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Solar Thermal Power Stations

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Fig. 1 Solar power plant of SEGS type in California (source: Pilkington Solar International)

ABSTRACT

Today we know that not the resources of energy carriers will limit the fossil electricity generation in the next few decades. But global warming and the rapid growth of the world population are forcing us to urgently develop alternatives. By the end of the21st century about 10 billion people in the world will claim mobility, communication, heating and cooling and some other comfort. There is a wide consensus that this demand can not be covered by fossil power plants without severe damage of the global ecosystem.

The future energy system will be a mixture. There will still be a relevant portion of fossil electricity generation, but with higher efficiencies than today. There will still be nuclear power stations, even if this option is not very popular. And there will be a growing contribution of several renewable technologies. In the large scale this will be mainly wind, hydro and solar thermal.

The principle of using concentrated solar radiation to produce electricity is known since more than hundred years. But it has never been used in larger scale until the beginning of the eighties of the 20th century when special conditions in California allowed to compete with fossil energy systems and its very low fuel prices.

Since 1984 nine solar thermal power stations with a total capacity of 354 MW were build in the Californian Mojave desert, all still in operation today. That proves the feasibility and the mature technology, but why has there never been build another power plant of this kind somewhere else in the world?

This paper lines out the history of solar thermal power plants up to now, gives an overview over different technologies, ongoing research efforts and their expected results, the necessary conditions for a significant change in worldwide energy supply as well as an outlook on the worldwide energy system and its solar contribution in the upcoming century.

KEYWORDS
renewable energy, solar electricity, solar thermal power plants, solar power plants, trough power plants, tower power plants

1 Introduction

Some months before the new millennium started the world population reached the number of 6 billion people, and the latest forecasts expect that this figure will rise up to approximately 10 billion at the end of this century. These supposed 10 billion people in the world will most likely have a higher standard of living than today’s average; to avoid wars forced by social and economic differences one should assume that this average standard of living will at least double (which is definitely far on the save side; some experts expect this figure to rise by factor 5 or more).

If one accepts that standard of living is closely linked to the energy consumption a very simple calculation shows the dramatic challenge in the energy sector worldwide during the coming 100 years. Approximately twice the population at a doubled standard of living will need approximately four times the electricity than today’s power park in the world can supply.

ORIENTATION

Solar electricity generation in general covers most of the renewable technologies. Besides technologies using geothermal or tidal energy all other renewables result from the power of the sun like wind, waves, hydro and even biomass. Solar electricity generation more specifically can be both photovoltaic systems, which use the sunlight to directly produce electricity, or solar thermal systems, which concentrate the solar energy, convert it into heat and finally feed turbines like in any conventional power station. Solar power stations in this chapter refer to this last option.

Such systems are not designed to supply remote farms or villages with electricity. Solar thermal systems have an installed power up to 200 MW. Such systems are grid connected and designed to be integrated in the existing energy supply infrastructure.

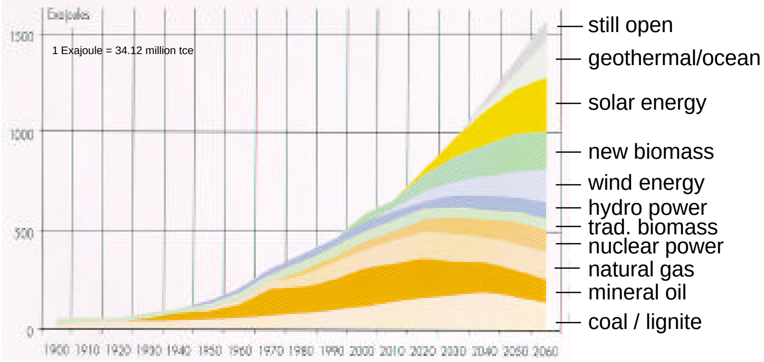


Fig. 2 Energy demand forecast (Source: Shell AG)

Even if there would be sufficient fossil resources to cover the growing demand, today we are already at a point where the CO_2 emissions are too high and effect severely our ecosystem. How could this work in the future? Will the future show a competition between decentralized stand alone systems and large grid connected systems? Stand alone systems are already the choice for remote applications, if the users accept some lower consumption standard than for grid connected users. And these systems will contribute significantly to bring electricity to the third of the world population in rural areas, which has today still no access to electricity at all.

Some experts believe, such small decentralized systems could replace today's electricity grid with it's big power plants. But how could stand alone PV systems cover the demand of megacities like Rio de Janeiro, Mexico City, Bombay or Cairo? How could big industries supply themselves with electricity cost effectively? It is the law of scale that larger systems in general can provide products more cost efficient than smaller ones, if both are running at the same capacity. Why shouldn't put some house owners their efforts together and install a joint electricity supply? There is no reason to not do it. The same will happen if two villages have to decide whether they build their own supply each or a shared one. The grid connected systems will survive and they will carry the biggest fraction of electricity supply worldwide, in 100 years as they do today.

The regions with highest birth rates in the world are countries with high or very high solar radiation. A big part of the population is concentrated in few areas, mostly along rivers or the sea coast. In a first approach solar power plant technology seems to be the natural solution for these sun belt countries.

Let's dive into some aspects of this technology to see whether it really keeps what looks so promising.

2 Solar Thermal Technologies

In general, solar thermal technologies base on the idea to concentrate solar radiation to produce steam which can then be used for electricity generation. In other words, solar thermal electricity generation is very similar to conventional power plants, the only difference is the fuel. It is the sun. This makes obvious, that collecting the solar energy which has relatively low density is one of the main engineering tasks of solar thermal power plant development. For concentration most systems use glass mirrors because of the very high reflectivity. Other materials are under development to meet the needs of solar thermal power systems. These systems can only use the direct radiation, but not the diffuse part of the sunlight because it can not be concentrated. Two principles of optical concentration are used, one is point focusing and the other line focusing. Line focusing systems are easier to handle. Because of the lower concentration factor the achievable temperatures are lower than those of point focusing systems. But higher temperatures normally mean higher efficiency. Both systems are used and their specific advantages and disadvantages will be discussed in this chapter.

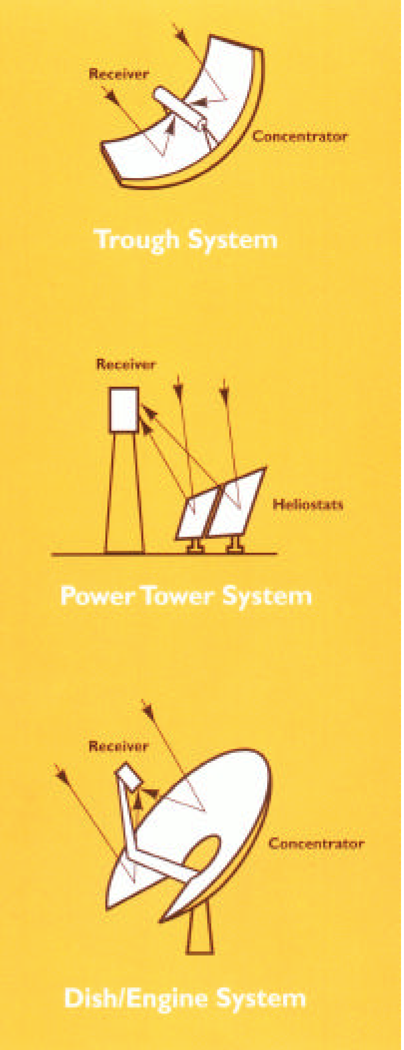


Fig. 3 Solar concentrating technologies

The architectures of the three main types of concentrating solar power (CSP) systems are shown in Figure 3. **Trough systems** use linear parabolic concentrators to focus sunlight to a receiver running along the focal line of the collector. The solar energy is absorbed in a working fluid (typically a heat-transfer oil, or in advanced systems, steam), which is then piped to a central location to power a conventional steam turbine. In a **power tower system,** a field of two-axis tracking mirrors reflects the solar energy onto a receiver that is mounted on top of a centrally located tower. The solar energy is absorbed by a working fluid (typically molten salt or air) and then used to generate steam to power a conventional turbine. The thermal energy can be effectively stored for hours, if desired, to allow electricity production during periods of peak demand, even if the sun is not shining. The third type of CSP system, the **dish/engine system,** uses a parabolic dish concentrator to focus sunlight to a thermal receiver and a heat engine/generator (located at the focus of the dish) to generate power.

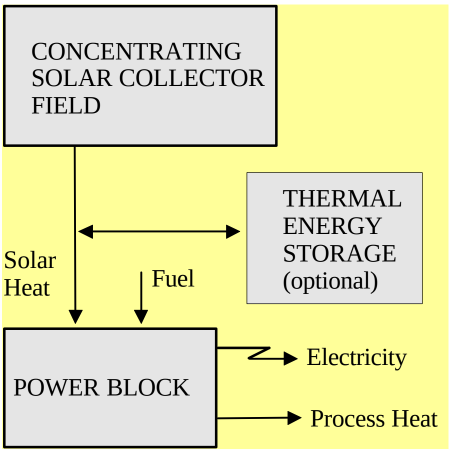


Fig. 4: Basic configuration of a solar thermal power plant

Because of their thermal nature, each of these technologies can be "hybridized", or operated with fossil fuel as well as solar energy (Figure 4). Hybridization has the potential to dramatically increase the value of CSP technology by increasing its power availability and dispatchability, decreasing its cost (by making more effective use of the power block equipment), and reducing the technological risk by allowing conventional fuel use in case the collector has to be repaired.

Moreover, the solar energy can be used for the co-generation of electricity and heat. In this case, the high value solar energy input is used with best possible efficiencies of up to 85 %. Possible applications cover the combined production of electricity, industrial process heat, district cooling and sea water desalination

Typical solar-to-electric system conversion efficiencies and annual capacity factors for the three technologies are listed in table 1. The values for parabolic troughs, by far the most mature technology, have been demonstrated in the field. The values for dish and tower systems are, in general, projections based on component and prototype system test data and the assumption of mature development of current technology. The overall solar-electric efficiencies are lower than the conversion efficiencies of conventional steam or combined cycles, as they include the conversion of solar radiative energy to heat within the collector and the conversion of the heat to electricity in the power block. The conversion efficiency of the power block remains basically the same as in fuel fired power plants.

System	Trough	Tower	Dish/Engine
Peak Efficiency	21%	23%	29%
Annual Efficiency	10 to 12% (d) 14 to 18% (p)	14 to 19% (p)	18 to 23% (p)
Capacity Factor	25% (d) to 70% (p)	25 to 70% (p)	25% (p)

Table 1 Characteristics of concentrating solar power systems (d = demonstrated, p = projected)

2.1 Line Focussing Systems

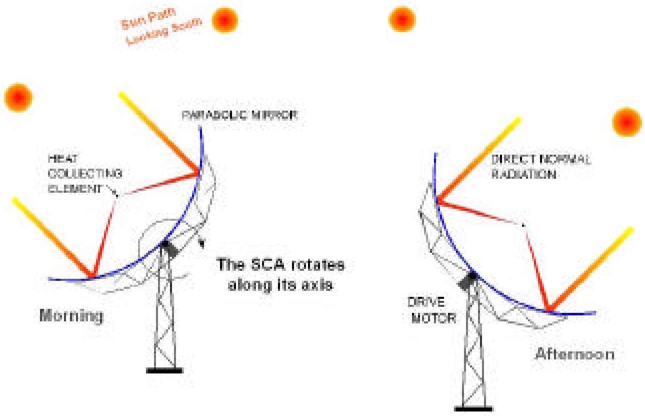


Fig. 5 A parabolic trough collector following the sun during operation

The reflective surface of a parabolic trough - mostly glass mirrors, but other materials could be used - concentrates the sunlight onto a receiver tube located along the trough’s focal line with concentration factors from 10 to 100. The troughs are normally designed to track the sun along one axis, predominantly north-south. The receiver tubes in the focal line have a special selective coating, to achieve best possible absorption of the solar radiation. In the tubes a heat transfer fluid collects the heat. In the SEGS (Solar Electricity Generating Systems, see Figure 1) type plants in California a synthetic thermal oil is used which allows operation temperatures of up to 400°C. This heat transfer fluid transports the energy through a system of pipes to a steam generator, hich feeds a steam turbine connected to a generator to produce electricity. This trough technology may also be used to provide process heat or to drive chemical reactions, but is currently best known for its applications in providing electrical power. During operation the system starts in the morning shortly after sunrise. The mirrors are facing east and will follow the sun over the day (see Figure 5). The first minutes in the morning are used to bring all systems up to operating conditions (see Figure 6). With 354 MW of parabolic trough power plants connected to the grid in southern California since the beginning of the 1980s, parabolic troughs represent the most mature CSP 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. No new plants have been built since 1991 because declining fossil-fuel prices in the United States resulted in unattractive economic predictions for future plants. The nine plants are located at three sites in the Mojave Desert near Barstow, California: Daggett (SEGS I and II), Kramer Junction

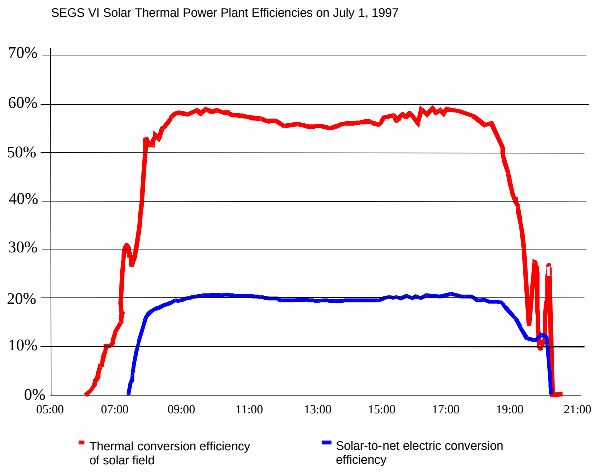


Fig. 6 Efficiency curve of the SEGS VI plant in the Mojave Desert in California, USA

(SEGS III through VII), and Harper Lake (SEGS VIII and IX).

The performance of these power plants has continued to improve over their operational lifetime. The Kramer Junction site has achieved a 30% reduction in operation and maintenance (O&M) costs during the last five years. This reduction is the result of major improvement programs for the collector design and the O&M procedures, carried out in collaboration of the Kramer Junction Operating Company and Sandia National Laboratories (Albuquerque). In addition, key trough component manufacturing companies have made advances. For example, SOLEL in Israel has improved the absorber tubes, and Pilkington Solar (formerly FLAGSOL, the German reflector producer) has developed improved process know-how and system integration and is working to initiate new projects in the world's sunbelt. The Abengoa Group, Spain, Bechtel Corporation, USA and Synthesis Solar AG, Germany, each have developed capabilities to be turnkey suppliers. This means that a strong competition will take place during the bidding of the next projects. We estimate that new plants, using current technology with these proven enhancements, will produce power today for about 10 to 12 US cents/kWh in solar only operation mode.

Fig. 7 The testloop of the European DISS project at the Plataforma Solar de Almería

The next generation of parabolic trough power plants is currently under development. On one hand much work is being done to develop improved collector systems. This includes optimized control systems, lighter support structures and of course lower costs. Innovative trough collectors for power generation have been recently presented by Duke Solar, USA and also by Synthesis Solar AG, Germany. On the other hand, the whole system is being optimized, which means reducing parasitic loads, optimizing startup procedures, and improving control strategies as well as the development of advanced solar/fossil hybrid schemes, especially the coupling with combined-cycle power plants. But the most important and most challenging step is to realize system cost reductions and efficiency improvements by substituting the synthetic heat transfer oil by water and steam. In this concept, the water is vaporized directly in the absorber tubes in the focal line of the collectors. The major advantage is that this technology allows to run the power plant without the synthetic oil heat transfer loop. This avoids costs (the heat transfer fluid is rather expensive, the heat exchanger from heat transfer fluid to steam is not needed etc.) and it also avoids the reduction of efficiency through the additional intermediate heat exchanger. The levelized electricity cost is expected to be 20-30% lower than in comparable SEGS type power plants.

These improvements are being implemented through ongoing research activities such as the German/Spanish Direct Solar Steam project (DISS, see Figure 7) and the new EuroTrough project, both co-financed by the European Commission, and also by private development and research activities.

2.2 Point Focussing Systems

2.2.1 Power Tower Systems

In more than 15 years of experiments worldwide, power tower plants have proven to be technically feasible in projects using different heat-transfer media (steam, air, and molten salts) in the thermal cycle and with different heliostat designs. U.S. and European industries (including Bechtel and Babcock Borsig Energy, which is the former Steinmüller) have expressed interest in commercializing second-generation power tower technology and have recently constructed and operated demonstration power plants.

Fig. 8 Solar Two, a molten salt receiver in the USA

At Barstow, California, a 10-MW pilot plant (Solar One) operated with steam from 1982 through 1988. It has then been operated as Solar Two, with molten salt as the heat-transfer and energy-storage medium, after modification of the complete plant in 1996 (see Figure 8). The system now has a few thousand hours of operating experience delivering power to the electricity grid on a regular basis. Solar Two has demonstrated, via storage, the feasibility of delivering utility-scale solar power to the grid 24 hours per day, if necessary.

In parallel, European activities have demonstrated the volumetric air receiver concept where the solar energy is absorbed on fine mesh screens and immediately transferred to air as the working fluid. Extensive validation of this concept has been demonstrated at the 2.5-MW (thermal) level by the Phoebus Technology Program Solar Air Receiver (TSA) tests conducted during the past few years at the Plataforma Solar de Almería in southern Spain (see Figure 9).

Power tower efforts in the United States, Europe, and Israel are targeted to achieve electricity generation costs of less than 10 US cents/kWh in the near term. This reduced cost will be accomplished by achieving:

Fig. 9 The CESA I test facility at the Plataforma Solar de Almería in Spain

- improvements in the heliostat field as a result of better optical properties, lighter structures, and better control. New heliostat design activities include the 150m² heliostat developed by Advanced Thermal Systems and the 170m² heliostat developed by Science Applications International Corporation (SAIC), both in the United States; the 150m² stretched-membrane ASM-150 heliostat of Steinmüller (under license from Schlaich, Bergermann und Partner, see Figure 10) in Germany; and the 100m² glass/metal GM-100 heliostat in Spain.

Fig. 10 The ASM-150; a 150m² stressed membrane heliostat

- improvements in heat-transfer media and receiver concepts. In addition to the Solar Two and TSA receivers described above, the current experiments for advanced receiver concepts include the high-flux molten-salt panel experiment at Solar Two and three volumetric receiver experiments in Europe and Israel.
- improvements in system integration by reduction of parasitic loads, optimization of startup procedures, and better control strategies.
- improvements in solar/fossil hybridization schemes, especially the coupling with conventional combined-cycle power plants. One concept under investigation in Israel employs a secondary reflector on the tower top to direct the solar energy to ground level for collection in a high temperature air receiver for use in a gas turbine. Coupling the output of a high-temperature solar system to a gas turbine could allow a higher efficiency than current steam turbine applications, faster startup times, lower installation and operating expenses, and perhaps a smaller, more modular system.

Solar preheating of the combustion air of gas turbines offers superior performance, as the solar energy absorbed in the heated air can be converted to electricity with the high efficiency of a Combined Cycle (CC) plant (Figure 11). This results in a reduced heliostat field size and thus less overall investment cost for the solar part as compared to solar steam generation. Solar air preheating has a high potential for cost reduction of solar thermal power. In addition, this concept could be applied to a wide range of power levels (1 to over 100 MW_{el}). At the smaller power levels, highly efficient recuperated gas turbine cycles can be used instead of CC. The solar share (up to 100 %) can be chosen flexibly by the receiver outlet temperature that may vary from today 800 °C to future 1200 °C or higher (Buck et al. 2000).

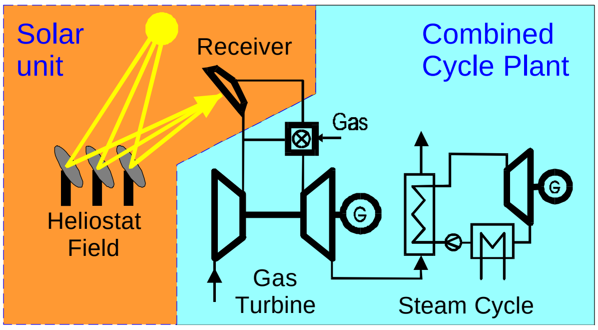


Fig. 11: Scheme of a solar-hybrid Combined Cycle system with REFOS Receiver for pre-heating of the combustion air

In 1996 the **REFOS** project (funded by the German Ministry of Education and Research BMBF) was initiated to demonstrate the technical feasibility of the required receiver technology. The aim of the REFOS project was to develop, build and test modular pressurized volumetric receivers under operating conditions representative for the coupling with gas turbines. Testing emphasis was on solar air preheating, accompanied by basic research on materials and solar methane reforming with steam.

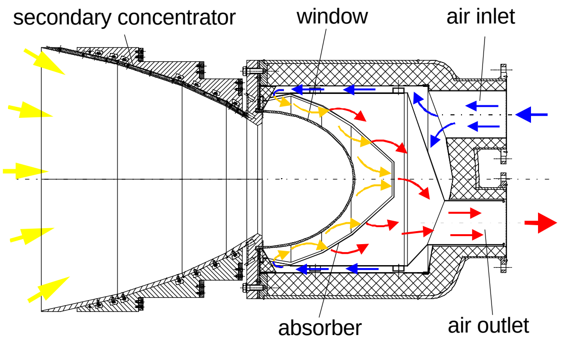


Fig. 12: Scheme of REFOS receiver module

The project successfully demonstrated the feasibility of the **REFOS** concept. It was led by DLR and was carried out in cooperation with CIEMAT, Spain.

The **REFOS** receiver is shown in Figures 12 and 13. The highly concentrated radiation reflected from the heliostat field first hits the secondary concentrator, where the concentration is increased to about 2000 times. Afterwards, it passes through a dome-shaped quartz glass window into the inside of the receiver vessel, where finally it is absorbed by the volumetric absorber. The pressurized air coming from the compressor or from a previous module enters through the air inlet, a ring channel, and the inlet absorber

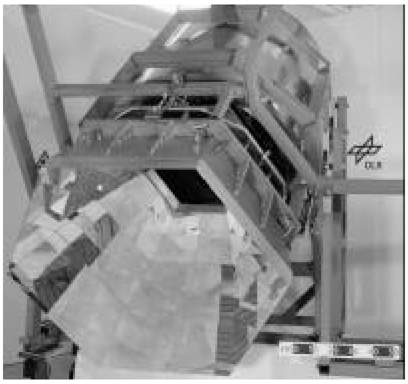


Fig. 13: Secondary concentrator

into the space between the window and the absorber. By the subsequent flowing through the volumetric absorber, the absorbed solar heat is transferred to the pressurized air. Passing through the air outlet, it finally arrives in the combustion chamber of the gas turbine.

2.2.2 Dish/Engine Systems

Several dish/engine prototypes have successfully operated during the last 10 years, but large-scale deployment has not yet occurred.

Currently in Spain, six units with a 9 to 10kW rating are operating successfully (see Figure 14). The German company Schlaich, Bergermann und Partner, working with the German companies Steinmüller (collector system) and SOLO Kleinmotoren (Stirling engine), developed these units. Three of these dishes have been continually operated with great success since 1992, accumulating more than 30,000 hours of operating experience. The new EuroDish development will advance this concept with the additional participation of MERO Systeme of Germany (structural system).

Fig. 14 The six DISTAL systems at the Plataforma Solar de Almería in Spain.

At the same time in the United States, SAIC installed two second-generation 25kW dish/Stirling prototypes for extended testing and evaluation. These systems incorporate cost reduction features, hybridization, and higher system reliabilities than previous prototypes to qualify them for mass production and commercialization.

With the participation of a utility consortium, research and development work in Australia has demonstrated the 400m², 100kW "big dish" of the Australian National University in Canberra. The objectives of the project are currently being redefined because of changes in the Australian utility environment. Applications may include central generation from a distributed field.

The use of dishes for stand-alone or grid-support installations will reach near-term markets as costs drop to less than 15 US cents/kWh. This lower cost will be achieved through:

- improvements in mirrors and support structures, improvements in hybrid heat-pipe and volumetric receivers coupled to Stirling and Brayton engines, and development of control systems for fully automatic operation; and

- improvements in system integration by reduction of parasitic loads, optimization of startup procedures, better control strategies, and hybrid operation of the Stirling and Brayton engines.

3 Sustainable Development - Dream or Option?

3.1 At the Edge of the Millennium

The awareness of the environmental impacts associated with power generation and use have escalated dramatically within the last decade, and this concern is certain to grow. Renewable energy technologies, however, offer solutions with minimal environmental impact. E.g., the energy payback time of a solar thermal power station is of the order of 0.5 years, while the economic lifetime is at least 25 years. The cumulated life-cycle carbon dioxide emission is in the range of 0.012 kg/kWh (Weinrebe 1999). While effective measures have not yet been introduced in most countries to internalize the environmental costs of electricity production, it seems likely that this will happen before long, thus making the development of clean energy technologies a wise investment. Thus, solar thermal power is a clear option in the future global electricity supply.

The international community of nations is concerned about climate change and environmental damages. The “Intergovernmental Panel for Climate Change” (IPCC)” demands drastical reductions of the greenhouse gas emissions in order to avoid a collapse of the world climate by global warming. In Kyoto 1998 the nations agreed to compelling CO_2 reduction quota; Japan committed itself to a 6%, US to 7% and the European Union to 8% CO_2 reduction of the 1990 levels until 2012.

As consequence of a study (Enermodal Engineering Ltd, 1999) conducted for the World Bank’s Global Environmental Facility (GEF), that predicts solar thermal electricity costs below 6 US cents/kWh after the year 2010, the World Bank is now willing to support market introduction of solar thermal power in India, Egypt, Morocco and Mexico, by covering incremental costs over the least-cost conventional alternative up to an actual fund totaling to 200 million US-Dollar (about 50 million US-Dollar per project).

The White Paper of the European Commission for a community strategy and action plan on renewable energies of 1997 foresees at least 1 GWe of solar thermal power systems implemented in Europe by the year 2010. This objective can be achieved by a scenario of a number of 25 to 30 commercial solar power plants with each of 30 to 50 MWe unit size and distributed along the South of Europe. The scenario sets an objective of 2,500 Euro/kWe investment and an overall generating cost of 8 Euro cents/kWh (short term) and 4 Euro cents/kWh (long term) for fossil/solar „hybrid" plants.

On this background, various commercial power plant project developments with unit outputs of 50 to 310 MWe and large solar fields of parabolic trough collectors are currently under way or are in a progressive planning stage by European and U.S. project developers supported by grants of the World Bank/GEF or other funds:

- in Greece: 50 MWe steam cycle solar thermal power plant to supply solar-only electricity to Crete’s island grid;

- in Egypt: 135 MWe natural-gas-fired combined-cycle with an equivalent solar capacity of 30 MWe in Kuraymat at the Nile river, with allocated 40 to 50 million US-Dollar GEF grant;
- in India: 140 MWe with naphta-fired combined-cycle and with an equivalent solar capacity of 35 MWe in Mathania/Rajasthan, with allocated 49 million US-Dollar GEF grant and 100 million US-Dollar loan from the German Kreditanstalt für Wiederaufbau (KfW);
- in Mexico: 310 MWe natural-gas-fired combined-cycle with an equivalent solar capacity of 40 MWe in the Northern Mexican desert, with allocated 40 to 50 million US-Dollar GEF grant;
- in Morocco: 150 MWe with natural-gas-fired combined-cycle with an equivalent solar capacity of 30 to 50 MWe close to the new gas pipeline from Algeria to Spain, with allocated 40 to 50 million US-Dollar GEF grant;
- in Spain: 50 MWe solar thermal steam cycle power plant in Sanlúcar near Sevilla or in Tabernas near Almería to supply solar-only electricity to the Spanish grid;
- in Iran: feasibility study on the implementation of a 100 MWe natural gas-fired combined-cycle and with a parabolic-trough field in the Yazd desert;
- in the USA: green electricity and renewable portfolio policies of various states favouring further development of solar thermal power plant technologies;
- in Brazil: PDF grant from UNDP/GEF to assess an initial Brazilian pilot demonstration plant.

A plan of market introduction initiated in Germany (SYNTHESIS programme) projects world wide solar power stations with a total capacity of 7 GWe by the year 2010 (Trieb, 2000). Several projects for the combined facilitation of electricity, district cooling and sea water desalination using solar thermal power are developed since early 1999 on a private basis within this programme.

3.2 What Needs to be Done

One key difference between conventional and solar thermal electricity generation is that the solar energy supply is variable and uncontrollable - unlike fossil or nuclear fuel. Coping with this variability presents one of the key engineering challenges for solar thermal power technology. Substituting fuels by solar collectors means substituting operational costs by investments. This is like building a fuel fired

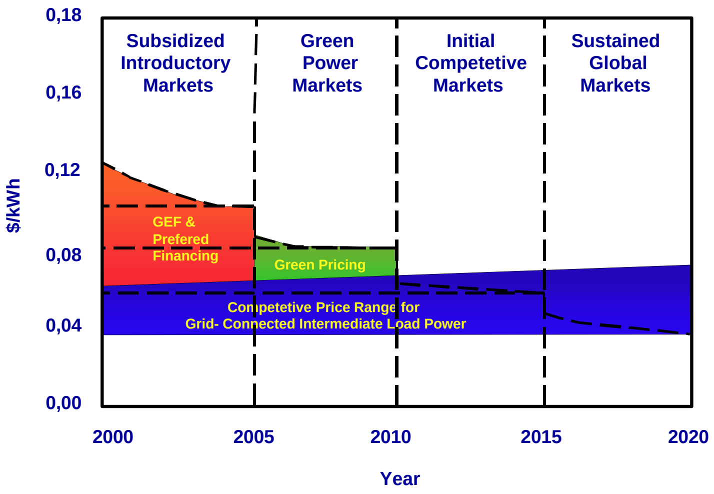


Fig. 15: Trough technology development steps and cost vs. Market opportunities (Price 1999)

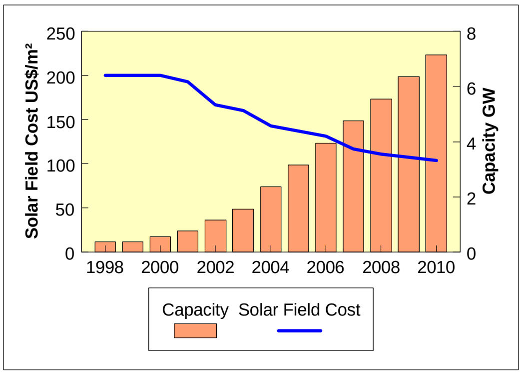
plant and buying and storing the fuel for the whole life cycle at the beginning. From this additional investment arise further additional capital costs by interests, insurance premia, taxes etc.

Market entry for solar thermal power technologies will therefore be based on three phases in order to start market introduction and successively initiate a learning curve for the cost reduction of the solar field components:

1. Solar Field Additions: To respond to the present market needs and reduce the amount of buy-down necessary to make solar power immediately competitive, small solar fields can be integrated into gas fired combined cycles and coal- or fuel oil fired steam cycle power plants. The additional investments required will be in the order of only $400 to 1500 per kW installed, achieving in base load operation a modest solar share of 5 to 25 %. In this initial phase, primarily subsidized introductory markets will be exploited.
2. Increased Solar Shares: With successively reduced solar field costs and increased green pricing and compensation premiums for CO_2 avoidance in the frame of the Clean Development Mechanism CDM or possibly based on tradable certificates, solar shares will be increased to about 50% and more by integration of the solar fields into coal- or oil-fired power stations.
3. Thermal Energy Storage: With further reduced solar field costs, thermal energy storage will become attractive enough to increase the solar operating hours and to further reduce the fossil energy input. In the long run, base-load operated solar thermal power plants without any fossil fuel addition are in principle possible.

In the medium term, a 50 % cost reduction of the solar field can be achieved by economies of scale, technical advancements, series production, increased competition and other learning effects (Figures 16 and 17). Thus, competitive solar thermal electricity costs will be achieved within a decade, if a continuous, world wide expansion of the solar thermal power market takes place (Trieb 2000).

Up to now, this evolution was blocked by the incremental cost with respect to conventional power generation. The fact that fuels are substituted by solar collectors - that is by capital goods - yields a large initial investment, an increased capital cost and the perception of a higher financial risk by potential investors, and leads to increased risk surcharges.



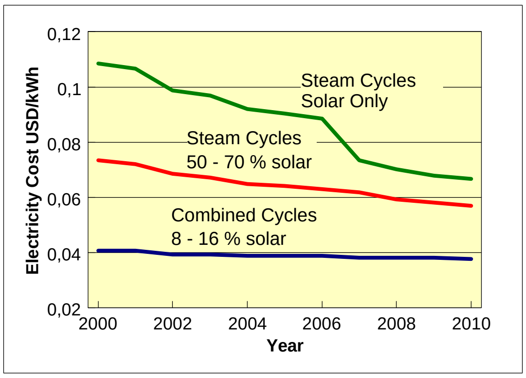


Fig. 16: (left) Development of the Solar Field Cost of Parabolic Trough Power Plants as Function of the World Wide installed Capacity as foreseen by the Synthesis Programme

Fig. 17: (right) Electricity cost of solar thermal power stations as foreseen by the Synthesis Programme

A scheme of finance developed in Germany within the SYNTHESIS programme (Trieb 2000) foresees to reduce the cost of solar power by attracting project partners from related business sectors that are willing to reduce the capital cost within their specific contribution to the projects, providing

- loans at low interest rates (banks),
- equity at low interest rates (investor groups),
- insurance at low rates (insurance and re-insurance companies),
- EPC and O&M with low risk surcharges (industry), and
- low taxes, custom duties and land cost (host country).

In this way, every partner of such a project contributes to cost reduction and start-up finance. Risk sharing and extensive risk management are major requisites for the project partners to reduce their risk surcharges. Together with the direct grant funding from GEF and possibly upcoming schemes of green power and emission trading, this will allow for competitive solar thermal power projects from now on, while the size of the collector field will be basically designed to funds.

Most projects will be developed as IPP, requiring an extensive contractual framework and long term agreements regarding operation, maintenance and supply of power, fuels and other services in accordance to the international standards. The conditions of finance will be normalized as the projected learning curve of solar power proceeds and the solar field becomes less expensive. It is expected that after 2010, no further start-up funding from private or public resources will be required.

3.3 How Could the Future Look Like?

The future of solar thermal power development will probably split into two major phases:

1. Market Introduction in Solar Countries (until 2010)
2. Build Out of Country Potentials in the South, and Import / Export Schemes for Solar Electricity from Solar Countries to the Northern Industrial Countries (after 2010)

The scenario of the world power demand in Figure 18 shows the challenge resulting from the goals of emission reduction established by UNFCCC - IPCC: in spite of a reduction

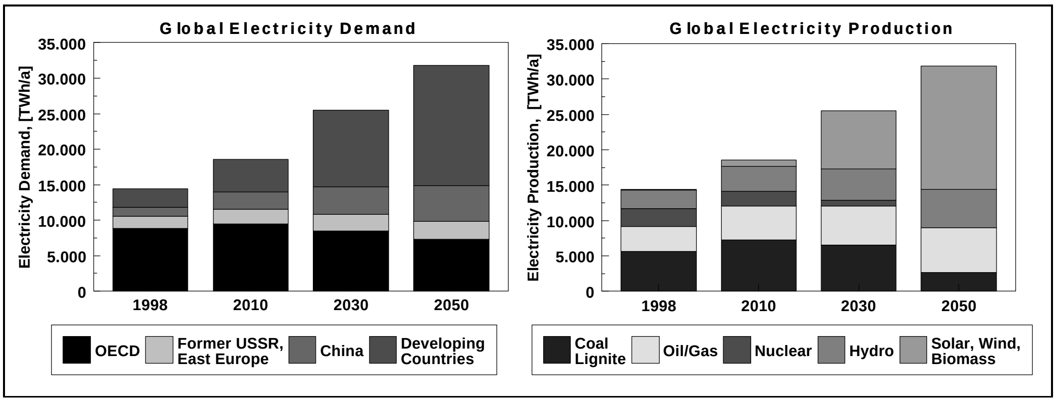


Fig. 18: Scenario of world power demand and production from fossil, nuclear and renewable energy sources until 2050 based on climate compatibility (DLR). Also refer to WEC 1995.

of the power demand in the industrial countries by more efficient energy use, the global power demand will more than double by 2050, mainly due to the growing electricity demand in today's developing countries. Nuclear power will play a declining role by that time due to an increased international awareness of the related risks. By 2050, renewable energy sources will have to supply more than today's total global electricity demand in order to establish a world power production compatible with stable atmospheric conditions.

The key role of solar thermal power in global climate protection is evident: solar thermal power plants are immediately applicable in the bulk electricity sector of many sunbelt countries during the ongoing phase of strong growth expected to remain in the coming decades, making in fact use of that growth to "solarise" the electricity sector.

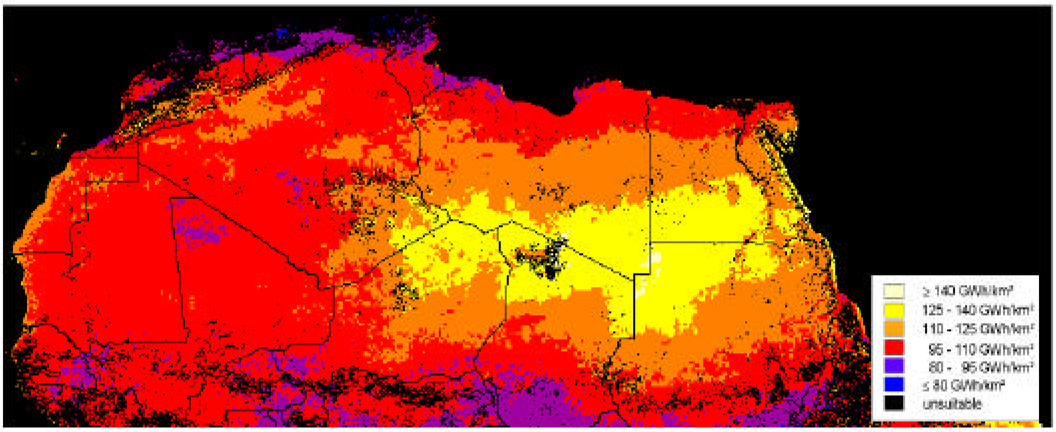


Fig. 19: North Africa – Annual solar electricity yield in GWh per km² of land area

The technical and economic potential of solar thermal power generation is tremendous. A recent study by DLR reveals (Brosaemle et al. 2000), that less than 1 % of the suitable areas for the placement of solar thermal power stations in Northern Africa would in

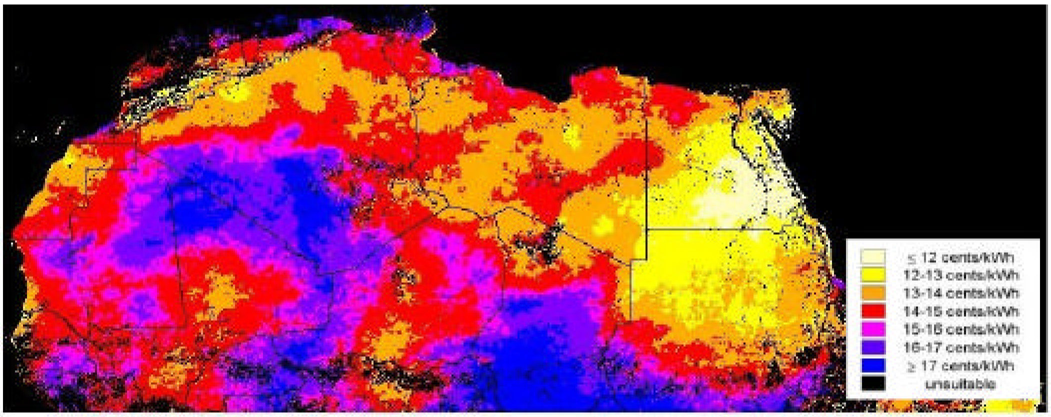


Fig. 20: Cost of Solar Thermal Electricity Generation in North Africa. Assumptions: Single Plant Capacity 200 MW, No Plant Clusters, Rankine Cycles in Solar Only Operation Mode, Interest Rate 8 %/a, Economic Lifetime 25 Years, Price Level 1998.

theory suffice to cover the 1998 world electricity demand, at electricity costs of less than 12 US-cents per kWh (cost level 1998) in solar only operation mode. (Figures 19 and 20). Particularly attractive sites can be found in Egypt (West of Aswan, Red Sea Coast) and Morocco.

The exploitation of this potential quickly comes to its limits, if it is restricted to the national boundaries of the involved countries. For example, the countries of the Maghreb region have vast resources of solar irradiation, and also land to place the necessary converters, but inadequate technological and financial resources, and their electricity demand is still relatively small. The contrary is true for Europe (Figure 21). In order to exploit the renewable energy potential of both regions in an efficient and economic way, an interconnection of the electricity grids shall allow the transmission of solar electricity from Maghreb to Europe. This synergy will not only reduce the cost of solar electricity in Europe, but also will create an income of hard currencies for the Maghreb countries, enabling them to finance and develop the renewable energy resources for their own demand and reduce their fuel consumption.

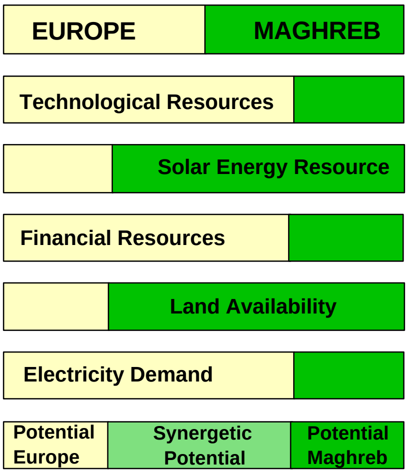


Fig. 21: The Regional and Synergetic Solar Energy Potentials of Europe and Maghreb (qualitative display only). Source: Hamburger Klimaschutz-Fonds

The technology needed for such a south-north-interconnection is state of the art: At present, 40 GW of electric capacity is transmitted by high voltage direct current transmission lines (HVDC) that are in operation world wide in more than 55 projects, mainly with the purpose to transfer hydro- and geothermal power from its source to urban or industrial centers of demand (Figure 23). The cost of transmission over 1000 km of distance is of the order of 1 US-cent/kWh, that means that solar power from the Maghreb could be consumed in Europe for about 7-9 US-cents/kWh by 2010, if such a scheme is established (Figure 22).

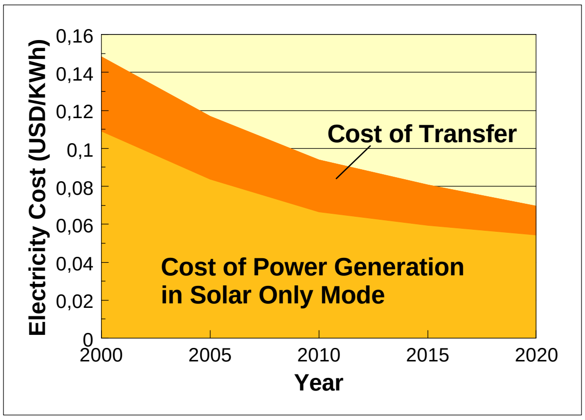


Fig. 22: Cost of Solar Thermal Power and Transmission by HVDC from Maghreb to Central Europe Assumptions: Single Plant Capacity 200 MW, No clusters. Rankine Cycle, Solar Share 100 %, Capacity of HVDC grid 2000 MW, Distance 3300 km, Loss of Transfer 16 %, Interest Rate 8 %, Depreciation 25 a

Figure 24 shows a scenario of electricity generation from renewable sources in Germany up to the year 2050 (Nitsch 2000). The electricity supply that is presently based on nuclear and fossil sources will have to change considerably in order to meet the international requirements for climate protection and equally the

German policy of non-nuclear power generation. According to these goals, nuclear power will disappear until 2030, and a shift from coal to gas powered co-generation and combined cycle power plants will have to take place. The scenario includes the use of national and import energies like solar thermal power from Maghreb (Solar Imports), hydro energy from Iceland and Scandinavia and geothermal power from Iceland (Other Imports), which would be imported through high voltage direct current (HVDC) transmission lines.

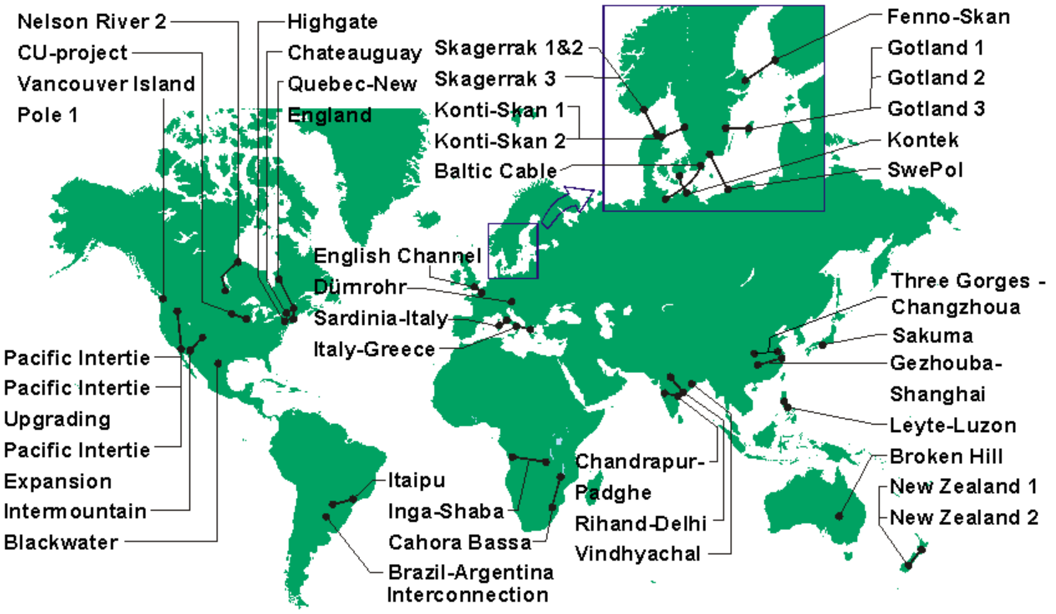


Fig. 23: 40 GW of World Wide HVDC Transmission Lines in 1999 (Source: ABB).

Comparing this scenario to an equivalent one that depends exclusively on national renewable power sources (Scenario B in Figure 25), the advantage of renewable power

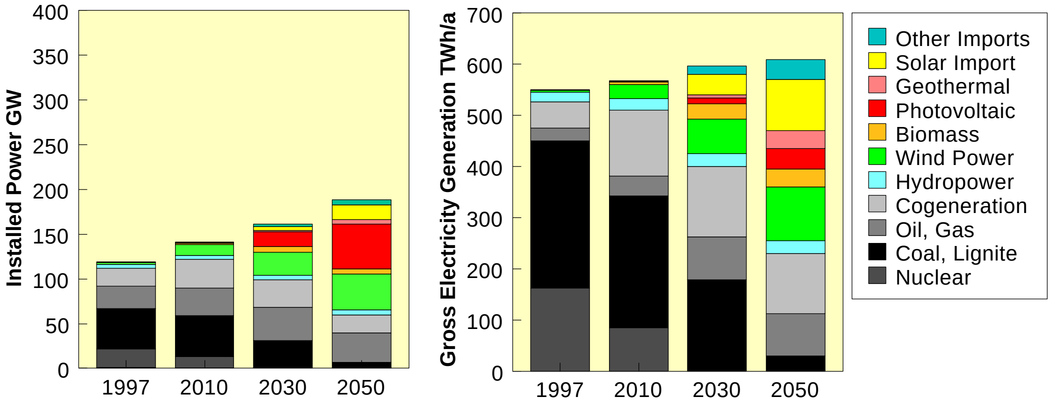


Fig. 24: Installed Power (left) and Annual Electricity Generation (right) according to a Sustainable Electricity Supply Scenario with 60 % Renewable Energy Share for Germany until 2050 (DLR)

imports in the Scenario A becomes obvious: the necessary installed power capacity is 50 % lower compared to the Scenario B. This leads to a considerable reduction of the necessary investments and the average electricity cost.

The lower necessary power capacity in Scenario A is achieved by a higher capacity factor of the renewable import power plants that would be located at very good sites where 5000 to 7000 annual full load hours of operation can be provided, while the national sources of wind and solar power in Germany yield an average of only 800 (PV) to 2500 (Wind) full load hours per year. The thermal storage capability of solar thermal power plants is a key advantage in this context. In the Scenario A, the share of highly fluctuating renewables (wind and PV) is 20 % while in Scenario B, their share is over 40 %. The B scenario would hence produce much higher power peaks in the German grid. Another drawback of the B-scenario is the fact that the German renewable energy resources would have to be exploited up to their potential limits already by 2050.

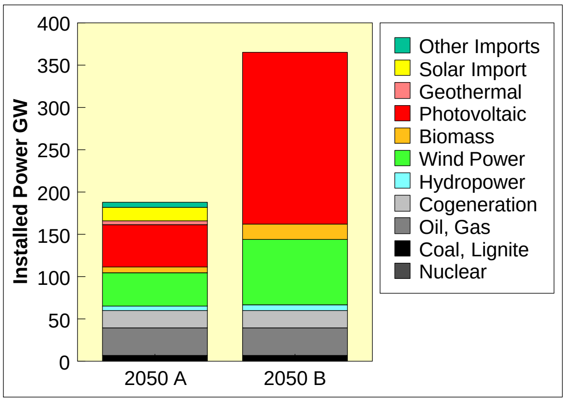


Fig. 25: Installed power capacity needed for two equivalent German electricity supply scenarios with 60% renewable energy share by 2050

A based on national and imported renewable energy sources

B based only on national renewable energy sources

The German example shows that renewable energy sources do not necessarily compete with each other. On the contrary, they complement each other, leading to consistent and sustainable pathways to a predominantly renewable, sustainable energy supply scheme if they are combined and applied in a well balanced manner.

4 Conclusions

During the first decades of this 21st century fossil energy carriers will play the main role in the worlds energy supply. But these resources will be used much more efficient than today. The renewables will contribute more and more. After the initial market introduction phase of large scale renewable technologies a significant and growing fraction of additionally installed new capacity will use these technologies.

It is a common misunderstanding, that renewables are not able to provide base load bulk electricity for the growing global power demand. The contrary is true: a well balanced mix of hydro, wind, PV, geothermal, biomass and solar thermal power certainly can provide base load, medium load and peak load power even in a highly industrialized country like Germany.

Solar thermal power plants, with their inherent storage capability and their potential to activate the synergetic renewable energy potentials of the countries of South and North, will play a key role in a sustainable global electricity scheme of the 21st century.

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