools. In Uganda a project is under way to replace the use of kerosene lighting in churches by SAS-power.
To enhance dissemination activities, developing countries are given opportunities to utilise the experiences of developed countries in PV technology. Task IX of the IAE PVPS deals with international collaboration efforts, through which developing countries could get support in the field [2].

3. CASE STUDIES

In the following case studies the design steps and the properties influencing the selection of SAS-components will be demonstrated. The software PVSYST is used for the design and lay-out of systems for moderate demand schemes, considering similar performance under local conditions for Addis Ababa, Ethiopia, and for a location near Vienna, Austria.

3.1 Addis Ababa, Ethiopia

In Ethiopia 90 % of the population have no access to supply of electricity. The main electricity supply is generated from hydroelectric power. Only densely populated areas near the large cities are connected to the electricity supply grid. PV application for water pumping, health stations and telecommunication are reported in the survey mentioned above [1]. The amount of installed PV power was not available in the survey, however, PV utilisation is very low, at least with respect to the enormous potential of solar irradiation.

Figure 1 shows the horizontal global irradiation at Addis Ababa [1990 data]. During eight months of the year the monthly horizontal irradiance is above 600 kWh/m^2. Only during the rainy season of June, July, August and September the amount of irradiation is slightly lower. The sun path diagram shown in Figure 2 shows that the sun is mostly overhead. Hence flat (0^0 tilt) orientation would provide maximum power from the PV module. When flat orientation is not convenient for installation, a low tilt angle would be recommended.

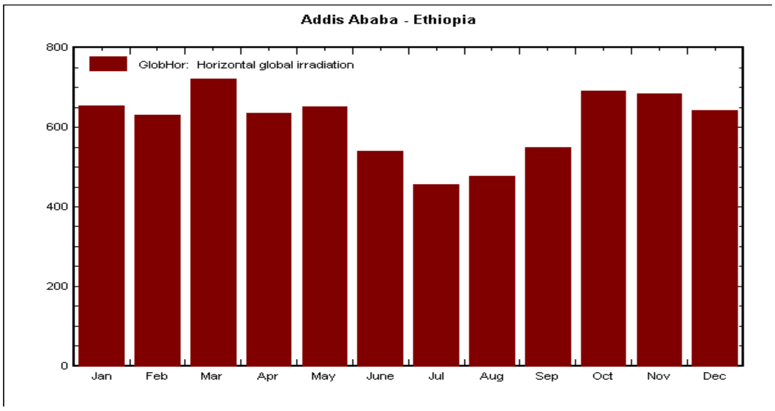

Figure 1 Horizontal global irradiation at Addis Ababa – Ethiopia.

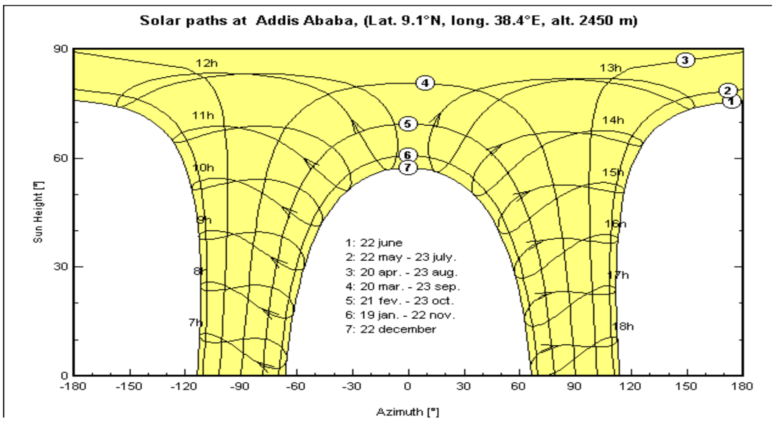

Figure 2 Solar path diagram at Addis Ababa.

In the calculations compiled below two examples for utilising SAS were considered. The first case study demonstrates SAS for lighting purposes as a replacement for conventional kerosene lamps, which still are mostly used in rural houses. The second example demonstrates SAS for lighting and appliances such as refrigerators, radio, TV etc. The consumption in this second case is representing electric loads typical for a health station, school or community centre in the developing countries – or a quite common domestic demand in the industrialised countries.

3.1.1 SAS replacing kerosene lamp

Kerosene lamps are used for lighting, be it in domestic homes, churches and mosques in rural areas. SAS could be used to replace the kerosene lamps and provide a better quality lighting. Considering a single kerosene lamp for lighting a house for about 4-5 hours daily, the fuel consumption is estimated up to 0.5 l per day. According to a study in developing countries the cost of the lamp and accessories (replacement parts) is estimated at 3.5 € per month. The additional fuel costs (kerosene) amount to about 7.5 € per month, making the total estimated cost 11,- € per month.

SAS to replace the kerosene lamp requires PV modules delivering 50-100 W_p and a battery. The total investment cost for such a system is estimated at 800 €. Assuming a rather short life time of 10 years to accommodate running costs and 6 % interest rate, the investment cost is found to be 10.5 € per month. This shows that the SAS is competitive in such application.

The initial investment cost of SAS is high, at least as compared to the income of a large part of the rural population in the country. Moreover, PV modules have regularly to be imported spending hard currency, which makes the financing of SAS difficult. However, to minimise costs domestic manufacturing some parts and assembly of components using local staff seems to be favourable. Perhaps in the near future - after further research and development - complete modules could be manufactured nationally.

3.1.2 SAS for lighting and appliances

After selecting the location and loading meteorological data, electricity load profile representative of a rural application has to be estimated. Table 2 shows typical electrical load figures for lighting and common appliances. The data is entered as User Load in the PVSYST software.

Table 1 Estimate of user loads.

Load	Power (W)	Duration (h/day)	Consumption (Wh/day)
Lighting	45	6	270
Radio	10	6	60
Refrigerator	75	8	600
TV	130	4	520
Total			**1,450**

Selecting horizontal plate (0^0 tilt) and assuming an albedo coefficient (The albedo coefficient is the fraction of global incident irradiation reflected by the ground in front of a tilted plane.) of 0.2, the number of modules required can be determined. For appropriate sizing of the PV array the following factors have to be considered: Loss of Load (LoL) probability 5 %, System autonomy 1 day, Battery 12 V, Operating battery temperature 20^0C.

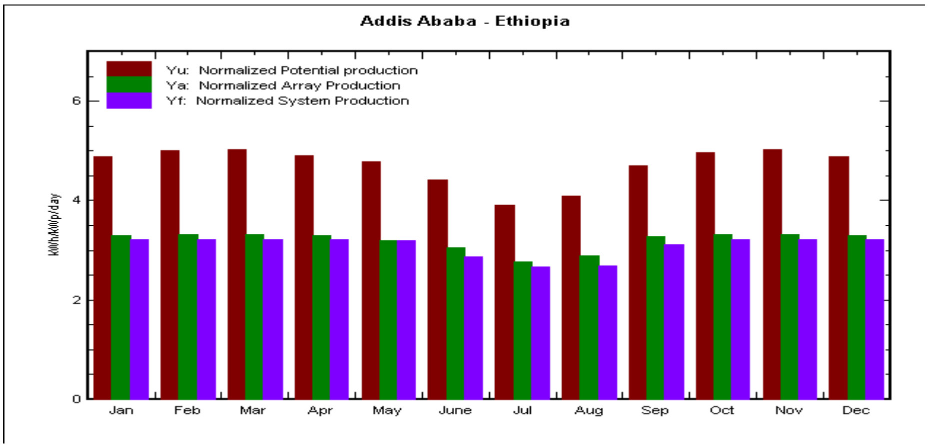

Figure 3 Normalised Performance Parameters (Addis Adeba)

The desired data lead to a 450 W_p PV system : 9x50 W_p modules, 2x80Ah batteries, and a regulator (27 A). Some of the simulation results for the system using the meteorological data described above are shown in Figure 3. The figure shows the Normalised Performance Parameters. The performance ratio (PR) varies from 0.50 – 0.65 and the Solar fraction during the rainy season of June, July and August varies between 0.8-0.9. This implies that during the rainy season there will be 10-20 % loss of load. If loss of load is not accepted, the SAS had to be oversized to 650 W_p PV system with 4x80Ah batteries. The PR in such a system will drop to 0.35-0.55.

3.2 Vienna-Austria

Considering a garden house or mountain hut with no grid access located near Vienna, similar user loads as shown in Table 1 could be assumed. For reasons of better comparison a load of 1,450 Wh/day was used as input to the PVSYST software. Figure 4 and Figure 5 show the horizontal irradiation and the sun path diagram for a location near Vienna.

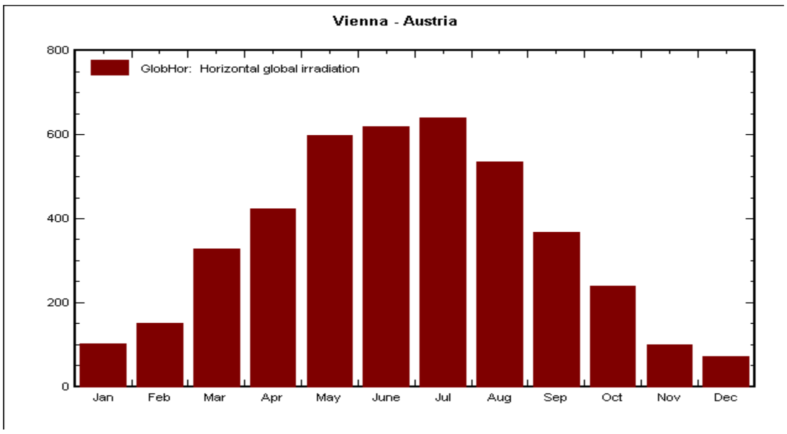

Figure 4 Horizontal global irradiation at Vienna – Austria.

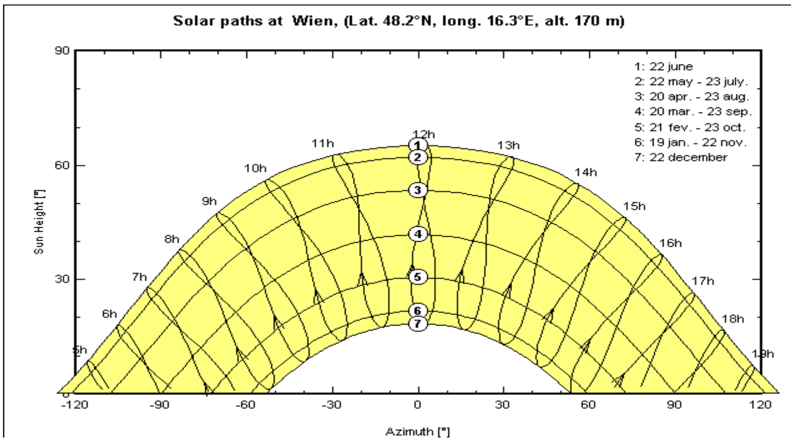

Figure 5 Solar path diagram at Vienna – Austria.

Selecting a tilt angle of 30^0 (which is optimum for Vienna) and an albedo value of 0.2, the number of modules required was determined. Assuming similar factors for the PV sizing as mentioned in the previous case results in 1,620 W_p modules power, 2x24 V, 96 Ah batteries and a regulator (50A).

Some of the simulation results of the system using the meteorological data described above are shown in Figure 6. The figure shows the Normalised Performance Parameters. The performance ratio (PR) varies from 0.15-0.45 and the Solar fraction during the winter season drops as low as 0.5.

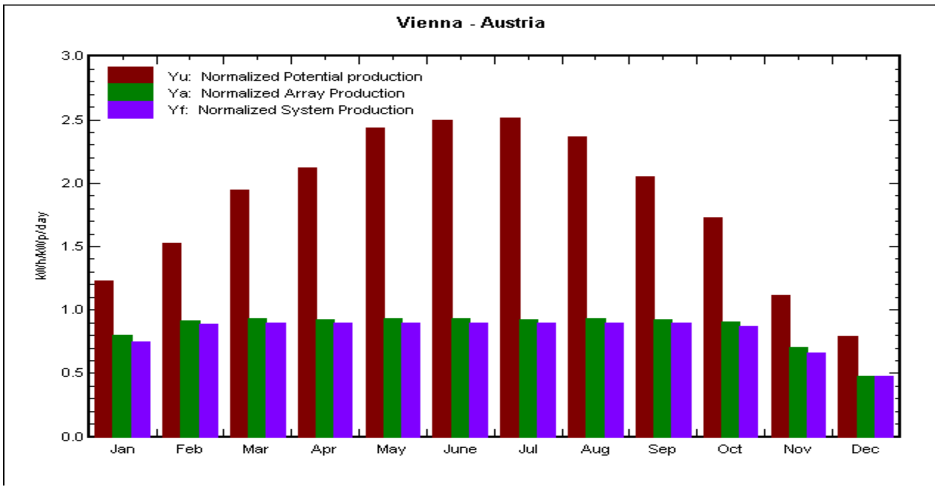

Figure 6 Normalised Performance Parameters.

3.3 Comparison

The following table compares the data and results of the two cases: Vienna versus Addis Ababa. As a result it can be noted from this comparison that due to the higher solar potential at Addis Ababa the PV system rating is about a third of that of the system at Vienna. Hence PV system costs are definitely cheaper at Addis Ababa.

Vienna / Austria	Addis Ababa / Ethiopia
• Data - Home system, Garden House or Mountain hut with no grid access - User needs 1,450 Wh/day	• Data - School, Health station or House near Addis Ababa with no grid access - User needs 1,450 Wh/day
• SAS PV components - 1,620 Wp Modules - 2x24 V, 96 Ah batteries - 1 regulator	• SAS PV components - 450 Wp Modules - 2x12 V, 80 Ah batteries - 1 regulator
• Performance Parameters - PR, 0.15-0.45 - Solar fraction > 0.5	• Performance Parameters - PR, 0.50-0.65 - Solar fraction > 0.8
• Estimated Investment Costs (€) - PV modules, 8100 - Batteries, 200 - Total 8300 - Energy costs **1.35 €/kWh** (10 years life, 6 % IR)	• Estimated Investment Costs (€) - PV modules, 4500 - Batteries, 200 - Total 4700 - Energy costs **0.80 €/kWh** (10 years life, 6 % IR)

References:

1. Bates, J. R., Wilshaw, A. R., Survey of Stand-alone Photovoltaic Programmes and Application in Developing Countries, 16th European Photovoltaic Solar Energy Conference and Exhibition, May 2000, Glasgow, UK.
2. Bates, J. R., et al, Development of Photovoltaic Technologies: Co-operation with Developing Countries, 16th European Photovoltaic Solar Energy Conference and Exhibition, May 2000, Glasgow, UK.

GRID-CONNECTED PHOTOVOLTAIC SYSTEMS AND BUILDING INTEGRATION

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ABSTRACT
An significant difference between stand-alone and grid-connected photovoltaic systems is that for the latter one no need exists to adapt the installed capacity to the local demand. Since the grid serves as a back-up whenever necessary, the capacity installed can be adopted to budgetary constraints, economic parameters, and available area. At present, even if subsidies and tax discounts are used, electricity generated by grid-connected photovoltaic systems is not cost-competitive in comparison to fossil fuel, hydro-, or nuclear power based electricity generation. Future progress will probably change the situation: The PV module cost trend is still decreasing; this fact and the uncertain market conditions for conventional energy resources gives rise to rather optimistic prospects.
Actual investment figures for grid-connected electricity generation systems add up to about 8 Euro/W_p, which is about four to five times the costs of conventional generation plants in central Europe. Despite the high costs, there are however successful and emerging market niches. This is e.g. true for building-integration in combination with trade on the solar stock exchange. Grid-connected building-integrated photovoltaic systems are considered to be a feasible option for a sustainable energy system, even if they still require financial support. Some funding programmes and subsidies are discussed in this article.
Another important precondition for an acceptance of the technology is the availability of powerful software tools to predict the output and the performance of the pv systems. The work presented in this article was done using the modelling and simulation tool PVSYST to imitate grid-connected building-integrated photovoltaics. By this means is was viable also to assess the effects of shading on the system, which is a factor to be accounted for in the built environment.

INTRODUCTION

The photovoltaic market

World-wide sales of photovoltaic products have been increasing at an average rate of about 15 % every year during the last decade, although there is no homogenous growth rate in applications in a global scale. This is mainly due to different insolation levels and to disproportionate budgetary conditions in the various countries. Nevertheless, it is believed that there is a realistic possibility for a continuing market growth at about a 15 % rate for the next ten years. At this rate, the world production capacity would be 1000 MW by the year 2010, and photovoltaics could be a $5 Billion industry. These benchmarks show the solar business to offer very exciting opportunities in the near term.[1]
However, for a more widespread use of photovoltaics the costs must be competitive with those of conventional methods of electricity generation. In the US, for example, the average price for electricity is 6-7 cents per kilowatt-hour. Today, photovoltaics can generate electricity at 40 cents per kilowatt-hour under very favourable circumstances, underlining the fact that a relative cost reduction by a factor of more than 5 is essential to reach competitiveness in the bulk electricity market.[2]
The most important factors influencing electricity costs from photovoltaics are the module

efficiency, lifetime and cost per unit area.
The situation mentioned explains why the markets, where PV was introduced first, where those lacking other energy infrastructures or those with extraordinary high energy cost levels (so-called high-value applications). These were the markets, where today's photovoltaic systems already are competitive with traditional ways of providing electrical power. Usually this applies to locations very remote from the electrical grid, serving vital needs like water pumping, remote communication, refrigeration, signal lights, emergency lighting, pipeline corrosion protection and village power.
In most of these cases there is no other competition than diesel generators – excluding for practical reasons a long distance extension of electrical transmission lines. As the costs of photovoltaic systems decline, the situation for cost-effectiveness is encouraged. For the ultimate application - bulk electrical power generation – a breakthrough is not expected to occur within the next 10 to 20 years, until PV-specific costs decline to a level below about 10 cents per kilowatt-hour. Various utility niche markets are expected to grow before these large-power markets will be accessible.
Market growth will be tied to the continuing decline in photovoltaic costs relative to conventional supplies. The industry will need to build larger, more cost-effective production plants that take advantage of economies of scale. Investment in these new, large plants will require identification of sustainable markets. Many high-value applications taken together, including international rural electrification projects, could provide the necessary market pull.

Applications of photovoltaic power

Even if still hampered by the cost situation photovoltaic power is used around the world. The applications of photovoltaic power can be divided into four groups, each of them representing a broad variety of appliances:

Industrial: The major field of application of photovoltaics for 30 years, including cathodic protection, telecommunication, navigational systems, telemetry, and other unmanned installations in remote areas, preferably even under harsh environmental conditions. In all these cases the load specifications are well known and the requirements for reliable power are high.

Rural: This segment includes applications which are typically connected to inhabited buildings (such as cabins, homes, villages, clinics, schools, farms) or to individually powered lights and small appliances. The load demands in this segment are not as well defined as for the industrial applications, the utilisation schemes are (can be) more flexible.

Consumer/Indoor: These products use photovoltaic cells to provide small amounts of power needed for electronic devices such as watches and calculators, as well as individually powered garden lights, small modules for portable computers and radios, and other applications.

Grid Connected: These systems are typically systems in a multi-kilowatt or megawatt scale that are directly connected to an existing power grid. Electric power is generated only during daylight hours, and is either consumed locally (at the site of generation, commercial buildings for example) or fed to the a utility grid to be conveyed to common consumption. Small 1-5 kilowatt rooftop systems usually are installed on top of individual homes, while larger systems can be found at commercial or industrial buildings to offset the daytime lighting or air-conditioning loads.

Large 100-500 kilowatt systems have been proposed to be located along utility feeder lines to improve power quality. Such systems can support power systems approaching their full capacity and can – by cutting the daytime peaks – replace or postpone rewiring or the installation of new and larger transformers.[3]

Up to now large utility scale power-generating stations[4] do not play an important role in the industrialised countries, but present a valuable option for the future.

GRID CONNECTED PHOTOVOLTAICS

In contrary to stand-alone systems, where the solar electricity produced has to be stored in batteries to serve the customers in "isolated" photovoltaic installations, grid-connected systems do not necessitate additional storage capacities, which make stand-alone systems more expensive. Nevertheless, stand-alone systems offer particularly great value for users and are therefore competitive and cost-effective in many application fields.
Even if cheaper than stand alone systems grid-connected systems are less competitive in terms of electricity generation costs, since they have to compete with common bulk electricity generation costs.
The specific investment costs for stand-alone and grid-connected PV-systems are about 10 respectively 8 $€/W_p$. Accordingly, the price per kWh generated by conversion from solar energy is more than five times higher than the fees customers have to pay for conventional kWh.
Despite of the fairly high costs, there are successful and increasing market niches also for grid-connected photovoltaics like the solar stock exchange. The grid takes the surplus and supplies electricity when the photovoltaic system cannot fully cover the demand. Given that, grid-connected photovoltaics are an important option for sustainable energy systems.

TECHNOLOGY

Photovoltaic systems in buildings

On site-storage is not essential for grid connected systems, since it is possible to sell "export" power to the grid during daylight hours and "receive" power at night. Depending on the tariffs such operational strategies can be quite attractive. However, the addition of storage to a photovoltaic system can increase its value, for example for so called uninterruptible power supplies (UPS[).5]

Photovoltaic systems can provide power for various purposes in a building and can serve an additional – architectural - purpose: dual use concepts combine electricity generation and roofing, structural wall or even window functions, can provide power for controls, fans, pumps, "smart" windows etc. With on-site storage, photovoltaic systems can also provide demand-side management to offset peak time loads, to reduce peak load power requirements - and hence costs - for the building, as well as providing high value peak load power to the grid. Such demand-side systems are much closer to economic viability than are supply side photovoltaic systems,[5] and development of appropriate products to meet such functions can open up a large market, since buildings consume a major portion of the generated electricity.[4]
For such a household system, the essential components are: photovoltaic panels, a power-conditioning unit (inverter) to make the electricity utility compatible, and metering equipment to measure the energy flow between the house and the grid. Standard photovoltaic modules still represent the mostly used conversion units to supplement grid power, but specific purpose-made products are expected to become of increasing importance.

Module mounting
The adequate area to install a PV-array has to be chosen with respect to possible influences from shading from buildings or trees. This done, modules for household systems usually are mounted on array frames next to the house. In many cases rooftop mounting offers the best position and the safest and most economic option. Typically, an integral mount would be used at newly constructed buildings, as replacing the conventional roofing material with photovoltaics would be the cheapest option. The development of frameless laminates could reduce costs further, while solar tiles (already available) fit into familiar structures and standard roof profiles.
Rack mounts are often used for retrofitting and although their costs are higher than for integrated systems they may perform better, allowing air flow around the modules and offering the opportunity of optimal tilting. Direct mounts fixed on top of – but close to - the roofing material are likely to suffer from overheating due to the inadequate air convection behind the modules.[4]

INVERTERS
Inverters are needed in photovoltaic power systems, since direct current (dc) - as produced by the photovoltaic array - has to be converted into alternating current (ac) to fit the grid conditions. Inverters use switching devices to convert dc to ac power, at the same time stepping up the voltage, typically from 12, 24, or 48 V to 220 V ac (for small systems) or even higher, if necessary for larger systems.[4] Two main types of inverters can be used to achieve ac power at the voltage used in the main grid: Line commutated, where the grid signal is used to synchronise the inverter and the grid, and self commutated where the inverter's intrinsic electronics lock the inverter signal with that of the grid. The inverter's position in the system is indicated in figure 1.

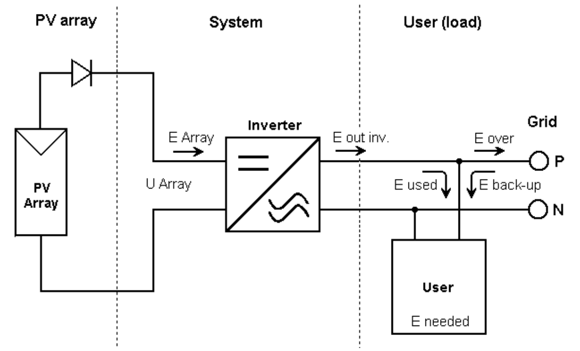


Figure 1: Schematic picture of a grid connected photovoltaic system. The system comprises a photovoltaic array, a dc-to-ac inverter, meters, and the load (the household and the electric grid).

The photovoltaic array's output voltage at standard operating conditions must be compatible with the nominal dc input data of the inverter. The maximum array open circuit voltage should also be well within the inverter's survival voltage range. Maximum power point trackers are commonly used with grid-connected inverters or, more often, integrated in the inverter to control the operating voltage of the array.

Inverter efficiency is an important issue to be considered when selecting the hardware. An improvement in the inverter efficiency of 1 % can result in an increase in energy output of 10 % over a year. In addition to operating efficiency, stand-by losses in periods of zero or very low load can be significant.

Safety, particularly via disconnect modes, is another important issue. Automatic start-up or "islanding", for instance, can result in adjacent lines and cables being energised even when the grid is disconnected. Isolation transformers are therefore recommended. Protection is also needed against excessive currents, surges, frequency excursions, and under and over voltages for dc input and ac output. The harmonic distortions, that is the content of higher order oscillations in the sinusoidal wave, must be low to protect both loads and utility equipment. The waveform must be acceptable to the utility, i. e. close to sinusoidal at 50±0.5 Hz. Non negligible dc injection would saturate the utility transformers.

UTILITY APPLICATIONS FOR PHOTOVOLTAICS

Grid connection allows the photovoltaic-system owner to sell any excess electricity and provide utilities with additional power at peak usage times. New technologies have boosted the viability of solar-power. Non-islanding inverters available on the market from manufacturers in the US and Europe make it possible to safely hook up solar-power systems to regional power grids. Such devices detect any irregular situation in the line connection (e.g. lines being shut down for repairs or other reasons), and disconnect automatically from the grid. This excludes potential hazards for the safety of line workers carrying out repairs, or others who are expecting a power line to be shut down. These new inverter apply computer codes automatically sensing when a line has been shut down. This innovation makes solar power a more safe and thus even commercially more viable option. Older inverters cannot be retrofitted with the new technology, but photovoltaic system according to the state-of-the-art are designed with these or similar features.[1]

The power rating of grid-tied inverters typically ranges from a few hundred watts to a few kilowatts. The power factor usually lies close to one. Depending on the impedance of the utility grid and the requirements some inverters can also deliver reactive power, thus influencing the ac quality.

Whatever the rating inverters must be capable to cope with the environment presented by the utility. This includes power transients due to near-by lightning, switching transients, voltage notches, sags, and swells. Even if some of these events may cause the inverter to disconnect from the power line (due to the anti-islanding circuitry), the device must be able to reconnect after a prescribed time delay and as soon as the self-check confirms that the disturbances ceased. Anyway, the threshold for cut-offs need be specified carefully to avoid frequent interrupts at conflicting grid conditions.[6]

Prior to large investments in power plants electricity utilities carefully scrutinise the field experience with photovoltaic systems. Satisfactory operation and maintenance data as well as reliability data are absolute necessities for making the technology credible with the utilities. The process of obtaining such data is under way, but apparently is not finished. Several grid-connected installations are undergoing evaluation, for example at the Photovoltaics for Utility-Scale Applications project in Davis, California, USA. Through this large, evolving utility-connected photovoltaic demonstration project, a public-private partnership is assessing and demonstrating the viability of utility-scale photovoltaic generating systems. Validation in such actual utility operating environments is the first step for utilities in defining the value of photovoltaics in their systems.
The demonstration of higher performance, lower cost and better reliability in today's photovoltaic systems is leading many different end users to assess the value of such systems

for their particular applications. Aggregation of these applications will lead industry to commit to larger, more cost-effective production facilities, leading to yet lower costs. Public demand for environmentally benign sources of electrical energy will hasten adoption of photovoltaics. The pace of these adoptions will be set by the economic viability of photovoltaics with respect to the competing options. It is no longer a question of "if" photovoltaic systems will gain adoption, but when and in what quantity this will happen. The energy system of the future is clearly within the scope of today's considerations.[7]

MODELLING OF BIPV

Realistic performance prediction is a necessary precondition for any economic assessment. This underlines the importance of adequate modelling. The following example illustrates the advantages of state-of-the-art computer based calculations for lay-out and output forecasts:
Shading is a general problem with any methods to utilise direct solar energy. Specifically in building integrated photovoltaic systems (BIPV) the effect of shading is exacerbated by the fact that if only one solar cell in a string module is shaded, all the electric output of the whole string is blocked, causing not only energetic losses but potentially even damaging the shaded solar cell due to back current overload. However, shading can never be totally avoided. Bird droppings, leaves, snow, or the shadow of objects in the surroundings of the photovoltaic panels, such as buildings, towers, chimneys and trees, often cause shading. Consequently, this effect was found to be the main reason for losses in the German "1000-Roofs-Programme". More than a half of the generators are partly or at certain times shaded. These are just a few important arguments in favour of including shading in the simulations of photovoltaic systems. Simulations can be done for example with the programme PVSYST. Here it is possible to create and position a photovoltaic array and pre-set obstacles (trees, buildings, towers, etc.; figure 2). The three-dimensional CAD tool allows the calculation of near shading effects on the system.
After the influence of shading has been clarified, calculations of irradiance on the photovoltaic cell can be performed (including the equations for a tilted plane and methods for irradiance assessment). The mathematical tools applied in the computer codes provide good opportunities for the simulation of unshaded and shaded photovoltaic generators, allowing a comparison of their performance. Many algorithms are implemented in simulation programs that can be used for efficient and rapid simulations of photovoltaic generators of different shape and in various arrangements. It is important, however, that the validity of the algorithms was verified by comparison with field measurements before using them for calculations of the performance of photovoltaic systems.

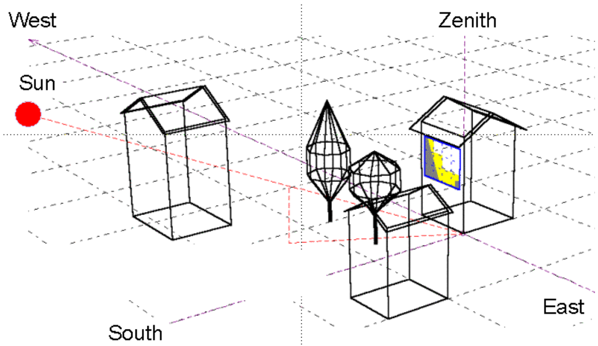
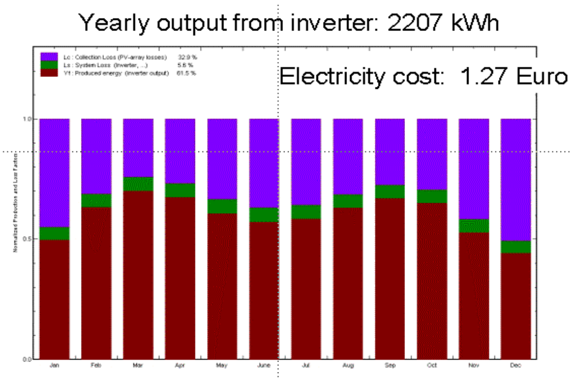
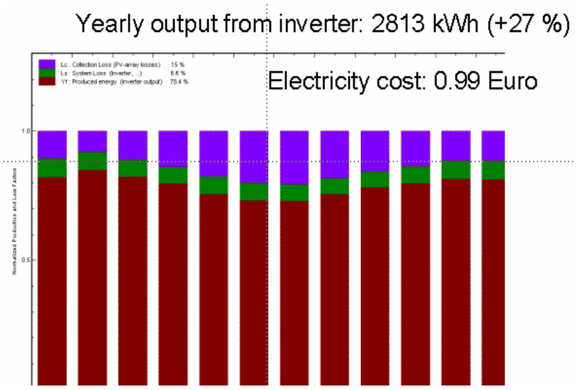


Figure 2: 3D simulation of near shading effects with the programme PVSYST. Vienna, January 22nd, 14.40 h. Sun height: 18 º, Sun azimuth: 30 º.

Figure 3a and 3b show the electric output for a shaded and unshaded BIPV system, respectively. One way to show the difference is the analysis of the sun path during one year. The sun path for Vienna is shown in figure 4.



(a)



(b)

Figure 3: Comparison between the yearly electric energy output in a shaded situation in Vienna, modelled in figure 2 (a) and an unshaded situation, at the same location, (b) during one year.

In order to get maximum power out of an installed photovoltaic system, it is necessary to keep the effect of shading low. It is therefore important to choose an optimal location, and to use shading tolerant systems which reduce losses in performance and prevent cell damage due to shading. Some simple measures, such as changing the module arrangement may also reduce the loss in performance, and increasing the knowledge about shading effects may therefore be considered as a practical tool towards increasing the efficiency of photovoltaic generators and reducing the high costs of photovoltaic electricity.

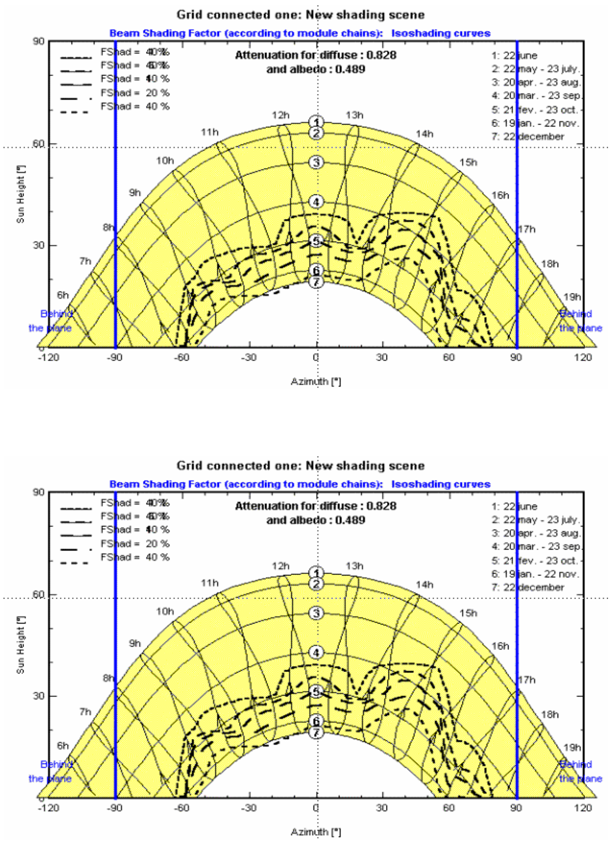


Figure 4: Shading losses at the path from sun to the photovoltaic array, during one year.

ECONOMY AND FUNDING PROGRAMMES

Solar electricity can become a main contributor of electricity to the energy system in the future, but solar technology needs support to find the way to the market. Regarding the fact that PV-electricity still causes much higher costs than electricity from other sources leads to a striking question: how to reach competitiveness? There are different strategies for promoting PV generated electricity applied in Germany and in other countries.

THE 100 000 ROOFS PHOTOVOLTAIC FUNDING PROGRAMME IN GERMANY

Germany's red/green coalition government has provided initial evidence of its plans to support renewable energy. An interest free loan programme, with a total value of nearly 500 million Euro, will promote the use of photovoltaic solar home systems. The project, which is expected to subsidise 40 % of the cost of an average PV unit, came into operation on January 1, 1999.

The six-year scheme offers individuals an interest free loan for the purchase of PV rooftop generating systems with an output exceeding 1 kW_p. Payback is over 10 years with two repayment-free years. After nine years, the remaining debt may be cancelled, providing the PV unit is still in use. The programme is expected to generate investment of about one billion Euro on PV systems with a total output of about 300 MW.

But this programme is not enough. Fritz Vahrenholt, Shell Germany, criticised the level of funding, since even with the subsidies proposed, PV systems in most areas of Germany would not be economically viable. Only in cities such as Berlin and Hamburg, where the local electricity provider already buys back surplus energy produced by solar systems at a rate of 0.5 – 1 Euro/kWh, this scheme will be attractive.

Full cost rates

In Germany, full cost rates may be introduced by the city councils (Aachen was the first). Up to now, it has been implemented in another 20 cities and is about to be implemented in many more. For the calculation of the actual payback rate the amount of electricity produced by an optimised model system during its 20 years lifetime is estimated. After that, a fee leading to full reimbursement of the capital (both the real investment costs for the system and the interest rate) over the lifetime of the system is calculated. This leads to a payback rate of for example 1.89 DM/kWh (since the beginning of 1999, only 1.76 DM). In Aachen, the authorities also decided to accept a total increase of the electricity rates of 1 % due to this programme.

Indirect policy issues –– Taxes and fees

The Swedish policies, which indirectly promote the use of PV power systems, comprise taxes and fees related to the energy production and the positive environmental protection effects. The current level of these taxes and fees, at actual PV system prices, is too low to have an impact on the PV market in Sweden. The carbon dioxide tax rate was 1999 approximately 0.37 SEK per kilogram released. The sulphur tax is levied on the sulphur content in the fuels and is based on a tax rate of 30 SEK per kilogram.[8]

DISCUSSION

Photovoltaic electricity has the potential to make considerable contributions to the electricity supply. It may provide the needed power for mankind and represents a sustainable and reliable energy system for the future. Anyway, for present grid-connected systems funding is still needed, which gave rise to several more or less efficient subsidising programmes implemented around Europe.

The prospective contribution of building-integrated photovoltaics has been estimated to be 10–30 % of the electricity demand.[9] For extensive use in the built environment, BIPV should become a common building construction material and serve as a versatile multifunctional building envelope element.

ACKNOWLEDGEMENTS

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THE POTENTIAL AND IMPLEMENTATION OF BUILDING-INTEGRATED PHOTOVOLTAICS ON THE LOCAL LEVEL:

Case Studies and Comparison of Urban and Rural Areas in Switzerland

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ABSTRACT

The economic and technical development of photovoltaics is predominantly shaped on the global level, whereas the implementation and the distribution strongly depend on local policies and actions. Comparing the potential of available and solar-architecturally suitable roof area between the urban environment of the City of Zurich and the rather rural Canton of Fribourg, it can be stated that the potential for contributions from photovoltaics to the electricity supply is three times higher in the rural area. Nevertheless, the City of Zurich has deployed its potential area much better. The present input of electricity produced by photovoltaic conversion to the grid is fifty times higher in the City of Zurich than in the Canton of Fribourg. This fact emphasises the local aspects of photovoltaics implementation.

1. INTRODUCTION

Two case studies performed recently illustrate and highlight the issue of building-integrated photovoltaics (BIPV). This paper was previously communicated at 16th European Photovoltaic Solar Energy Conference and Exhibition in Glasgow in May 2000 and is adapted to the presentation at the Solar Energy Summer School in Klagenfurt (24th of July – 4th of August 2000).

1.1 Context

The economic and technical development of photovoltaics is predominantly shaped on the global level, whereas the implementation and the spread strongly depend on local policies and actions. Participants in the growing photovoltaics market are increasingly becoming aware of the decisive role of local factors and actors. Sound and comprehensible data are therefore needed for efficient action and successful strategies.

1.2 Contents

This paper presents two case studies - one in a typically urban context, the other in a typically rural area. A comparison of the essential data highlights the potential of building-integrated photovoltaics (BIPV), the opportunities and barriers of the implementation of BIPV between rural and urban areas and their differences and similarities.

1.3 Objectives

The objective of the study was to provide extensive and concise data about the structure and texture of the existing building stock including specific and regional topics and taking into account technological, economic, financial, social and legal aspects. The introduction of a new assessment tool gave way to a detailed survey of the solar-yield oriented potential; an additional analysis of local factors and a reflection about the intentions and opinions of local actors contributes to a complete and precise data set.

In order to stick to a strongly implementation-oriented approach the studies were carried out in close co-operation with utilities and authorities in the City of Zurich and in the Canton of Fribourg.

1.4 Methodological Background

In the past years a tool has been developed to assess the PV potential on buildings [1] and to classify the available areas with regard to differentiated solar yield figures. By means of this tool, the PV potential for different types of buildings (according to age, number of floors, type of use, roof shape, etc.), for different regional areas and for different categories of relative and absolute solar yield, etc. can be discerned. The regional building stock can therefore be precisely characterised taking into account the essential technical data for BIPV. The results are characterised by a high accuracy and by a level of detail previously not obtained.

Social, legal, financial and other aspects are analysed and evaluated on the local level. Furthermore, local decision makers are contacted to understand their view and acting regarding the deployment of BIPV.

In this way, data were collected for each region and comparisons between the different regions made. Conclusions can be drawn to set a successful framework.

This paper analyses the roof area available for PV installation and distinguishes between areas with very good and good solar yield (high yield: > 90 % of the maximum annual solar irradiation, good yield: 80 % < x < 90 % of the maximum annual solar irradiation) and explains thereafter the differences stated between the urban and rural region.

2. URBAN CASE STUDY: CITY OF ZURICH

2.1 Characteristics of the Area examined and Study Objectives

The City of Zurich is the largest city in Switzerland with 360'000 inhabitants and 92 km^2 of land area (11 km^2 of ground floor area). The electricity consumption is 2.7 TWh/y.

The study examined the roof area potential for PV use in the whole building stock and its distribution for eleven different building categories in 1997. The technical and economic developments were considered and potential scenarios formulated taking into account the specific positive and negative factors prevailing in the local context of the City of Zurich [2].

2.2 Method

The study assessed the solar-yield differentiated BIPV potential. 14 typical zones were selected within the City of Zurich, the solar morphology of about 2'500 buildings was analysed in-depth. These extensive empirical data could be combined with very detailed statistical data from the local Office for Statistics. This data base allows almost any kind of analysis and extrapolations relevant for BIPV potential scenarios and future solar energy concepts taking into account factors like property structure, city planning zones, building types, roof shapes, installation size, energy yield, building periods, etc.

Table 1: BIPV (roof area) potential in the City of Zurich for fourteen building categories

Building category	*Number of buildings*	*BIPV (roof area) potential (m^2) with high solar yield*	*%*	*BIPV (roof area) potential (m^2) with good solar yield*	*%*
Residential (1 unit)	*9'877*	*90'758*	*3*	*331'651*	*7*
Residential (> 1 unit)	*16'631*	*952'464*	*36*	*1'747'631*	*38*
Resid. + Commercial	*8'016*	*374'694*	*14*	*758'050*	*16*
Administrative	*1'013*	*197'067*	*7*	*236'845*	*5*
Commercial	*3'119*	*416'707*	*16*	*595'995*	*13*
Tourism	*486*	*37'904*	*1*	*58'996*	*1*
Industrial	*1'952*	*272'730*	*10*	*376'673*	*8*
Agricultural	*453*	*26'615*	*1*	*33'046*	*1*
Build. for cultural use	*115*	*19'083*	*1*	*29'564*	*1*
Buildings for sports	*671*	*82'112*	*3*	*82'112*	*2*
Schools	*722*	*90'780*	*3*	*140'395*	*3*
Hospitals	*230*	*10'979*	*0*	*99'090*	*2*
Churches	*234*	*24'591*	*1*	*49'441*	*1*
Other buildings	*3'488*	*71'609*	*3*	*78'585*	*2*
All buildings	*47'007*	*2'668'093*	*100*	*4'618'072*	*100*

2.3 Results

a) BIPV Roof Area Potential

The BIPV roof area potential is calculated for the existing building stock. Table 1 shows the potential for suitable areas with at least 90 % resp. 80 % of the maximum annual solar yield.

About 20 % of the gross roof area (13.7 km^2) is suitable and has a fairly high solar yield, another 14 % has a fairly good yield. 31 % of the roof area is unsuitable due to construction elements and another 22 % due to shading, the remaining roof area has to be eliminated purely for an insufficient solar yield.

b) Solar Electricity Potential

The solar electricity production potential according to the state-of-the-art technology is 0.27 TWh/y for the high yield roof area and another 0.17 TWh/y for the good yield roof area, totalling 0.44 TWh. These values correspond to roughly 10 % resp. 16 % of the actual electricity consumption in the City of Zurich (2.7 TWh/y).

3. Rural Case Study: Canton Fribourg

3.1 Characteristics of the Area examined and Objectives

The Canton of Fribourg is located in the middle of Switzerland between the mountainous regions of the Alps and of the Jura. Its area is about 1600 km^2 (18 km^2 of ground floor area) and is predominantly rural. The population is 230'000 inhabitants. The electricity consumption is 1.8 TWh/y

This study examined the roof area potential for PV use in the whole building stock and its distribution for eleven different building categories in 1998 [3].

3.2 Method

The study assessed the solar-yield differentiated BIPV potential. About 700 buildings were selected at random and integrated in a high performing extrapolation structure.

There are four steps to follow for the collection of empirical and statistical data:

- identification of individual buildings in the data base and on digitized land-registers,
- localisation of individual buildings on digitized land-registers and aerial pictures,
- sampling of roof elements of individual buildings by means of stereoscopes (in 3-D) and
- registration of the sampled empirical data in the statistical data base.

Table 2: BIPV (roof area) potential in the Canton of Fribourg for eleven building categories

Building category	*Number of buildings*	*BIPV (roof area) potential (m^2) with high solar yield*	*%*	*BIPV (roof area) potential (m^2) with good solar yield*	*%*
Public + administrative	*2'927*	*510'744*	*9*	*620'576*	*7*
Residential (< 4 units)	*37'405*	*983'153*	*17*	*2'251'150*	*25*
Residential (> 4 units)	*1'963*	*242'863*	*4*	*268'192*	*3*
Resid. + commercial	*1'919*	*179'825*	*3*	*330'076*	*4*
Agricultural resid.	*7'960*	*554'913*	*10*	*1'537'596*	*17*
Other agricultural	*8'505*	*676'126*	*12*	*1'029'963*	*12*
Transport infrastructure	*959*	*109'962*	*2*	*118'447*	*1*
Commercial	*1'750*	*517'628*	*9*	*517'628*	*6*
Industrial	*3'548*	*989'234*	*18*	*1' 090'791*	*12*
Tourism	*317*	*50'209*	*1*	*57'722*	*1*
Other buildings	*24'764*	*829'965*	*15*	*1'057'181*	*12*
All buildings	*92'017*	*5'644'624*	*100*	*8'879'321*	*100*

3.3 Results

a) BIPV Roof Area Potential

The BIPV roof area potential is calculated for the existing building stock. Table 2 shows the potential for suitable areas with at least 90 % respectively 80 % of the maximum annual solar yield.

About 25 % of the gross roof area (22 km^2) is suitable and has a fairly high solar yield, another 15 % has a fairly good yield. 20 % of the roof area is unsuitable due to shading and another 15 % due to construction elements. The remaining roof area has to be eliminated purely for an insufficient solar yield.

b) Solar Electricity Potential

The solar electricity production potential with today's "common" technology is 0.56 TWh/y for the high yield roof area and another 0.30 TWh/y for the good yield roof area, that is 0.86 TWh/y. These values roughly correspond to a third respectively almost half of the actual electricity consumption in the Canton of Fribourg (1.8 TWh/y).

4. RESULTS AND COMPARISON

Some considerable differences can be stated by taking the figures concerning the potential and actual BIPV contribution to the electricity supply (following sections).

4.1 Potential BIPV contribution to the electricity supply

In the fairly rural Canton of Fribourg, the solar-architecturally suitable roof area could be used for the generation of 0.86 TWh solar electricity, which corresponds to 48 % of the actual electricity demand.

In contrast, in the City of Zurich, the roof area of the same quality could be used for the generation of 0.43 TWh solar electricity, which corresponds to 16 % of the actual electricity demand.

The potential BIPV contribution to the electricity supply (by simplifying other factors interfering in the distribution of solar electricity) is thus three times higher for the rural area. The most important reason for this is the ratio of ground floor area per inhabitant.

Table 3: Factors influencing the potential BIPV solar energy contribution to the electricity supply for the City of Zurich and the Canton of Fribourg (selection)

Factors influencing the potential BIPV contribution to the electricity supply	*City of Zurich (urban)*	*Canton of Fribourg (rural)*
Electrical use intensity (annual electricity consumption per unit ground floor area)	*243 kWh / m^2*	*99 kWh / m^2*
Available ground floor area per capita	*30 m^2/ capita*	*82 m^2/ capita*
Utilisation factor I (architecturally suitable roof area with high solar yield per ground floor area)	*0,25 m^2 / 1 m^2*	*0,30 m^2 / 1 m^2*
Utilisation factor II (architecturally suitable roof area with good solar yield per ground floor area)	*0,45 m^2 / 1 m^2*	*0,50 m^2 / 1 m^2*
Maximum annual solar irradiation on best oriented surfaces	*1167 kWh / m^2*	*1250 kWh / m^2*

4.2 Actual BIPV contribution to the electricity supply

The actual BIPV solar electricity production is less than 20 MWh in the Canton of Fribourg, which corresponds to 0.001 % of the actual electricity demand.

The actual BIPV solar electricity production is around 1300 MWh in the City of Zurich, which corresponds to 0.05 % of the actual electricity demand.

The actual BIPV contribution to the electricity supply (by simplifying other factors interfering in the distribution of solar electricity) is fifty times higher for the urban area.

Most important reason for this is the very favourable environment in the City of Zurich including the well-known solar stock exchange [4,5], pro-active marketing by the utility, hardly any legal construction restrictions, political and economical commitment and appropriate financing schemes.

Table 4: Aspects favouring PV implementation in the City of Zurich (selection)

- *Information / marketing*
- *Image / attitude with utilities, authorities, customers, etc.*
- *Financing schemes (e.g. solar stock exchange)*
- *Perception and conception of added value*

5. CONCLUSIONS

Some conclusions can be drawn on the methodological and result level:

- in-depth analysis of the building stock applying the newly developed tool to assess the solar-yield-differentiated BIPV potential yields highly accurate results
- evaluation of social, legal, financial and other aspects on the local level were analysed in order to discern particularly positive and negative factors for the implementation of BIPV
- comparison of the BIPV potential and implementation is made between two regions - one in a typically urban context, the other in a typically rural context
- useful data for the actions and strategies of the decision makers in and around the PV domain were provided

The case studies were carried out in Switzerland, one in an urban context, the other in a rural region. These case studies allow to show similarities (possible thumb rules to determine the BIPV potential) and differences of the building stock and of the basic conditions between urban and rural areas and to bring out favourable and unfavourable basic conditions for the implementation of BIPV on the local level.

It can be concluded that e.g. the potential contribution of BIPV to the electricity supply of the Canton of Fribourg is three times as high as in the City of Zurich but the actual contribution of BIPV to the electricity supply of the City of Zurich is fifty times as high as in the Canton of Fribourg. These facts show clearly how much local factors and actors matter for the potential and, above all, for the implementation of BIPV. The results generated are finally of use for actions and strategies of decision makers in and around the PV field.

On-going studies within the frame of international projects show that the methodology / tool set presented can be adequately transferred. Potential figures look fairly similar for areas in NW Europe. Solar-architecturally suitable building areas could be used for producing the equivalent of 20 – 30 % of the actual electricity demand.

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Workshop PV SYSTEMS – Summary and Conclusions

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1. INTRODUCTION

PV is a technology still in development. Therefore, progress is expected as well with regard to market penetration as concerning technical improvement. The conclusions presented are based on the state-of-the-art of the technology and cover the various fields of applications and demand profiles: stand-alone systems, grid-connected plants and potential future concepts.

2. TECHNOLOGY

Photovoltaics (PV) convert light directly into electricity. Thus, solar electricity is generated silently and ecologically, avoiding (at least, as long as operational) environmental pollution, and necessitating very low maintenance.

PV is very versatile, its modularity, rigidity, and reliability allow a great variety of applications: water pumping, rural electrification, communication, medical care, other domestic and commercial appliances, traffic signals, etc. The overall performing records are quite good, even if cost competitiveness is limited to very specific cases.

PV conversion is viable utilising different cell technologies with efficiencies ranging from 7% for amorphous materials, 10 % for Copper-Indium-Selenium thin cell technology (as just one example of multiple varieties) to beyond 15 % for mono-crystalline Silicon. The data refer to good commercial modules are concerned, the efficiency level slowly but steadily growing.
Best of its kind cells (laboratory and prototype scale) have been measured at about 50 % better performance as compared to the respective figures mentioned above

PV system applications can be classified mainly in two different fields: stand-alone and grid-connected schemes.

3. APPLICATIONS
3 A: STAND-ALONE SYSTEMS

Stand-alone systems are "isolated" PV installations. Since electricity generation and consumption usually do not coincide, the solar electricity has to be stored in batteries. This makes stand-alone systems more expensive.
Actual costs of stand-alone systems are 10,- € per Wp. Even at that costs PV-systems are competitive in remote areas like in the "3rd World" and in alpine regions; and in small appliances like calculators, parcometers.
Stand-alone systems offer particularly great value for users and are therefore competitive and cost-effective in many application fields.

3 B: GRID-CONNECTED SYSTEMS

Grid-connected systems necessitate in most cases a so-called inverter to act as an interface between the DC-power source and the AC – grid. Such systems are less cost-competitive although they are cheaper than stand-alone systems. The costs for grid-connected systems total about 8,- € per Wp. In comparison to the costs of conventional kWh customers have to pay the price of a solar kWh is about five times higher.

Despite of the fairly high costs, there are successful and increasing market niches, which especially is true for the solar stock exchange: The grid takes the surplus and supplies electricity when the PV system can't cover all the demand.

Grid-connected PV is an important option for a sustainable energy systems.

4. POTENTIAL, NEEDS, FUTURE

Photovoltaic electricity can make a considerable contribution to the electricity supply, as a matter of fact the potential of building-integrated PV is assessed to be about 10 – 30 % of the electricity needed.

Support is needed in every domain and on every level – starting with research up to marketing initiatives, launching and continuing local and global activities.

Concerning grid-connected systems, BIPV should become a common building construction method, the modules or PV devices serving as a versatile multifunctional building envelope element.

PV can play an important role in future energy concepts, since it can provide an essential part of the power needed for a future sustainable and performing energy system. Anyway, growing demand of a steadily increasing world population will be a challenge for mankind.