Combined Solar Power and Desalination Plants for the Mediterranean Region

Sustainable Energy Supply using Large Scale Solar Thermal Power Plants

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Abstract

The paper gives a review of concentrating solar power technologies and shows their perspectives for sustainable development and climate protection. New concepts for the combined generation of power and water are presented together with instruments for enhanced project assessment using remote sensing technologies and geographic information systems. The vast solar energy resources of the South can be activated by international renewable energy alliances and allow for a smooth transition of the present electricity schemes to a sustainable power system based on renewable energy sources.

Introduction

The challenges of the 21st century are numerous: climate change, increasing scarcity of fossil energy resources and the concentration of reserves in only a few regions of the world, scarcity of fresh water and expanding deserts, fast growth of urban centres and of their energy demand, globalisation and a fair distribution of wealth in order to avoid severe social conflicts.

Most of those challenges are related a to a sustainable energy supply, not only for today's industrialised countries but also for developing economies and for the economies in transition. The access to sufficient and clean energy is the motor of modern societies and economies, and with the increasing importance of information-, communication- and transportation technologies, also the importance of energy, particularly in terms of electricity will increase. Clean water is another key for sustainable development, with an increasing shortage ahead in many countries of the South.

The paper shows the importance of renewable energies, especially of concentrating solar power systems, for a future sustainable energy supply. Although the goals described here may look rather visionary, they are based on the present state of the art of science, technology and systems analysis. Many industrial countries are already initiating a transition of their electricity supply schemes to higher renewable energy shares, by supporting market introduction and expansion of those technologies. Lately, the European Union has set a goal to double its renewable energy share until 2010, and the Intergovernmental Panel on Climate Change recommends a world wide reduction of 75 % of carbon emissions by the end of this century in order to avoid dangerous, uncontrolled effects on climate and on the world's economy.

Future energy systems shall not only be sustainable in terms of environmental impact, but also from a technical, social and economical point of view. Solar thermal power generation will play an important role in a well balanced mix of renewable energy sources, efficient power technologies and rational use of energy.

In the present paper, the expected technical and economical performance of combined solar power and desalination plants as well as their perspectives for the Northern and Southern countries will be described together with the state of the art of modern instruments for resource- and project assessment.

Concentrating Solar Power Technologies

Concentrating solar power technologies use solar radiation to achieve high temperatures and to generate steam or air with high energy density, which can then be used for electricity generation and other purposes. Thus, solar thermal power plants are very similar to conventional power cycles, the only difference is their fuel.

The main challenge of solar thermal power engineering and development is to concentrate solar energy witch has a relatively low density. Mirrors with up to 95 % reflectivity that continuously track the sun are required for this purpose (Figure 1). They make use of direct solar radiation only, as the diffuse part of the sunlight cannot be concentrated. There are two types of concentrators, one focuses the sunlight on a point, the other one on a line. Line focusing systems like Fresnel- and parabolic trough concentrators are rather simple and inexpensive. With a concentration factor of approximately 50 to 100, they achieve operating temperatures of 400-600 °C. Point focusing systems like solar towers are more sophisticated in terms of technology and costs, but with concentration factors of 500 to 1000, they reach operating temperatures of up to 1200 °C and higher.

Figure 1: Concentrating solar collector systems with (a) Fresnel concentrators, (b) parabolic trough concentrators and (c) the solar tower concept with surrounding heliostat field.

The one-axis-tracking parabolic trough- and Fresnel concentrators reflect the sunlight on a receiver tube in the focal line of the collector. The concentrated solar energy is absorbed by the tube and transported by a working fluid (typically heat-transfer oil or water/steam) to a central location to drive a steam turbine. In a solar tower system, a field of two-axis tracking mirrors reflects the solar energy onto a receiver that is mounted on top of a tower located in the centre of the field. There, the concentrated solar energy is absorbed by a working fluid (typically molten salt or air). Because of their high temperatures, point focusing systems can be used to generate hot air for the operation of gas turbines and combined cycle systems [1], [2], [3].

Solar heat can be stored during the day in concrete, ceramics or phase change media. At night, it can be extracted from the storage to run the power block. Fossil and renewable fuels like oil, gas and organic waste can be used for co-firing the plant, providing power by demand, as base- or peak load (Figure 2).

Solar thermal power plants may acquire a considerable share on clean electricity generation in the 21st century. They are one of the best suited technologies to achieve the global goals of CO_2-emission reduction. The energy payback time of a solar thermal power plant is in the order of 0.5 years, while the economic lifetime is at least 25 years. Life cycle emissions of greenhouse gases amount to 0.010-0.015 kg/kWh, which is very low in comparison to those of gas fired combined cycles (0.500 kg/kWh) or steam/coal power plants (0.900 kg/kWh).

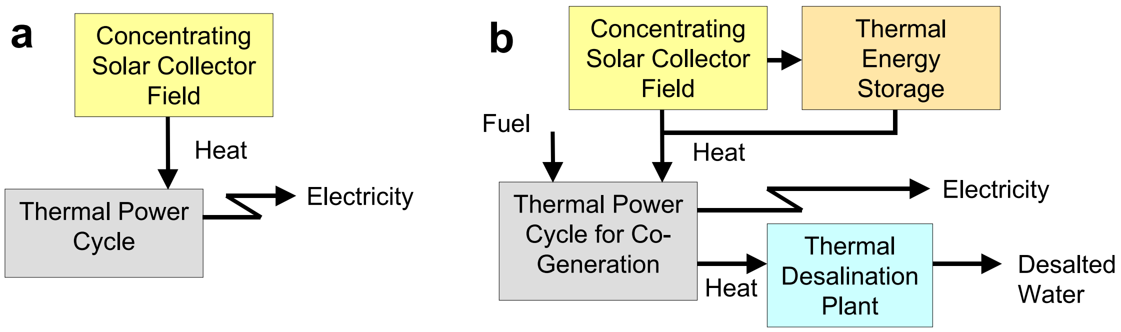

Figure 2: Solar thermal power plant configuration for (a) electricity generation and for (b) the combined generation of power and water with backup fuel and energy storage.

In the case of co-generation of electricity and heat, the high value heat from the solar field as well as the backup fuel energy is used with up to 85 % efficiency. Possible applications cover the combined production of electricity, industrial process heat, district cooling or sea water desalination.

Combined solar power and desalination plants integrate proven technologies. The heart of those plants is a steam turbine co-generation system used for electricity generation and thermal seawater desalination (Figure 2 b). A 200-MW plant of this type with e.g. 7500 full load operating hours per year under the economic and meteorological conditions of e.g. Dubai would deliver approximately 1.5 billion kWh/y of electricity and 60 million m³/y of freshwater at approximately 4.3 €-cents/kWh and 1.30 €/m³, respectively[1]. This is enough water for approximately 50,000 people plus electricity for 250,000 people. At present, such a plant without thermal storage and with a solar share of 25 % would cost about 800 M€. In about ten years, the same plants, but with increased collector fields and added thermal energy storage, will have a solar share of 80 % and cost approximately 1 billion €, while the cost of electricity and water will slightly decrease (Figure 5).

Thus, solar thermal power plants will allow for a smooth transition from the present energy supply based on fossil fuels to a future system based to a large extend on solar energy. Being one of the most effective technologies in terms of technical, economic and environmental sustainability, solar power and desalination plants will considerably reduce greenhouse gas emissions and local pollution. As an important preventive measure, they will mitigate the danger of national and international conflicts caused by fuel or water scarcity, and reduce the economic risks related to the increasing cost of those resources [4], [5].

The investment of such plants can be partially covered by regional and international development funds, or in the long term, by emission trading. Running costs are very low, because ‘solar fuel’ is free of charge. The combat against desertification will thus have a new, powerful ally which will not only attack the symptoms, but also some major causes of climate change.

Resource Assessment by Satellite Remote Sensing and GIS

A major barrier when initiating solar thermal power projects is the insecurity of investors with respect to the available solar energy resource and with respect to the economic performance of such projects. This obstacle can be overcome by an extensive and systematic analysis of the solar radiation climatology and of the economic plant performance in a project region. Information on the solar radiation intensity - in the case of concentrating systems direct normal irradiation (DNI) is relevant - is obtained with high spatial and temporal resolution using remote sensing satellites. They regularly provide data on cloudiness, aerosols, ozone, water vapour and other atmospheric components. Hourly data of DNI over several years in a geographic grid of approximately 5 km x 5 km is appropriate for this purpose.

Another resource that is required is land for the placement of the solar collector field. Land suitability is defined by properties like topography and land cover as well as by the current use that may be exclusive, e.g. in the case of a dense forest or a national park. The technical and economic performance of solar power projects is furthermore influenced by the necessary infrastructure and by natural risks, that may be a criterion for exclusion or at least an important cost factor.

[1] Economic parameters: interest rate 10 %, fuel cost 7.5 €/MWh (Dubai 2000), economic lifetime 25 years

Combining all that data with a geographic information system (GIS) and using this database as input for a detailed performance model, a systematic ranking of sites for a whole country like e.g. Morocco can be obtained (Figure 3). The analysis reveals the range and spatial distribution of electricity costs, the total potential of solar power generation, and identifies the best sites of the region under investigation. The potential of solar electricity generation in Northern Africa is impressive: the remaining suitable areas in Morocco shown in Figure 3 would theoretically suffice to cover the total present world electricity demand [6].

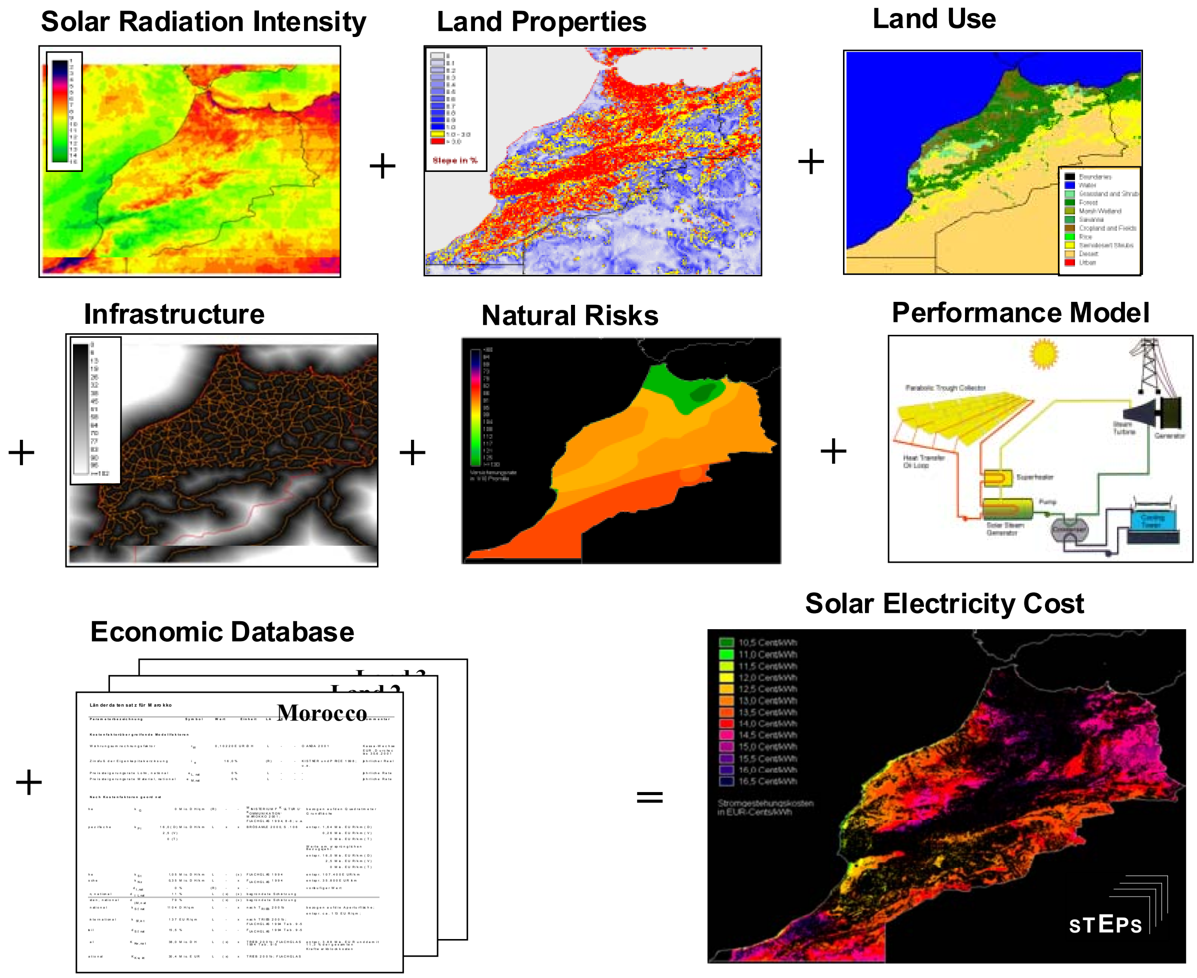

Figure 3: Different data sets of a geographic information system describe the solar energy resource, the available land resources and the performance of solar thermal power generation in Morocco. The example shows a systematic ranking of sites with respect to the cost of solar electricity generation using DLR's expert system *STEPS* (200 MW plants, parabolic trough technology, no storage, no fuel backup, no cogeneration*)*. The regions in black are excluded by various criteria. The geographic resolution of the resulting map is approximately 1 km x 1 km.

International Renewable Energy Alliances

The exploitation of the tremendous solar energy potential in North Africa quickly comes to its limits if it is restricted to national boundaries. Although the North African countries have vast resources of solar radiation and also land to place the necessary solar collector fields, the technological and financial resources are limited, and the local electricity demand is relatively small. The contrary is true for Europe (Figure 4, left). In order to exploit the renewable energy potential of both regions in an efficient and economic way, an interconnection of the electricity grids may allow for the transmission of solar electricity between North Africa and Europe (Figure 4, right). The synergies of such a scheme will not only reduce considerably the cost of solar electricity in Europe, but also will create an additional income for the North African countries, enabling them to finance and develop their renewable energy resources for local use and for export [7], [8], [9], [10].

The technology needed for such a south-north-interconnection is state of the art: at present, more than 40 GW of electric capacity is transmitted by high voltage direct current transmission lines (HVDC) that are in operation world wide in over 55 projects, mainly with the purpose to transfer hydro- and geothermal power from remote sites to the urban or industrial centres of demand. The cost of transmission over 3500 km of distance is of the order of 2 €-cents/kWh, that means that solar power from North Africa could be supplied to Central Europe at a cost of about 6 €-cents/kWh, if such a scheme is established (Figure 5). Combined solar power and desalination plants will mainly produce power and water for the increasing demand in the Mediterranean, while surplus solar electricity may be exported to the North.

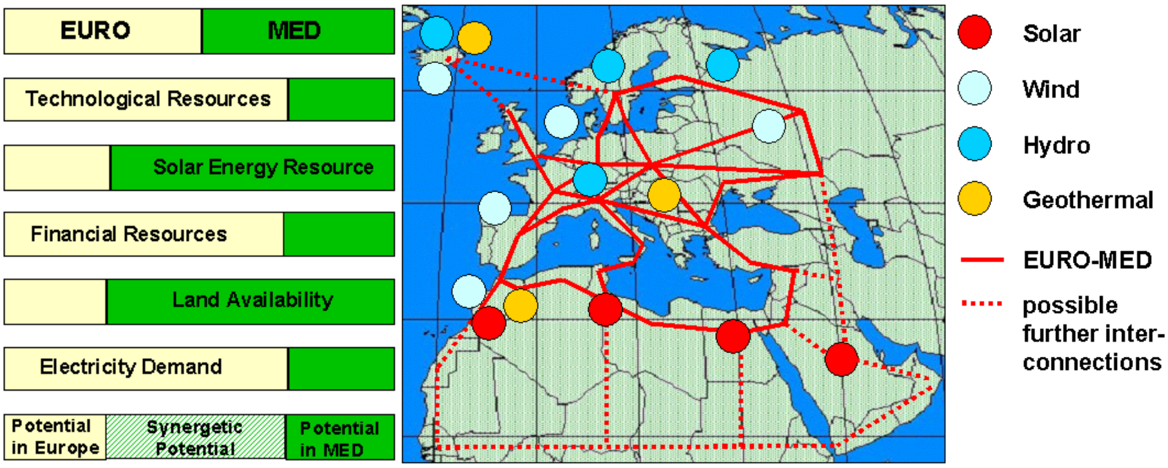

Figure 4: Vision of a Euro-Mediterranean power pool interconnecting the most productive sites for renewable electricity generation in the North and the South of Europe. Such an international alliance will activate the large synergetic renewable energy potential of both regions, which otherwise could not be exploited to the same extend because of national limitations.

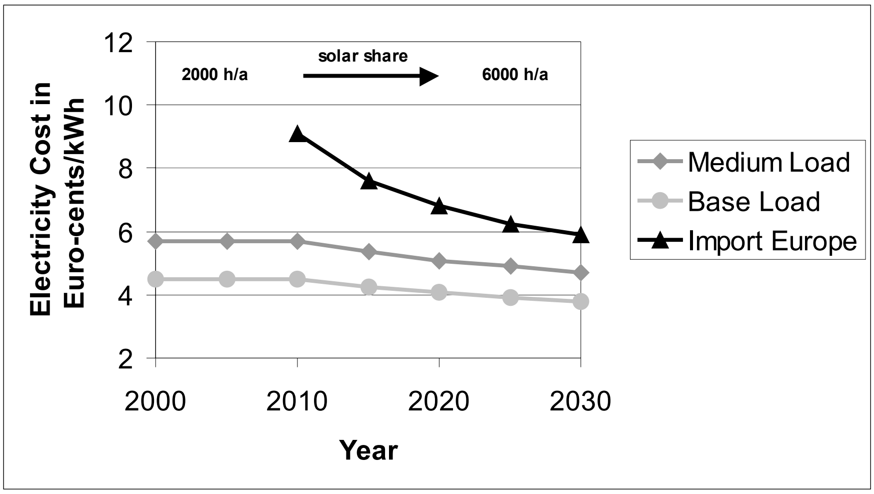

Figure 5: Outlook of electricity cost for combined power and water generation with increasing solar share. Assumed revenues for water 1.30 €/m³, interest rate 10 %, 25 years economic life, annual DNI 2350 kWh/m²y. HVDC-transmission over 3500 km, solar power transmitted only, total transmitted power 2000 MW, maximum losses at full load 15 %, investment 1.4 billion €.

Renewable Electricity for Base Load Demand

Now a major question is, how will large amounts of solar power fit into a national electricity supply system? It is a common misbelieve that renewables are not capable of providing base load electricity, because they are disperse, fluctuating and unpredictable. Of course, some renewables, like wind-power and photovoltaics, cannot easily follow and compensate the fluctuations of the electrical load. Though, from the point of view of fitting demand curves, they are not very different to nuclear- and lignite power plants, which are typical base load power plants and only operate in steady state. E.g., the reduction of the load at night is a well known problem for utilities with high contributions of nuclear power or lignite, and they try to persuade customers to shift loads from day to night in order to get a better capacity factor.

Looking at it from another point of view, the typical daily load pattern results from the combined demand of a lot of disperse, fluctuating and unpredictable customers. Together, they yield a load curve with relatively slow and fairly predictable fluctuations. Exactly the same happens with a well balanced mix of renewable sources and co-generation technologies, as can be appreciated in Figure 6.

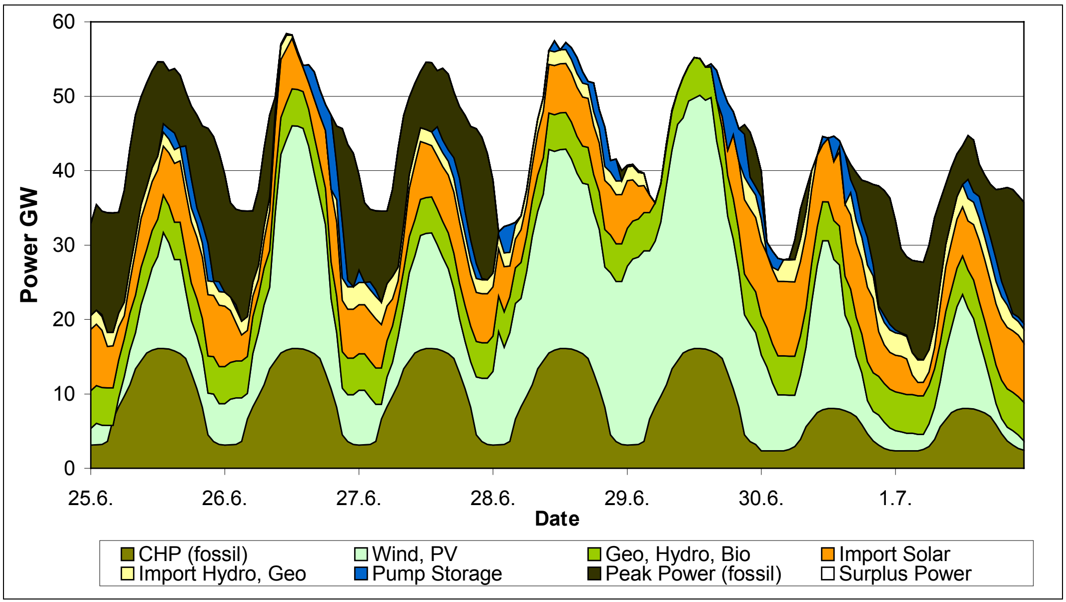

Figure 6: Hourly simulation of the electricity load and generation in Germany in the year 2050 in a scenario assuming a steady expansion of renewables in the power sector.

Because most people are active at daytime, load curves show a typical minimum during the night. This obviously fits well to a supply system with high solar electricity shares. Also, co-generation of heat and power (CHP), both for household- and industry applications, fits very well into this pattern, as heat is mainly required during the productive daytime. Figure 6 shows part of a simulation of the German electricity sector in the year 2050 based on a scenario with 60 % solar share. By that time, the average electricity cost will range between 5 and 6 €-cents/kWh, which will be lower than that expected for power from fossil sources. Co-generation, wind power and photovoltaics will cover most of the traditional base load demand and follow the daily load curve fairly well. Less fluctuating renewables like geothermal power, hydropower, biomass, and renewable electricity imports from solar thermal and hydro-plants will take over the medium load demand. Only the remaining peak load demand, which in such a scenario will be lower than at present, will be covered by fuel fired power plants. Thus, the emissions of the power park will be reduced to 25 %, as compared to 1990 [11].

A well-balanced mix of renewables and co-generation fits better to the power demand than conventional base load plants. Short-time fluctuations are fairly compensated if many plants are distributed over large areas, and if different sources (wind, solar, hydro etc.) are used. The predictability of renewables is not a greater problem than that of the load, and will continuously improve using satellite remote sensing technologies. Traditional base load plants powered by lignite, nuclear or fusion energy will hardly fit into a sustainable future electricity supply, as their inertia prevents them from covering the expected peak load demand.

The situation in the countries of the South may be different today, but in the course of the 21st century it will become more and more similar to that of today's industrialised countries, and they may start to experience the same problems. Instead of adopting obsolete schemes from today's industrial countries, the growing economies of the South have now the unique chance to enter a new, sustainable era of clean power generation and quickly close up with the changing power systems of the North.

Conclusions

Combined solar power and desalination plants apply the principle of co-generation to achieve the best possible technical and economic efficiency of solar energy conversion. They deliver two key products for economic development, that is power and water, both at a reasonable and also sustainable cost. In terms of environmental impact, they produce much less pollution and greenhouse gas emissions than equivalent fossil fuel fired systems. The rather simple technology involved, the vast resources in terms of solar energy and land, and the potential of solar electricity exports to Europe, gives the countries of the Southern Mediterranean a unique perspective for clean development and industrialisation in the 21^{st} century.

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