SPECIFIC COST DEVELOPMENT OF PHOTOVOLTAIC AND CONCENRATED SOLAR THERMAL SYSTEMS DEPENDING ON THE GLOBAL IRRADIATION - A STUDY PERFORMED WITH THE SIMULATION ENVIRONMENT GREENIUS

Dr. Volker Quaschning and Winfried Ortmanns
Deutsches Zentrum für Luft- und Raumfahrt e.V., Plataforma Solar de Almería, Apartado 39, E-04200 Tabernas, Spain
phone: +34 – 950387906, fax: +34 950 36 5313, E-Mail: volker.quaschning@psa.es

Abstract – This paper describes detailed simulations of solar thermal parabolic trough power plants, non-tracked and two-axis-tracked PV systems. Altogether 61 sites in Europe and North Africa covering a global annual irradiation range from 923 to 2438 kWh/(m² a) have been chosen. Simulation results are usable irradiation by the systems, specific annual system output and levelised electricity costs. Costs assumptions are made for today's costs and expected costs in 10 years considering different learning curves for the three techniques. This will lead to a cost reduction by 50 % for PV systems and by 40 % for solar thermal power plants. The simulation results clearly point the optimal irradiation range for the best system output and best-cost solution of the different system variants. At low irradiation values the annual output of solar thermal systems is much lower than of PV systems. On the contrary, at high irradiation values solar thermal systems provide the best-cost solution even in 10 years if we consider higher cost reduction factors for PV. Electricity generation costs much below 10 Eurocents per kWh for solar thermal systems and about 15 Eurocents/kWh for PV can be expected in 10 years in North Africa.

1. INTRODUCTION

Professional simulation tools offer the possibility to compare different types of solar electricity generation systems at different sites. In the last years, DLR has developed the simulation environment greenius to analyse renewable power projects. Besides technical parameters such as the annual system output this software calculates detailed economical key parameters. Three types of photovoltaic and solar thermal parabolic trough systems have been simulated at 61 sites for this paper. Altogether 183 simulation runs assuming today's cost and expected costs in 10 years provide the basis for this paper.

2. EXAMINED TECHNOLOGIES

2.1 Photovoltaics

Since costs estimations for concentrating PV installations have a high uncertainty, only non-concentrating PV systems are considered. For the simulations in this paper two types of photovoltaic systems have been chosen:

- Non-tracking system with 30° slope angle
- Two-axis tracking system

For the following calculations, the nominal efficiencies of both systems are the same, whereas the annual efficiencies are site dependent.

2.2 Solar Thermal Power Plant

With 354 MW of solar electric generating systems (SEGS) parabolic trough power plants connected to the grid in Southern California since the mid-1980s, parabolic troughs represent the most mature solar thermal power technology. To date, there are more than 100 plant-years of experience from the nine operating plants, which range in size from 14 MW to 80 MW. Most of the currently planned solar thermal power projects are also parabolic trough power plants. For this reason, this paper considers state of the art parabolic trough power plants as shown in Fig. 1.

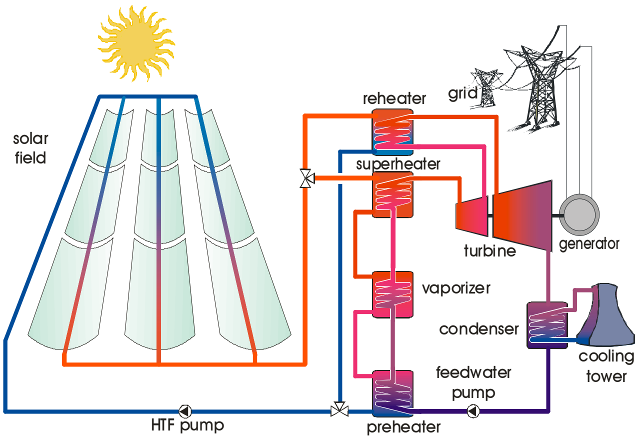

Fig. 1. Scheme of a parabolic trough power plant

2. THE GREENIUS SIMULATION SOFTWARE

During the last years, DLR has developed the new simulation environment greenius (*www.greenius.net*) for the technical and economical analysis of renewable power projects such as photovoltaic, solar thermal or wind power plants (Fig 2 and 3). The input for the simulation is hourly meteorological data of global irradiance, direct normal irradiance and ambient temperature. With this meteo data, site information, technical system data and economical specifications, the greenius simulation environment calculates the system output, system efficiencies and other technical parameters and provide various economical key values (Quaschning et al., 2001).

Due to the very rapid calculations and its flexibility, greenius is a perfect tool for system comparison and was already used for the calculations at other studies (Quaschning et al., 2002). Thus, the greenius simulation environment was also used to perform the technical and economical calculations presented in this paper.

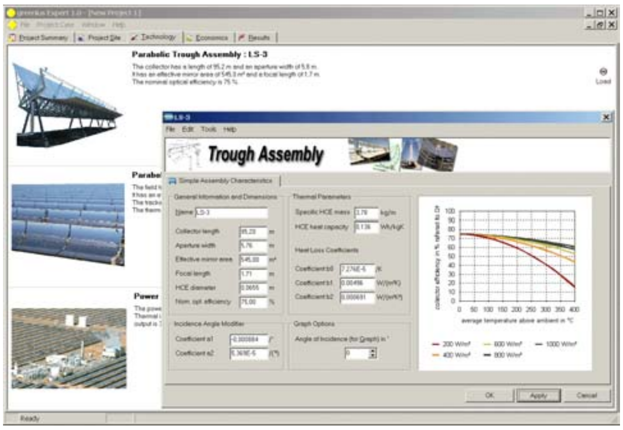

Fig. 2. Screenshot of the parabolic trough system specification at the greenius simulation environment

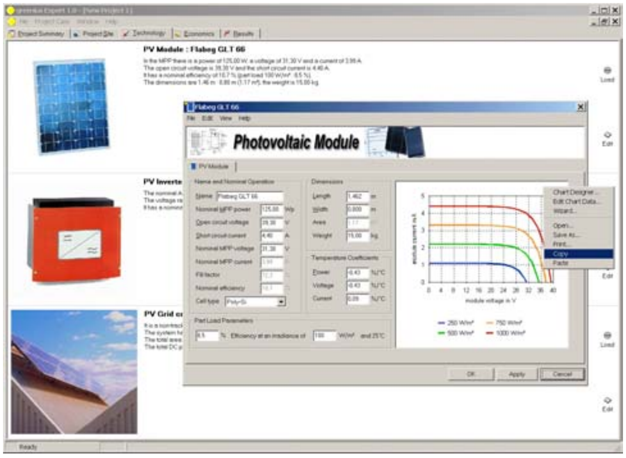

Fig. 3. Screenshot of the photovoltaic system specification at the greenius simulation environment

3. SITE, SYSTEM AND COSTS SPECIFICATIONS

3.1 Simulated sites

The further simulations were made for 61 sites in Europe and North Africa. Altogether these sites cover a global annual irradiation range from 923 kWh/(m² a) in Dublin (Ireland) until 2 438 kWh/(m² a) in Luxor (Egypt). The databases S@tellight (www.satellight.com) and Meteonorm (www.meteonorm.com) provided mean hourly global, diffuse and direct normal irradiance values for the simulations. The greenius simulation environment also calculated the direct irradiation on a one-axis-tracking, north-south-oriented concentrating collector (trough collector) and the global irradiation on a fixed, 30° south-tilted plane and the global irradiance on a two-axis-tracking system (Fig. 4).

The direct irradiation on the one-axis-tracking system is lower than the global irradiation on a fixed system and the irradiation on 2-axis-tracked systems for irradiation values below 2 000 kWh/(m² a). This shows clearly, that the use of tracked and concentrated solar systems is difficult in Middle and North Europe regions. The absolute difference of the annual irradiations of the different tracking variants is nearly the same over the full irradiation range. Hence, the advantage of two-axis-tracking system compared to one-axis-tracking systems decreases with increasing annual irradiation sums. On the other hand, tracking systems will have a much higher output than non-tracking systems at regions with high irradiation values.

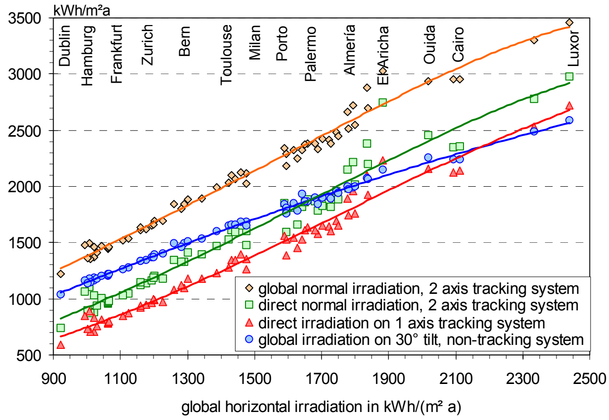

Fig. 4. Direct normal irradiation, direct irradiation on a 1-axis tracked collector, global irradiation on a 30° tilted plane and global irradiation and 2-axis tracked plane as function of the global horizontal irradiation

3.2 System efficiencies

Today's efficiencies of good systems have been chosen for the simulation. The annual system efficiency of the monocrystalline silicon PV system of about 11 % was almost constant with the site irradiation decreasing a little at higher irradiation values due to the negative influence of correlated higher ambient temperature (Fig. 5.). This result is not astonishing because PV module efficiency is almost constant over large irradiance ranges and decreases with higher temperatures.

On the contrary, the annual system efficiency of the parabolic trough system increases significantly with the annual irradiation sum. The part load efficiency of the steam turbine cycle is much lower than the nominal efficiency. The efficiency is also reduced at days with fluctuating irradiance values due to the capacitive behavior of the thermal system. Therefore, the annual system efficiency of a today's solar thermal trough power plant varies between 10 % and 14 % for the considered irradiation range.

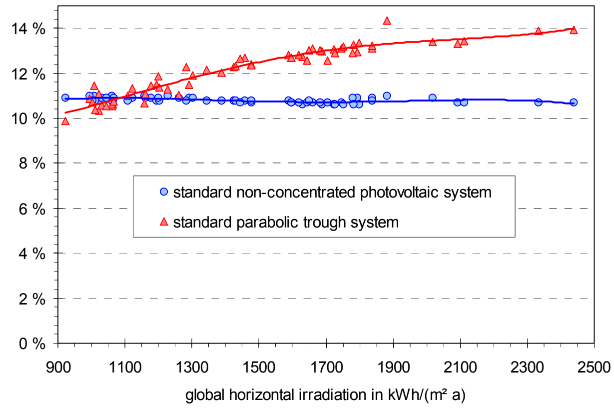

Fig. 5. Annual system efficiency of photovoltaic systems and 1-axis tracked concentrated parabolic trough systems as function of the global horizontal irradiation

3.1 Costs assumptions

For comparability reasons all costs are related to square meters of effective system area. Assuming a PV module efficiency of 13.5 % one square meter can hold PV panels with a capacity of 135 W_p. Finally, overall system costs of 5320 €/kW_p result in area related costs of 720 €/m². Operation results of existing PV systems have provided net present values of the costs for operation and maintenance of about 200 €/m². Installation and operation costs of tracked PV systems are higher than the costs of non-tracking systems. The cost assumptions for the parabolic trough power plant are valid for a system with a capacity of about 30 MW. These costs are much lower than the costs of PV systems (see table 1) but still in the same magnitude as in the 1990s, since the installation rates for solar thermal power plants are not very high today. For all systems a lifetime of 30 years and an overall discount rate of 7 % were assumed.

Table 1. Assumptions for today's systems costs

Net present value in €/m² for System	Installation	Operation	Total
Non-tracking PV system	720	200	920
2-axis-tracked PV system	900	270	1170
Parabolic trough power plant	450	180	630

Looking at the PV learning curve, there is a cost reduction by 20 % when doubling the market volume (Woditsch, 2000). In the past, this doubling was achieved almost every 4 years. Assuming the same growth rates for the next decade, there will be a cost reduction by 50 %.

For solar thermal parabolic trough power plants the progress ratio is about 0.88 (Enermodal, 1999). In other words, a price reduction by 12 % can be expected when doubling the market volume. On the other hand, possible growth rates of solar thermal power are higher. These power plants start from a lower annual production rate and they have not the same production limits as PV. Combining lower price reduction and higher growth rates leads to an overall cost reduction for parabolic trough power plants of about 40 % within the next 10 years. Table 2 summarizes the assumptions for solar thermal power and PV.

Table 2. Assumptions for system costs in 10 years

Net present value in €/m² for System	Installation	Operation	Total
Non-tracking PV system	360	100	460
2-axis-tracked PV system	450	135	585
Parabolic trough power plant	270	108	378

4. SIMULATION RESULTS

3.1 Annual output

Fig. 6 shows the specific annual system output of the non-tracking and two-axis-tracking PV system as well of the solar thermal power plant. Up to annual global irradiation values of about 1700 kWh/(m² a) the output of the solar thermal system is the lowest because the efficiency and the usable irradiation are disproportional low. Since the system efficiency of the solar thermal system at very high irradiation values is much higher than the efficiency of the PV system, the specific annual output of the solar thermal system becomes here nearly the same as of the two-axis-tracked PV system.

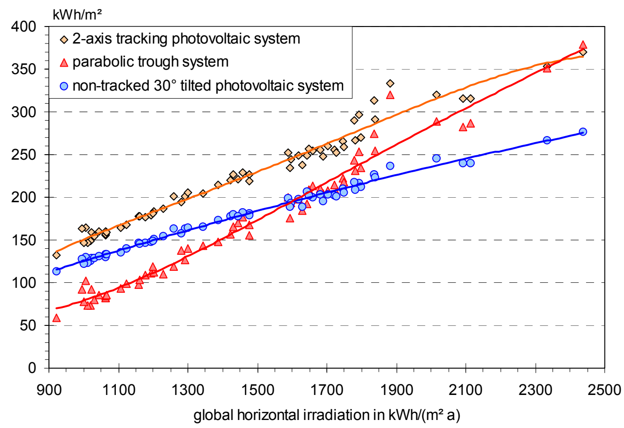

Fig. 6. Specific annual output of fixed and tracked photovoltaic systems and 1-axis tracked concentrated parabolic trough systems as function of the global horizontal irradiation

Fig. 7 shows the levelised electricity costs combining the specific output of fig. 6 and the specific costs assumptions of table 1. Since today's costs of solar thermal power plants are lower than of PV systems, the levelised electricity costs are also lower above global irradiations of 1100 kWh/(m² a) although the specific output of the PV system is higher until 1700 kWh/(m² a). Nevertheless, there is a high uncertainty in the simulation results of solar thermal power plants at very low irradiations. Due to the high investment costs for multi megawatt solar thermal power plants, sites with higher annual irradiations are recommended.

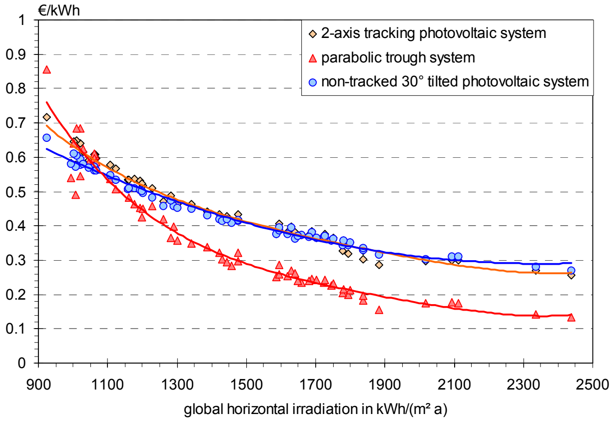

Fig. 7. Today's Levelised electricity generation costs for photovoltaic systems and 1-axis tracked concentrated parabolic trough systems as function of the global horizontal irradiation

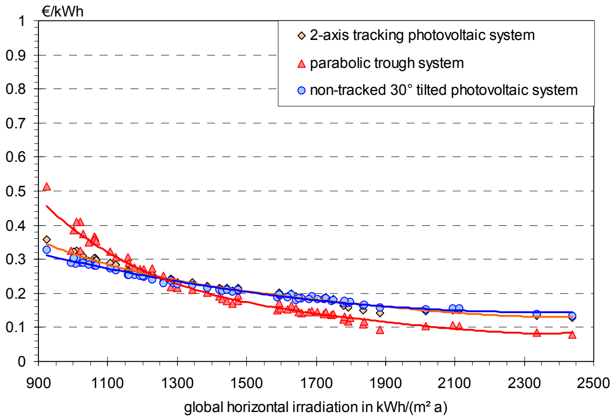

Fig. 8. Levelised electricity generation costs in 10 years for photovoltaic systems and 1-axis tracked concentrated parabolic trough systems as function of the global horizontal irradiation

In 10 years, the break-even irradiation for the generation costs of non-concentrating and solar thermal systems move to higher irradiation values. In South Europe both technologies can produce with costs below 20 Eurocents/kWh. Solar thermal power plants remain the best-cost solution in South Europe and North Africa with possible generation costs below 10 Eurocents/kWh. Tracked PV systems have little costs advantages in North Africa.

5. CONCLUSIONS

Simulation runs of non-tracking PV systems, two-axis-tracking PV systems and solar thermal trough power plants have given detailed results of technical and economical parameters for 61 sites in Europe and North Africa. These results demonstrate the high performance of simulation tools like the greenius software developed by DLR. Furthermore, the results show clearly the optimal operating ranges for solar thermal power and PV systems. The costs estimations show that levelised electricity costs can come down to a reasonable range below 10 Eurocents/kWh for solar thermal power in North Africa within the next 10 years. Thus, solar electricity will get a more important role in the struggle against global warming.

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