ABSTRACT

Accumulated installations of photovoltaic solar systems in the European Union have reached almost 2 GW at the end of 2005. The generated electricity was in the range of 2 to 2.5 TWh or merely 0.8 ‰ of the 3000 TWh consumed in 2005. Standard models predict an average yearly growth of electricity consumption in Europe of 1.3% until 2020. The European Photovoltaic Industry Association Roadmap aims for a total installed capacity of 41 GW photovoltaic solar systems or an electricity generation in the range of 49 TWh or 1.1%. To reach the 41 GW in 2020 a continuous annual growth of 30% for 15 years is necessary. If we assume, that 50% of this 41 GW will be installed in two Solar I regions in Europe (Southern Italy and Southern Spain), this can correspond to 50% or more in those geographic areas at certain times of the day and distribution problems of this electricity are not addressed yet.

INTRODUCTION

In 2005, the photovoltaic industry produced world-wide some 1,700 MWp of photovoltaic modules and has become a 8 bill. € business. In the past couple of years, the annual growth rate has been above 40%, making further increase of production facilities an attractive investment for industry. This development was triggered by implementation programmes in Japan and Germany, with more and more counties joining as well as smaller self sustaining markets for commercial information technology applications, solar home systems and consumer applications. However, these large and policy supported implementation programmes also bear the risk of major market disturbances if the political and public support is reduced or cut at all.

It might sound a modest goal to supply 1% of European electricity by 2020. In case of the introduction of energy saving measures to reduce the annual consumption by 1% per year, these 49 TWh could represent even 2% of total electricity demand. But even to reach this target the main challenge for the photovoltaic industry is to maintain the current high growth rates for the next 15 years and to keep the broad public support. If the solar photovoltaic systems are not equally distributed in Europe, but considerably concentrated in those regions with the best solar resources, another challenge will be the ability of the local grids to absorb and distribute the amount of electricity generated by the photovoltaic systems.

CHALLENGES TO MAINTAIN THE GROWTH

According to investment analysts and industry prognoses, solar energy will continue to grow at high rates in the coming years. An investment report published by Credit Lyonnais Security Asia forecasts that the photovoltaics sector has a realistic potential to expand from € 5.8 billion in 2004 to € 25 billion in 2010 corresponding to 5.3 GWp in annual sales [1].

The different Photovoltaic Industry Associations, as well as the European Renewable Energy Council (EREC), have developed scenarios for the future growth of PV. Table 1 shows the projections of the Japanese, US and EPIA roadmaps combined with the EREC 2040 “Advanced International Policy Scenario” (AIP) and the “Dynamic Current Policy Scenario” (DCP) [2].

Table 1: Evolution of the cumulative solar electrical capacities until 2030
(Sources: Japanese, US, EPIA Roadmaps and EREC 2040 scenarios)

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA [GW]</td>
<td>0.14</td>
<td>2.1</td>
<td>36</td>
<td>200</td>
</tr>
<tr>
<td>Europe [GW]</td>
<td>0.15</td>
<td>3.0</td>
<td>41</td>
<td>200</td>
</tr>
<tr>
<td>Japan [GW]</td>
<td>0.25</td>
<td>4.8</td>
<td>30</td>
<td>205</td>
</tr>
<tr>
<td>World-wide DCP [GW]</td>
<td>1.00</td>
<td>8.6</td>
<td>125</td>
<td>920</td>
</tr>
<tr>
<td>World-wide AIP [GW]</td>
<td>1.00</td>
<td>14.0</td>
<td>200</td>
<td>1,830</td>
</tr>
</tbody>
</table>

Material challenges

The extremely high growth rates of the photovoltaics industry during the last years led to the current temporary shortage in silicon feedstock, because the silicon production capacity did not grow at the same pace. Like in any other industry, raw material availability and the corresponding prices will influence demand and supply and will be a key driver for new developments and innovation within the industry. To cope with the current silicon
shortage, three trends can be observed at the moment:

- Silicon producers have now reacted and are in the process of increasing their production capacities, which will ease the pressure on the supply side within the next two to three years.
- Wafer based solar cell manufacturers accelerate the move to thinner silicon wafers and higher efficient solar cells to save on the silicon demand per Wp.
- New thin film solar cell manufacturers are entering the market to supply the growing demand for PV modules. Significant expansions of production capacities are underway, which would increase the 94 MW thin film shipments in 2005 by a factor of five by 2008 and could even reach 1000 MW by 2010.

If thin film should supply 25% of the photovoltaic devices by 2010, the growth of production capacities must be about double as high as the rest of the industry [1]. 2010 Silicon technology should deliver about 4,000 MWp per year, requiring 40,000 metric tons of Si-feedstock, about 40% more than today’s entire world production capacities of semiconductor silicon (28,000 metric tons). In 2020 a worldwide solar cell production of about 50 GW is necessary to reach the respective roadmap goals. If 50% of this would come from silicon wafer based concepts as estimated by PVNET [4], 150 to 200,000 metric tons of silicon would be required.

However, this is only one material challenge, which has to be solved. During the last decade, world wide silver demand was relatively stable between 750 and 850 million ounces. In 2002 the photovoltaics industry used about 3 million ounces for front and back contacts and had an annual production of 560 MW. By 2020 annual solar cell production is planned to increase roughly by a factor of 100. This indicates that a technology change is necessary in order not to become the largest single industry to depend on silver. Therefore, European funded projects like the Integrated Project ‘Crystal Clear’ look not only for the reduction of silicon use per W but alternative contact technologies as well.

Some of the currently developed thin film technologies might also experience material constraints. According to B. Sanden, CIGS, CdTe and Ru-dye-sensitised PV cells will most likely be constrained by the indium, tellurium and ruthenium availability [5]. Nevertheless, he calculated that these thin film technologies could, with the introduction of recycling schemes provide 6 TW of PV installations by 2100. In this respect, 2020 material requirements are no roadblock for these technologies, but the challenge remains to get to the market.

Support challenges and how to argue

As already pointed out earlier, most of the spectacular growth in the field of photovoltaics is still depending on public and policy support, either in the form of buy-down programmes, renewable portfolio standards, tax incentives or feed-in tariffs etc. Calculations of the German Association of Grid Operators (VDN) show that the amount paid by the German electricity consumers for solar electricity will rise from about 20 million € in 2000 to 1.35 billion € in 2011.

On the other side, macro- and socio-economic effects of photovoltaics are more difficult to see and therefore, are often neglected. So far traditional energy analysts overestimate the cost of renewable-based electricity and significantly underestimate the projected costs of fossil fuel expenditures and the impact of energy price increases on GDPs [6]. Awerbuch et.al. estimate that the introduction of a 10% renewable energy share into the US and EU-15 energy supply could have a GDP effect of $ 50 to 100 billion just by stabilising fossil fuel prices and reducing price fluctuations. This is on top of the avoided fuel costs, which for EU-15 are in the order of € 100 to 150 billion (2002 prices) if renewable energies would increase their share from 10% to 20% by 2020.

In 2005 the European Commission calculated, that a 10 $/bbl price increase of oil from 50 to 60 $/bbl would cost the Union about 0.3% growth and the US 0.35%. For the European Union the negative GDP effect will be in the order of € 41.9 billion in 2005 to 2007. Further price increases would worsen the situation. The introduction of renewable energies and as one example solar electricity into existing energy supplies reduces the supply risk and can, despite a higher “stand alone” kWh generating cost lower the overall costs of an optimised energy portfolio mix.

Additional benefits are job and wealth creation by production, installation and maintenance of solar systems as well as the resulting electricity production. The effects are positive for every country, as most of the jobs are created locally for installation, maintenance and marketing. If countries have to import their fossil energy, about 80% of the money is exported.

According to EPIA new PV production facilities create about 20 jobs per MW of capacity adding about 30 additional jobs per MW installed capacity in the wholesale, retail, installation and maintenance services sector. These later jobs are mostly located on a regional level near to the final customer.

Since the introduction of the feed-in law in Germany employment in the renewable energy sector has more than doubled compared to 1998. The latest figures given by the German Renewable Energy Association (BEE) in June 2005 count more than 140,000 people employed in this sector (including Services and R&D) with approximately 20,000 in Photovoltaics [3]. According to an industry survey amongst renewable energy companies in Germany every second company plans to increase the number of employees by 30 to 100% within the next 5 years. Photovoltaic companies are amongst the most optimistic ones and in total expect a doubling of employment by 2010. In 2004 Photovoltaics accounted for a turnover in Germany of € 1.5 billion and 70% of the added value remained inside Germany.

It is interesting to note that since 1999, the majority of investments in solar cell production facilities in Europe were made in Germany and Spain – the two countries that offer the most stable and realistic legal framework conditions for citizens investing in a PV system. For the whole of Europe, one can estimate current employment figures in Photovoltaics in the range of 25 to 27,000.
CHALLENGES TO ABSORB THE ELECTRICITY: CASE STUDY OF SOUTHERN ITALY

The intermittent character of photovoltaic generated electricity is often quoted as a problem for the electricity grid. However, after a number of studies it is generally accepted that intermittent sources of electricity generation only affect the grid stability of the current grid if their share exceeds at least 20%. Therefore, 1% of photovoltaic electricity should not represent a problem at all.

However, under the assumption that 50% of the 41 GW will be installed in two Solar I regions in Europe (Southern Italy and Southern Spain), this can correspond to 50% or more in those geographic areas at certain times of the day and can lead to local problems.

To do a first step in the analysis of this problem, we made a case study for Italy, which due to its specific set up of the grid enabled us to highlight some of the problems, which could occur in other places later as well.

We have used a few examples to point out two aspects of large scale production of solar electricity:
1. Grid capacity needed to manage summer peak generation of PV electricity in the Southern regions;
2. Security of delivery of solar electricity from Sicily to other regions determined by hourly fluctuation of clouds, assuming 4 geographical scales.

The summer period (April to September) 2005 is analysed, using data from the electricity grid operator Terna and the HelioClim-2 solar radiation database.

Terna - Rete Elettrica Nazionale SpA is in charge of electricity transmission and dispatching over the high-voltage (HV) and extra-high voltage (EHV) grid throughout Italy. In terms of grid safety and stability Terna grouped the Italian regions which have the best solar radiation conditions in two sectors. Basilicata, Calabria, Campagnia and Puglia are grouped together and are called "Napoli" whereas Sicily is "Palermo". The data on monthly electricity loads have been taken from the monthly reports available online [8].

For the analysis of the solar radiation climate in summer 2005 in the Southern Italy, we have used a sample of the hourly data from the database HelioClim-2 (courtesy of Ecole des Mines de Paris, France). The database contains time-series of daytime global horizontal irradiance for every hour, starting from February 2004. This database with spatial resolution of roughly 8 x 10 square km is operationally calculated from Meteosat-8 satellite images using the Heliosat-2 method [9]. The data is accessible from the SoDa web service [10].

Grid capacity needed to manage peak PV generation

Two highlights characterised the Italian electricity demand in 2005:

- A new all-time peak load on the national power system (55,015 MW, +2.6% compared to 2004) was recorded on 20 December 2005 at 18:00
- A new summer peak load (54,163 MW, +1.2% compared to 2004) was recorded on 28 June 2005 during the late morning.

The assumption of 10 GWp of solar photovoltaic electricity in Southern Italy could result on clear spring and early summer days in a maximum electricity production of 7.5 GW compared to 9.5 to 9.8 GW peak loads and would be more than 70% of the electricity needed in the region. Base load accounts for roughly 4 GW or 40% of the peak load and the different medium loads add another 3 to 4 GW. The medium loads could probably be adjusted on a daily basis to the solar production, but during peak PV generation more than 5 GW of electricity would have to be exported from the region that is more than the available grid capacity of 2.7 GW for exchange with the "Rome" sector and Greece, cited by Terna (Fig. 1).

Fig. 1. Output map for a 1 kWp solar PV system at optimum inclination and transfer capacity limits under conditions of operational integrity of the grid (data source: [8] and [11])

Security of delivery of PV electricity due to hourly fluctuation of clouds

The amount of incident solar radiation is determined by astronomical factors, terrain, and state of the atmosphere, while clouds are the most important factor controlling short-term fluctuation. Although astronomical and terrain effects are predictable with high level of accuracy, short-term variability of atmospheric constituents, and namely clouds, can be assessed only by statistical methods.

In this example we have studied effects of hourly fluctuation of cloudiness on solar electricity generation within the region. Attenuation by clouds is quantified by clear-sky index (ratio of real-sky to clear-sky global irradiance; one of parameters calculated in the HelioClim-2 database), where values around 1 indicate clear-sky conditions and values around 0 strong attenuation of global irradiance by clouds.

For each consecutive hour and pixel we calculated change of the clear-sky index. This means that for the given moment compared with an hour before, the change
around 0 characterizes just minor fluctuation from the previous hour, positive change means decrease of cloudiness (and increase of the irradiance), and negative change corresponds to stronger attenuation by clouds (i.e. drop of irradiance). On the example of the city of Palermo and the Sicily island we calculated the cloud effects at three scales – primary grid cell size $9 \times 9$ km$^2$, for area of a circle with radius of 30 and 50 km and for the whole island.

Fig. 2 shows that for an area represented by 9-km grid cell, the hourly change of clear-sky index stays within the limit of 0.05 in 84% of occurrences (1228 out of a total of 1464). Within a spatial range of one grid cell around Palermo, sudden drop or rise in irradiance (change of clear-sky index by the value more than +/-0.5) occurred more than 20 times last summer. This would have impact on local electricity flows in case of high concentration of PV capacity within such small area.

If PV capacity is to be distributed over larger area (30 or 50-km circle from the city), then the stability would increase to 88 and 89% respectively, and sudden changes in cloud cover (clear-sky index higher than +/-0.5) would occur only 3 times and once, respectively, in the season.

Assuming that PV is evenly distributed over the whole island of Sicily, the hourly changes at the exit point of the transmission grid in the Messina strait would be influenced by hourly change of clear-sky index higher than +/-0.05 only in 4.5% of occurrences (66 times over the summer period). Last summer it happened only 2 times that clear-sky index dropped or rose within one hour interval by more than 0.15 over the whole island.

This example indicates that uncertainty of solar electricity generation distributed evenly over larger regions might drop down significantly in Southern regions of Italy. However in other regions this may vary due to geographical differences in climate dynamics.

As outlined here, the time analysis of solar radiation from satellite images can improve our knowledge of intermittency of PV power generation over regions.

## CONCLUSION

In general 1% PV electricity is possible, even 2%, if energy saving measures are introduced. In order to avoid material shortages production capacities for silicon feedstock have to be ramped up at the same growth rates than solar cell production. New cell and module designs need to be introduced to avoid a dominating dependency on rare materials like silver.

Under the assumption of a 20 GW capacity build up in Solar I regions, a reinforcement of the grid and/or the introduction of local short term storage has to be considered. As outlined in this study, current satellite data (Meteosat-8) and methods provide the basis for the estimation of security of PV electricity supply and delivery within regions on a time scale from 15-min up to daily values.

## ACKNOWLEDGEMENT

The authors would like to thank Prof. Lucien Wald from Ecole des Mines de Paris for consultations and for providing us the hourly values of global radiation from HelioClim-2 database for Italy for the period April to September 2005.

## REFERENCES