# Solar Power – Photovoltaics or Solar Thermal Power Plants?

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## Abstract

Many people associate solar energy directly with photovoltaics and not with solar thermal power generation. Nevertheless, large commercial concentrating solar thermal power plants have been generating electricity at a reasonable cost for more than 15 years and some new solar thermal power plants are soon to be erected. This paper compares the two technologies, providing a short description of how they work, areas in which they operate and cost-developments.

## 1 Principles

About one percent of the surface of the Sahara desert would be sufficient to supply the entire worldwide electricity demand from solar thermal power plants. For that reason, many people hope solar thermal power will be implanted in sun-belt countries. In contrast to photovoltaic plants, solar thermal power plants are not based on the photo effect, but generate electricity from the heat produced by sunlight.

### 1.1 Photovoltaics

Semiconductor materials such as silicon are used in photovoltaic solar cells. In the cells incoming photons separate positive and negative charge carriers. This produces an electrical voltage and the electrical current can drive a load. Since solar cells are modular, they can be assembled in units of any size (Figure 1). An inverter converts DC voltage to AC and feeds the solar power into the grid.

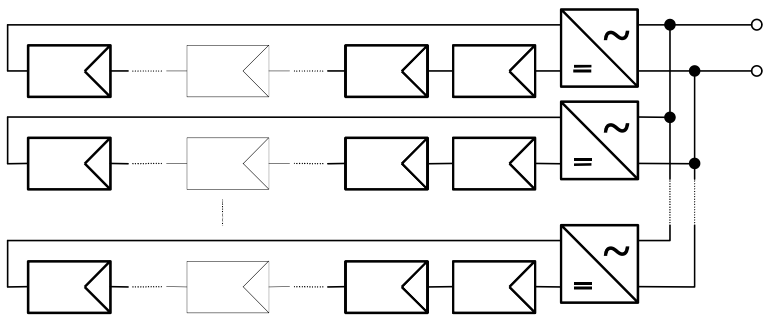

*Figure 1: Photovoltaic modules and inverters build up a photovoltaic system*

## 1.2 Solar Thermal Power Plants

Of the various types of solar thermal power plants, parabolic trough and solar power tower plants are described in more detail below.

The “trough” collectors that make up the solar field of a parabolic trough power plant are large cylindrical parabolic mirrors that concentrate the sunlight on a line of focus (Figure 2). Several of these collectors are installed in rows about a hundred meters long and the total solar field is composed of many such parallel rows.

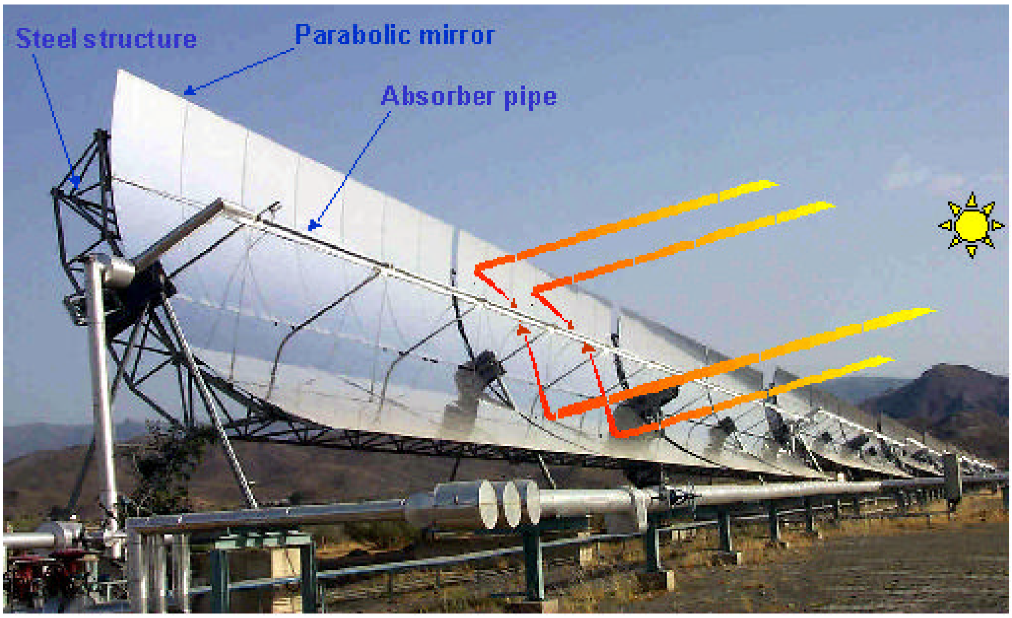


*Figure 2: Principle of the parabolic trough solar collector*

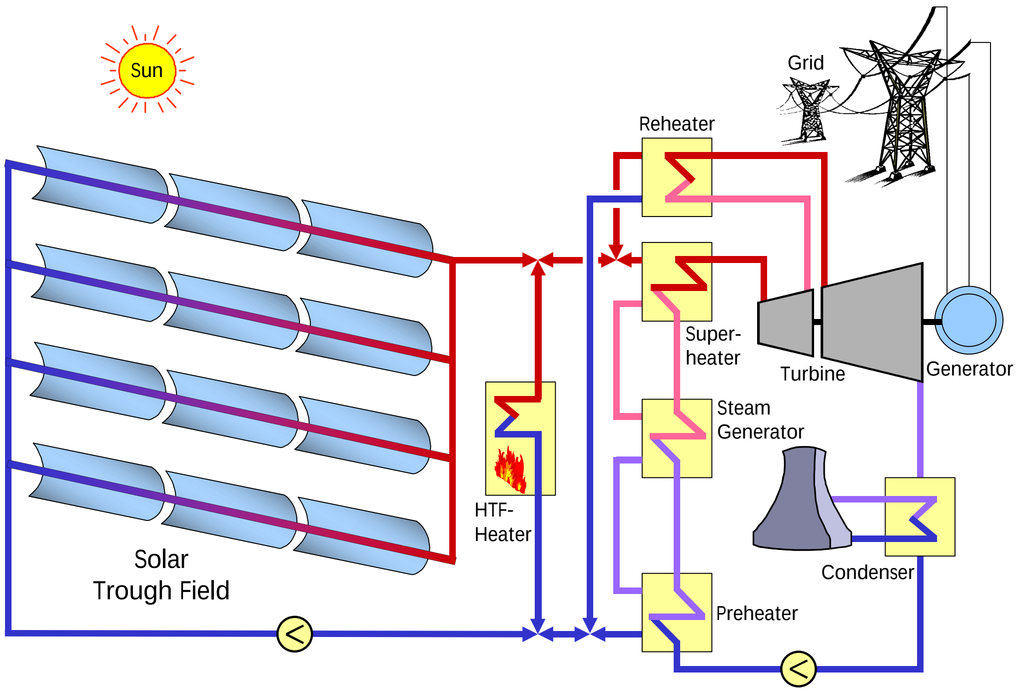


*Figure 3: Principle of the parabolic trough solar power plant*

All the collectors track the path of the sun on their longitudinal axes. The mirrors concentrate the sunlight more than 80 times on a metal absorber pipe in the line of focus. This pipe is embedded in an evacuated glass tube to reduce heat loss. A selective coating on the absorber tube surface lowers emission losses. Either water or a special thermal oil, runs through the absorber tube. The concentrated sunlight heats it up to nearly 400 °C, evaporating water into steam that drives a turbine and an electrical generator. After passing through the turbine, the steam condenses back into water that is returned to the cycle (Figure 3).

A fossil burner can drive the water-steam cycle during periods of bad weather or at night. In contrast to photovoltaic systems, solar thermal power plants can guarantee capacity. This option increases its attractiveness and the quality of planning distribution over the grid. Thermal storage can complement or replace the fossil burner so that the power plant can be run with neutral carbon dioxide emissions. In this case, heat from storage drives the cycle when there is no direct sunlight. Biomass or hydrogen could also be used in the parallel burner to run the power plant without carbon dioxide emissions.

*Figure 4: Experimental central receiver system at the European research center Plataforma Solar de Almería in Spain*

The solar field of a central receiver system, or power tower, is made up of several hundred or even a thousand mirrors, called heliostats, placed around a receiver at the top of a central tower. (Figure 4). A computer controls each of these two-axis tracking heliostats with a tracking error of less than a fraction of a degree to ensure that the reflected sunlight focuses directly on the tower receiver, where an absorber is heated up to temperatures of about 1000 °C by the concentrated sunlight. Air or molten salt transports the heat and a gas or steam turbine drives an electrical generator that transforms the heat into electricity.

# 2 Reference Systems

Both photovoltaics and solar thermal power plants have proven their feasibility in many operating years at a large number of reference systems. There are relevant megawatt-size reference systems in both technologies.

## 2.1 Photovoltaics

Only a few photovoltaic demonstration systems in the megawatt range were built in the last decade. At the moment various large systems are planned or under construction. Reliable general conditions given by fed-in laws in Germany and Spain support the erection of new large system. The number of new systems will increase continuously within the next year resulting in decreasing costs.

*Table 1: Examples of photovoltaic systems in the megawatt range*

| Place of large PV plants | Country | Installed capacity | Start of operation |
|---|---|---|---|
| Toledo | Spain | 1.0 MW | 1994 |
| Serre | Italy | 3.3 MW | 1994 |
| Munich | Germany | 1.0 MW | 1998 |
| Herne | Germany | 1.0 MW | 1999 |
| Tudela | Spain | 1.2 MW | 2001 (planned) |
| Relzow | Germany | 1.5 MW | 2001 (planned) |
| Relzow | Germany | 3.5 MW | 2002 (planned) |

## 2.2 Solar Thermal Power Plants

The first commercial parabolic trough power plant was built in the Mojave Desert in California in the year 1984. By 1991, nine trough power plants with a total capacity of 354 $MW_e$, which feed about 800 million kWh per year into the grid, had been erected on more than 7 km² (Figure 5). Eight of them can also be driven with fossil fuel to produce electricity during bad weather or at night. The annual share of the thermal energy produced from gas is limited by statute to 25 percent. The total investment in all of the systems was more than 1.2 billion USD. A large number of the plant components were produced in Europe. The levelized cost of solar electricity was reduced from 0.27 USD per kWh in the first power plant to about 0.12 to 0.14 USD per kWh in the last installed system.

Although solar thermal electricity is much more reasonable than photovoltaic electricity, no more commercial power plants have been erected since 1991. However, an increasing number of project developments make the new construction of parabolic trough systems very probable. The World Bank has made 200 million USD in financial assistance available for new combined-cycle gas and solar thermal power plants in developing countries. In Spain, a law increasing compensation for electricity produced from solar thermal energy with a premium of 20 PTA/kWh (about 12 Euro cents/kWh) above the market price of 6 to 7 PTA/kWh (about 4 Euro cents/kWh) is expected shortly.

*Figure 5: Aerial view of the solar thermal power plats at Kramer Junction in the US-Californian Mojave desert (photograph: KJC)*

## 3 Areas of Operation

The areas where photovoltaic systems and solar thermal power plants can operate overlap only in a narrow range (Figure 6). Due to their modularity, photovoltaic operation covers a wide range from less than one Watt to several megawatts and photovoltaic systems are able to operate as stand-alone systems as well as grid-connected systems.

Solar thermal power plants can work in both areas as well. Dish/Stirling systems are small units in the kilowatt range. The above-mentioned parabolic trough and solar tower power plants operate only in the megawatt range.

Global solar irradiance consists of direct and diffuse irradiance. When skies are overcast, only diffuse irradiance is available. While solar thermal power plants can only use direct irradiance for power generation, photovoltaic systems can convert the diffuse irradiance as well. That means, they can produce some electricity even with cloud-covered skies.

Since in middle and northern Europe there is only a relatively small share of direct irradiance, it does not make much sense to install solar thermal power plants there. However, in southern Europe and North Africa it is the direct irradiance that dominates.

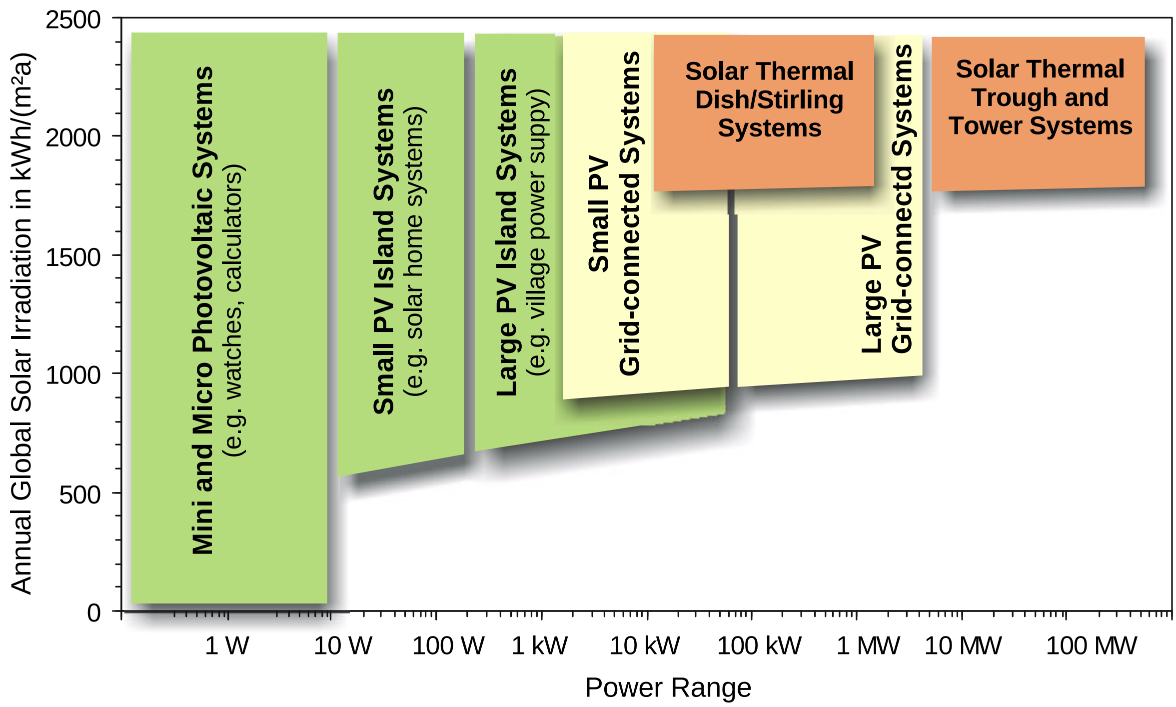


*Figure 6: Operational areas for solar thermal power plants and photovoltaic systems depending on the installed capacity and the annual global solar irradiation*

Figure 7 shows the increase in direct normal irradiation, that is the direct irradiance on an area perpendicular to the sun, and global horizontal irradiation with latitude in Europe and North Africa. The increase in direct normal irradiation is greater than the increase of the global horizontal irradiation, that is, the diffuse and direct irradiation on a horizontal surface. As a result the output and the profitability of solar thermal power plants in the South is much higher than for photovoltaic systems.

Figure 8 presents the resulting levelized electricity costs for both technologies. Since market introduction of photovoltaic systems is much more aggressive than that of solar thermal power plants, cost reduction can be expected to be faster for photovoltaic systems. But even if there is a 50% cost reduction in photovoltaic systems and no cost reduction at all in solar thermal power plants, electricity production with solar thermal power plants in southern Europe and North Africa remains more cost-effective than with photovoltaic systems. Therefore, there are areas in which one or the other of the two technologies should be preferred for technical and economic reasons.

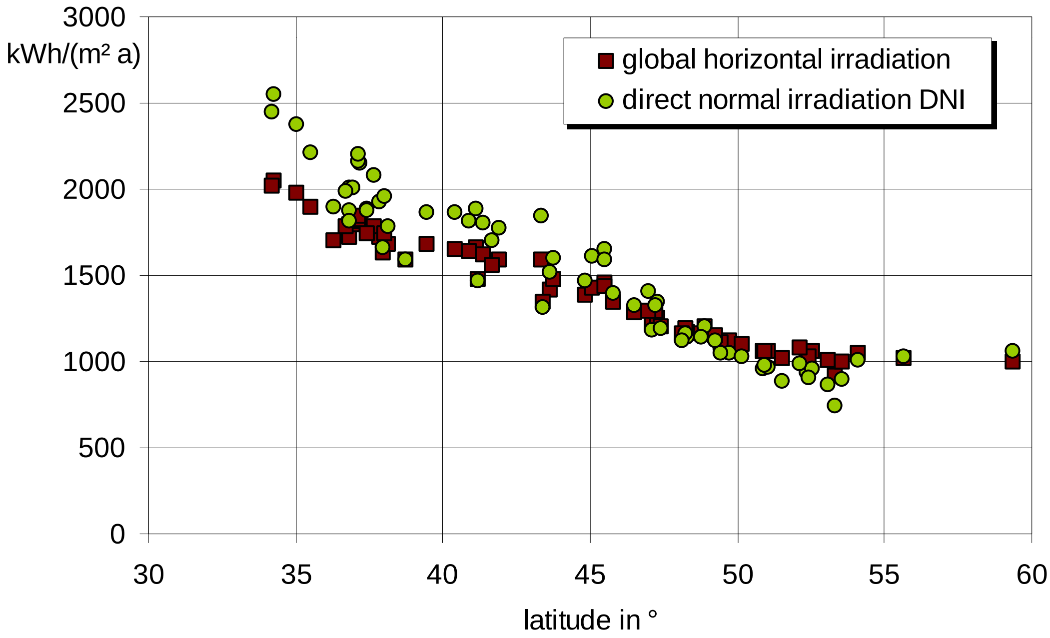


*Figure 7: Global horizontal irradiation and direct normal irradiation in various locations in Europe and North Africa depending on latitude*

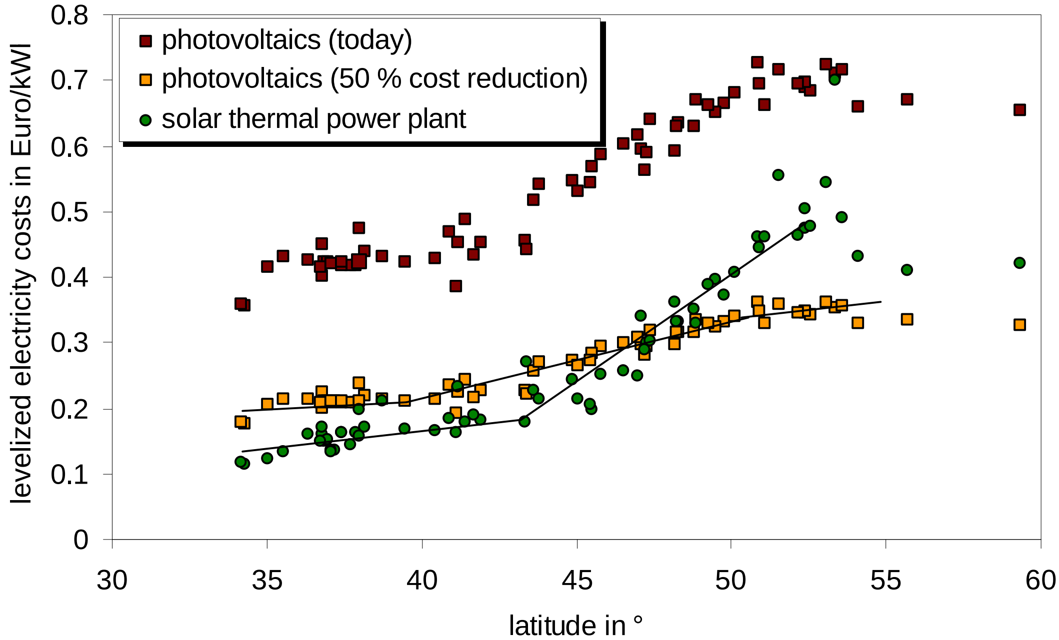


*Figure 8: Present levelized electricity costs for solar thermal power plants and photovoltaic systems as well as levelized costs for photovoltaic systems with 50 % cost reduction for locations in Europe and North Africa depending on the latitude*

## 4 Future perspectives

Although small photovoltaic systems and photovoltaic stand-alone systems today are already competitive with conventional electricity supply systems, the situation for grid-connected systems is totally different. Their cost can be improved if they are integrated into buildings, however, if there is no significant increase in fossil fuel prices, large grid-connected photovoltaic systems will still depend on governmental support in the mid term.

The situation for solar thermal power plants is similar, although series production can reduce the levelized electricity costs significantly below 10 Euro cents/kWh. Because of future needs for climate protection, both technologies require urgent support. Together these are the renewable technologies with the highest potential that can cover not only the electricity demand in southern Europe, but can also contribute significantly to the power supply in middle and northern Europe.

## 5 Conclusions

Solar thermal and photovoltaic electricity generation are two promising technologies for climate-compatible power with such enormous potential that, theoretically, they could cover much more than just the present worldwide demand for electricity consumption. Together both technologies can provide an important contribution to climate protection. Photovoltaic systems have advantages for low-power demand, stand-alone systems and building-integrated grid-connected systems. Solar thermal power plants are best operated in large grid-connected systems. Due to the higher direct solar irradiation in the South they are most useful in southern Europe and North Africa where their potential is very high. Solar electricity can be also exported to middle and northern Europe in the future. Even if only a small percentage of its potential put to work, solar electricity generation will be an important pillar in the struggle against global warming.

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