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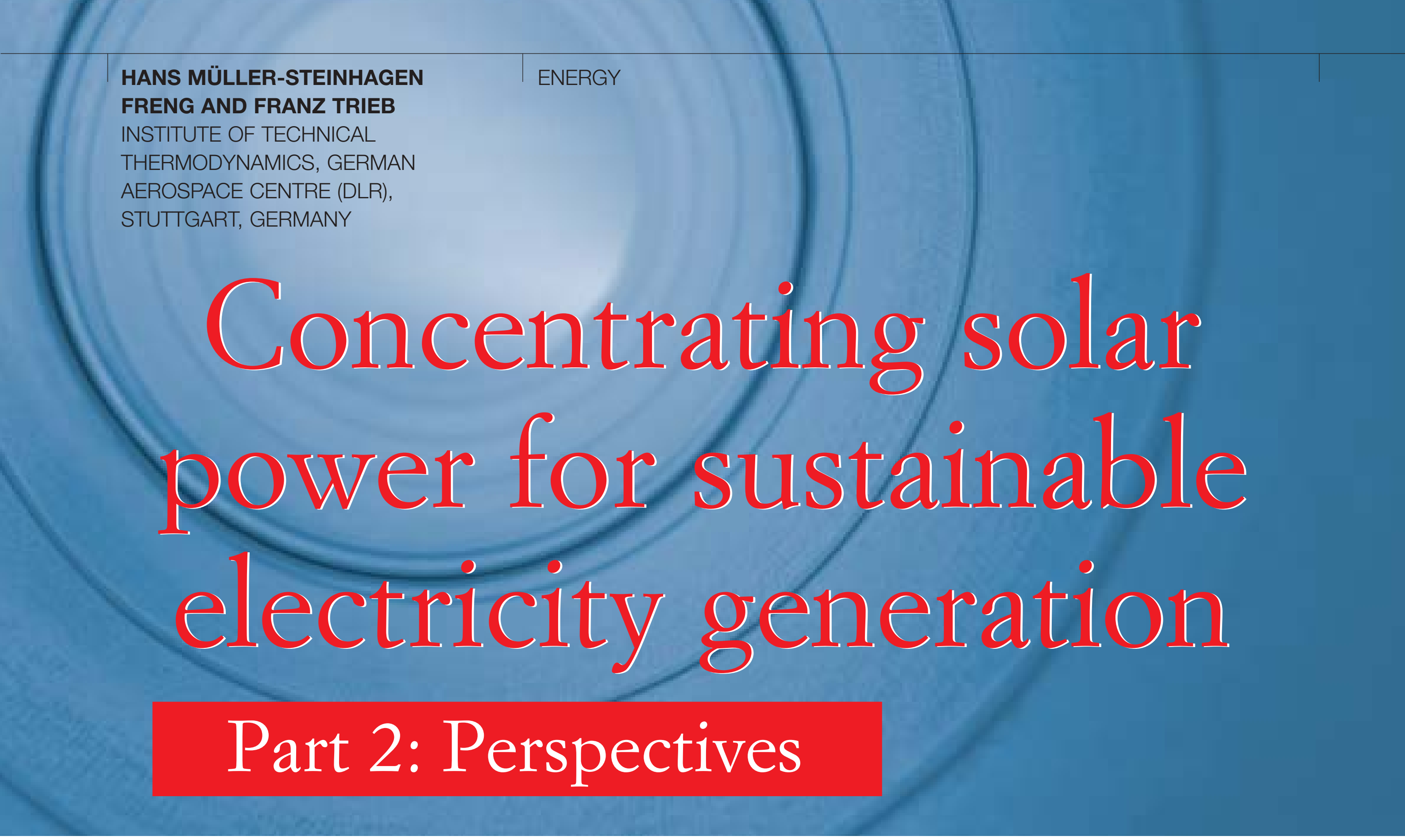


Concentrating solar power for sustainable electricity generation

Part 2: Perspectives

The limited supply of fossil hydrocarbon resources and the negative impact of CO_2 emissions on the global environment dictate the increasing usage of renewable energy sources. Concentrated Solar Power (CSP) is the most likely candidate for providing the majority of this renewable energy because it is highly cost-effective and its supply is not restricted if transported from the World's solar belt to the population centres. Three main technologies have been identified during the past decades for generating electricity in the 10 kW to several 1000 MW range: the dish/engine technology, which can directly generate electricity in isolated locations; the parabolic trough technology, which produces high pressure superheated steam; and the solar tower technology, which produces air above 1000°C or synthesis gas for gas turbine operation. While these technologies have reached a certain maturity, as has been demonstrated in pilot projects in Israel, Spain and the USA, significant improvements in the thermo-hydraulic performance are still required if such installations are to achieve the reliability and effectiveness of conventional power plants. This article is divided into two parts: Part 1 in the previous issue of Ingenia focussed on CSP technologies, their history and state of the art. Part 2 describes the technical, environmental, social and economic perspectives of CSP in a future energy world aiming at sustainability.

In 2000 the world population reached 6 billion people and the latest forecasts expect that this figure will rise to approximately 10 billion at the end of this century. These 10 billion people will most likely have a higher standard of living than today's average, with assumptions ranging from 2 to 5 fold improvement. Since the standard of living is closely linked to the energy consumption, a simple calculation shows the dramatic challenges facing the worldwide energy sector in 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. Even if there were sufficient fossil resources to cover the growing demand, a point would soon be reached where the CO_2 emissions are too high and would severely and irreversibly damage our ecosystem. Figure 1 illustrates the development of fossil fuel combustion, CO_2 content in the atmosphere, average global temperatures and costs due to storm damages from 1970–2000.

Shell AG (2002) suggests a scenario (Figure 2) where sustainable growth in energy provision may be achieved in future decades. The future energy system will be a mixture of various factors. There will still be a relevant portion of fossil electricity generation, but with higher efficiencies than today. There will also be nuclear power stations, even if this option may not be very popular today, and a growing contribution of several renewable technologies. At a large scale this will be mainly wind, hydro and solar thermal. CSP is the most likely candidate for providing the majority of electricity from renewable sources because it is amongst the most cost-effective renewable electricity technologies and its supply is not restricted if transported from the world's solar belt to the population centres.

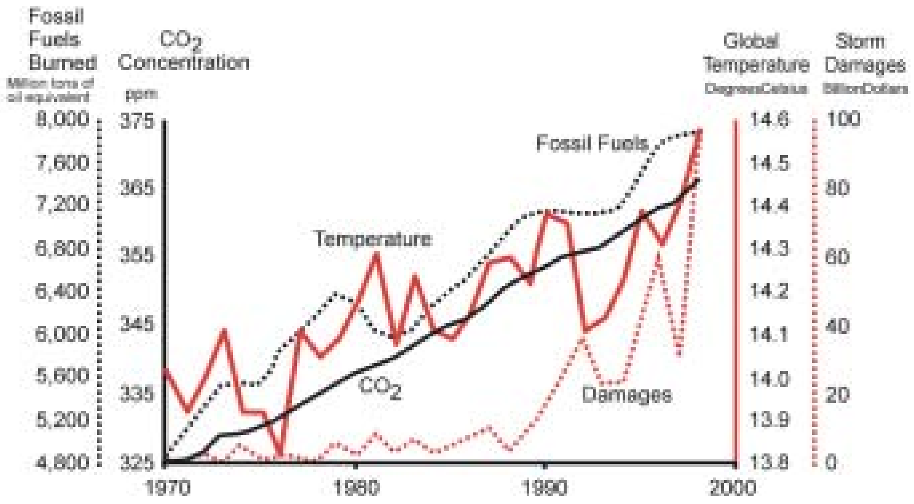


Figure 1 Energy and climate (Source: EarthWatch)

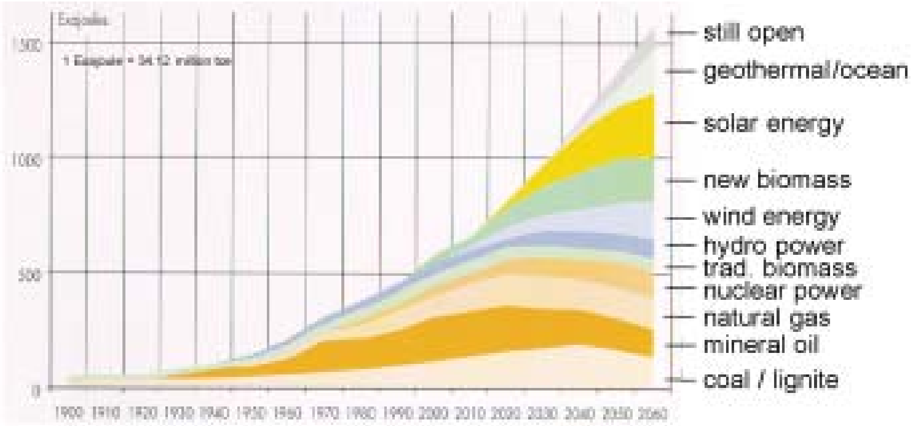


Figure 2 Energy demand forecast (Source: Shell AG)

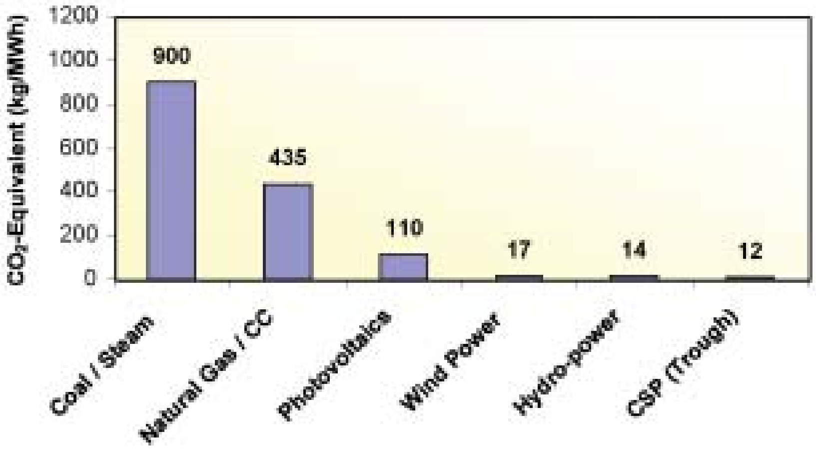


Figure 3 Life cycle greenhouse gas emissions of different power technologies per generated electric MWh (Source: DLR)

A key for sustainable development

Life cycle assessment of emissions from CSP systems shows that they are very well suited for the reduction of greenhouse gases and other pollutants, without creating other environmental risks or contamination. For example, each square metre of collector surface can avoid as much as 250–400 kg of CO_2 emissions per year. Life cycle greenhouse gas emissions of different power technologies per generated electric MWh are shown in Figure 3. The production of the power systems is based on an energy mix with emissions of 700 kg CO_2 per MWh; the CSP value corresponds to an 80 MW parabolic trough steam cycle in solar operation, photovoltaics and CSP are assumed to operate under conditions of North Africa. For comparison, a combined cycle plant (CC) is also included. As illustrated, CSP power plants produce several orders of magnitude less carbon dioxide on a life-cycle basis than competing fossil-fired plants.

The energy payback time of the concentrating solar power systems is approximately 5 months. This compares very favourably with their expected life span of approximately 25–35 years. Moreover, most of the collector materials and foundations can be recycled or used again for further plants.

Co-generation systems for solar electricity generation and thermal seawater desalination could, in the near future, become a motor for the industrial and agricultural development of desert areas. A 200 MW plant of this type with, for example, 7500 full load operating hours per year would deliver approximately 1.5 billion kWh/y of electricity and 60 million m^3/y of freshwater for irrigation and other purposes.

In the short term, at least 50% of the solar field equipment can be manufactured in most countries of the south, consisting mostly of relatively simple structures of concrete, steel and

Figure 4 Global distribution of the solar electricity generating potential of CSP in GWh/km²y (Source: DLR, ISET)

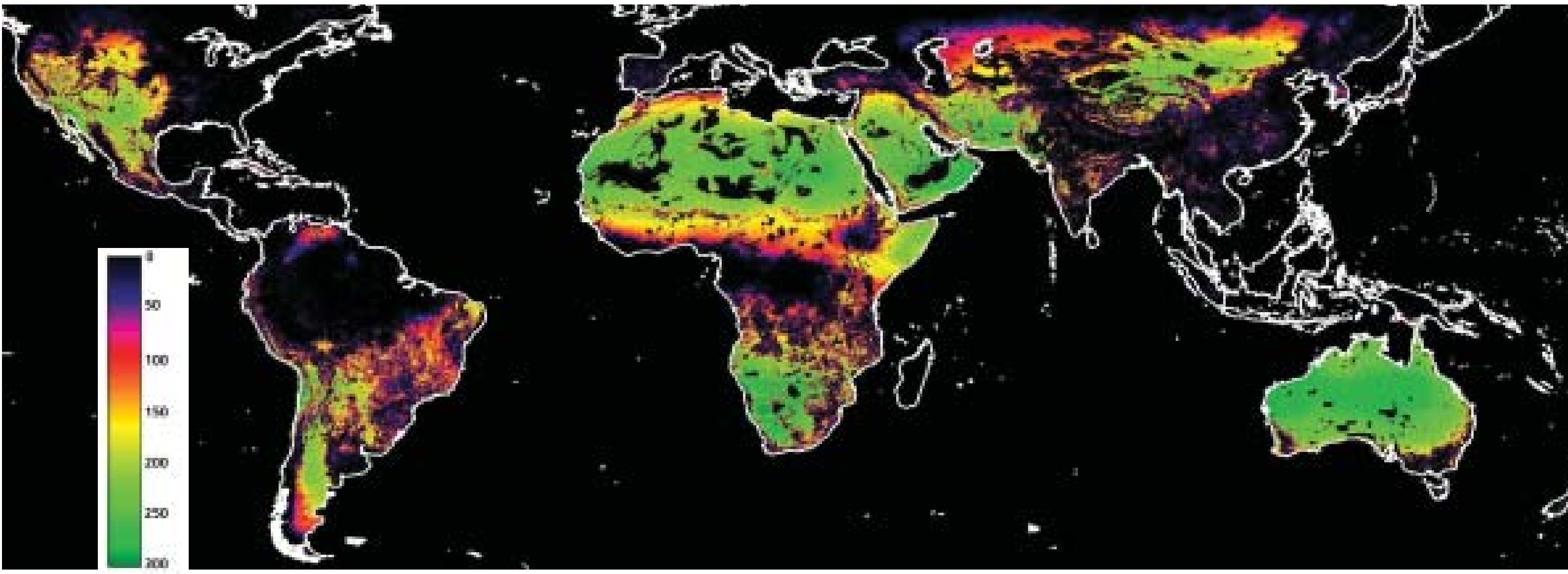
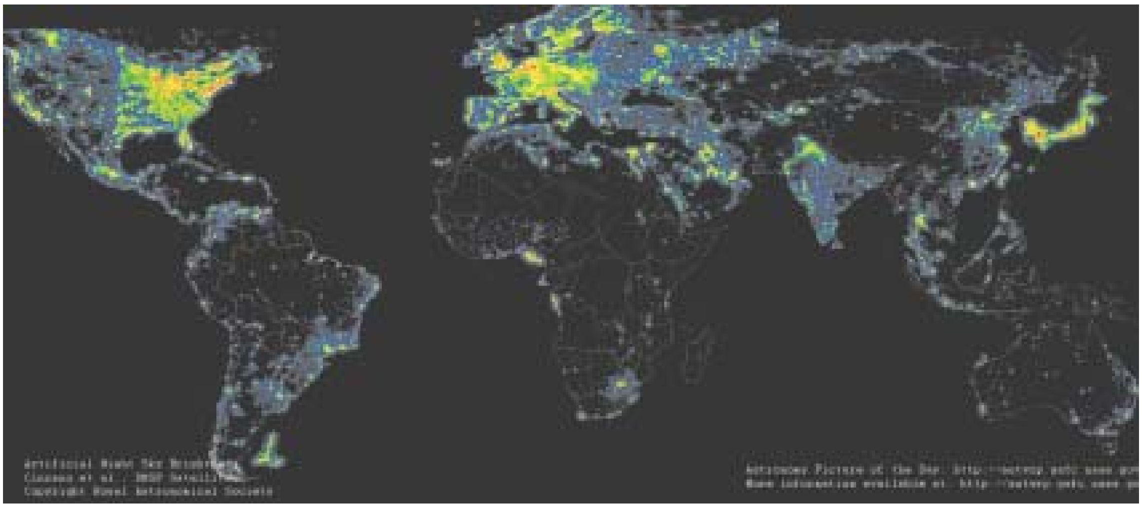


Figure 5 Global artificial night sky brightness (light pollution) as indicator for electricity demand (Source: P. Cinzano, F. Falchi (University of Padova), C. D. Elvidge (NOAA National Geophysical Data Center, Boulder). (Copyright: Royal Astronomical Society)



glass. In the long term, a national scope of supply of 80–100% can be achieved. Large quantities of desalted water as by-product of solar electricity will create a chance to reclaim arid land for human settlement, production and development and to protect regions that are now endangered by desertification. Thus, the south will strongly participate in the benefits of the deployment of this technology.

The technical and economic potential of CSP is tremendous: less than 0.1% of the suitable areas for the installation of solar thermal power stations worldwide would in theory suffice to cover the total global energy demand. Particularly attractive sites can be found in North Africa, the Arabian Peninsula, the South American Atacama desert, the North- and Central American West, South Africa, Australia and Mongolia (Figure 4).

However, the exploitation of this potential would soon come to its limits if it was restricted to the national boundaries of the countries in question. For example, the countries of North Africa have vast resources of solar irradiation and plenty of land to place the solar collectors, but inadequate technological and financial resources and their electricity demand is still relatively small, although steadily

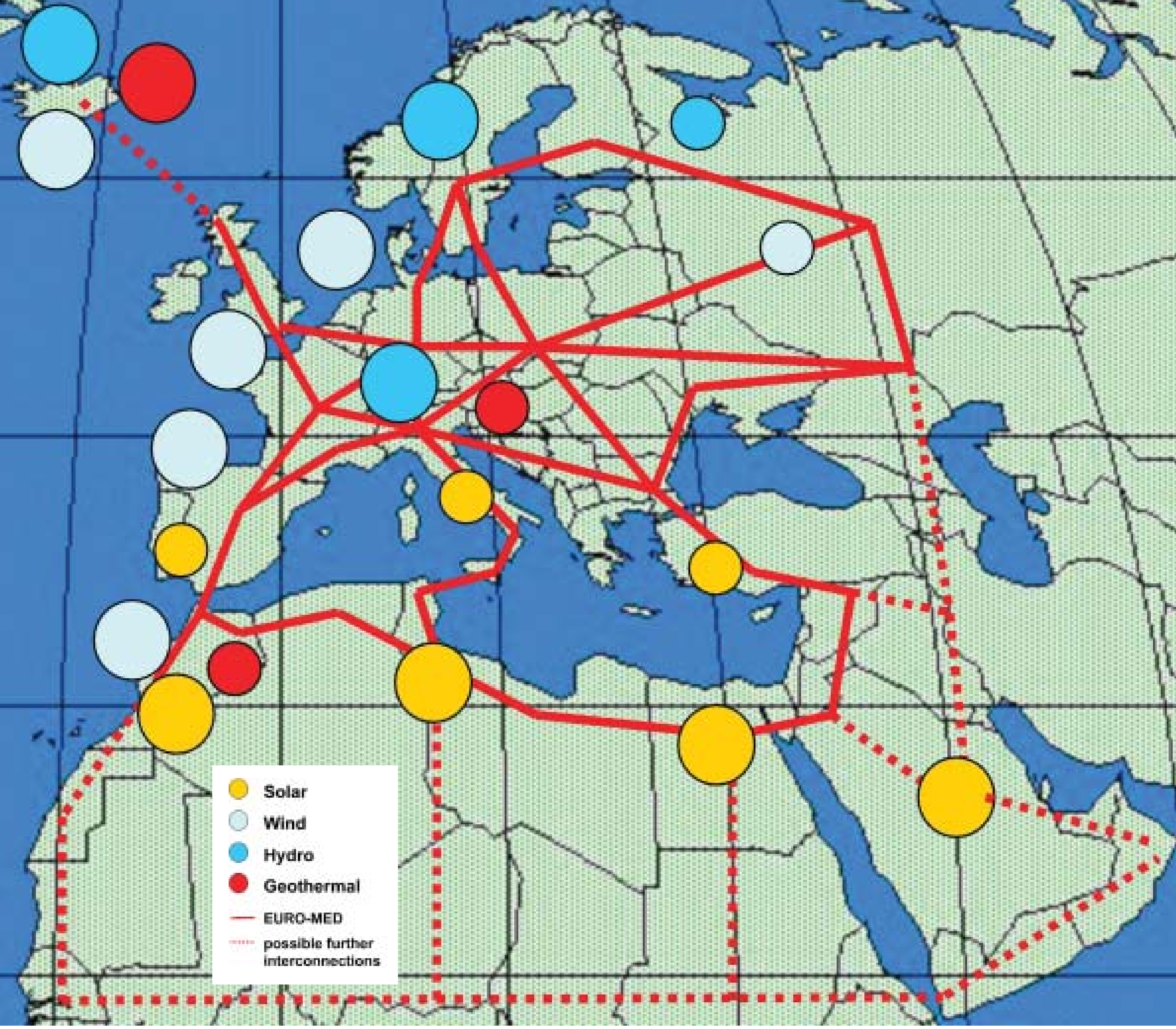


Figure 6 Vision of a future Euro-Mediterranean grid interconnecting sites with large renewable electricity sources and sites with high demand for clean electricity (Source: DLR, ISET)

growing (Figure 5). The contrary is true for Europe.

In order to exploit the renewable energy potential of both regions in an efficient and economic way, an interconnection of the electricity grids of both regions would allow for the transmission of solar electricity to Europe (Figure 6) and stabilise the North African power grid. This synergy would not only reduce the cost of clean solar electricity in Europe, but would also create considerable financial benefits for the North African countries, enabling them to finance the sustainable economic development of their region. The technology needed for such a south-north interconnection is already state-of-the-art. At present, 640 GW of electric capacity is transmitted by high voltage direct current transmission lines (HVDC) that are in operation worldwide in more than 55 installations, mainly with the purpose to transfer hydro- and geothermal power from its source to urban or industrial centres of demand. The length of such lines reaches up to 2000 km, their transmission capacity up to 12 000 MW.

In combination with combined power and desalination plants, such a policy would effectively reduce the risks of regional conflicts related to the increasing scarcity of energy and water in the Mediterranean and Arabian region and worldwide, and encourage good neighbourly relations between Africa and Europe. As an example, the 200 MW combined power and desalination plant described above would provide enough power and water for approximately 50 000 people in North Africa plus extra electricity for about 250 000 people in Europe (or for 2.5 million people in Africa, considering their lower demand per capita).

Market Perspectives

The first commercial solar tower power plant is presently being built in Empoli, Italy, benefiting from a special rate for combined heat and power and from additional subsidies. Two pressurised 250 kW central receivers (designed by DLR) will supply gas turbines with hot air for electricity generation, combined with heating and air conditioning systems. The plant will go online in 2004.

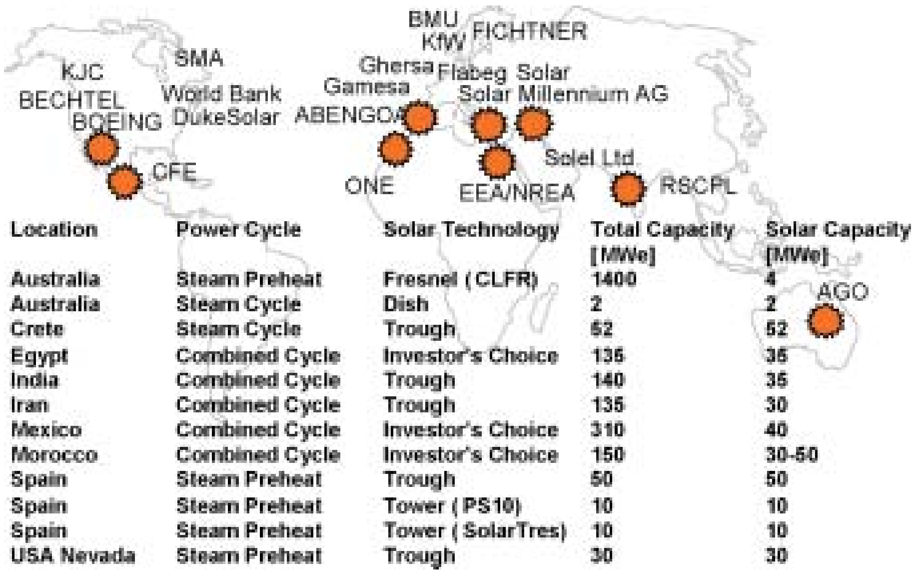
The Global Environmental Facility (GEF) aims to reduce anthropogenic greenhouse gas (GHG) emissions by increasing the market share of those low GHG energy technologies that are not yet widespread least-cost alternatives in the recipient countries. In the framework of operational program No.7 of the GEF, the governments of Brasil, Egypt, India, Iran, Jordan, Mexico, Morocco and South Africa are seeking the support of CSP projects (Figure 7). The GEF and other organisations recognise the value of developing clean and sustainable technologies and are offering significant economic incentives, to deploy initial plants.

In August 2002 in Spain, Royal Decree 2818 has been signed, guaranteeing a premium of €0.12 per kWh in addition to the market prices, for solar thermal electricity in plants of up to 50 MW of power capacity. At the moment, four projects are being developed, ranging from 10 MW power towers to 50 MW parabolic troughs with thermal energy storage.

The Israel Ministry of National Infrastructures, which is also responsible for the energy sector, decided in November 2001 to introduce CSP to the Israel electricity market in 2005 as a strategic element, with a minimal power of 100 MWe and to increase the CSP contribution up to 500 MWe at a later stage. This decision was approved in April 2002 as part of the future development of the national electricity market.

The US Congress and the US Department of Energy, with support from the Western Governors' Association, started an initiative of installing 1000 MW of new parabolic trough, power tower, and dish/engine solar capacity in the south-western United States by 2006.

All these projects add up to more than 500 MW of solar-electric capacity already in the pipeline today, with good chances to start implementation between 2004 and 2006. Substantially more project assessment is undertaken all over the world, based on those CSP technologies that now are ready for the market. Figure 8 shows a scenario of CSP market expansion, with growth rates of 20–25% per year, which is a conservative estimate considering the growth of 30–50% per year experienced by photovoltaic and wind power. Following that path, CSP will gain a share of 1% of the global power plant market by 2015, increasing to 2% by 2020 and to 5% by 2025. No negative impact on the labour market is to be expected from CSP expansion as the conventional power cycles and even backup fuels will still be required by the



Location	Power Cycle	Solar Technology	Total Capacity [MWe]	Solar Capacity [MWe]
Australia	Steam Preheat	Fresnel (CLFR)	1400	4
Australia	Steam Cycle	Dish	2	2
Crete	Steam Cycle	Trough	52	52
Egypt	Combined Cycle	Investor's Choice	135	35
India	Combined Cycle	Trough	140	35
Iran	Combined Cycle	Trough	135	30
Mexico	Combined Cycle	Investor's Choice	310	40
Morocco	Combined Cycle	Investor's Choice	150	30-50
Spain	Steam Preheat	Trough	50	50
Spain	Steam Preheat	Tower (PS10)	10	10
Spain	Steam Preheat	Tower (SolarTres)	10	10
USA Nevada	Steam Preheat	Trough	30	30

Figure. 7 CSP projects presently under development (steam preheat = hybrid solar/fossil plant) (Source: IEA-SolarPaces)

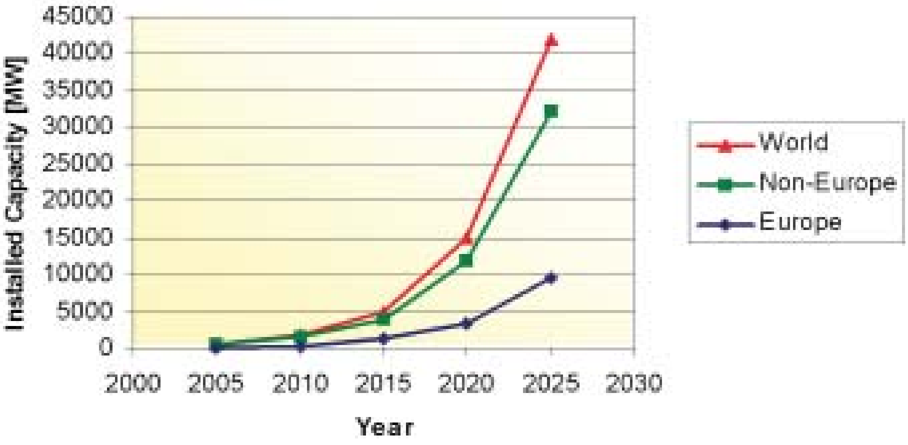


Figure 8 Scenario of a world wide CSP capacity expansion until 2025 (today 354 MW) (Source: IEA-SolarPaces)

CSP plants, and additional personnel will be needed to build and operate the solar part.

The opportunities of using CSP for the combined generation of power and water are also impressive: taking as an example the countries of North Africa, a deficit of power generation of 84 billion kWh/y must be covered until 2025 if a growth rate of only 2% per year is assumed, which is a rather conservative estimate (Table 1). For water, the situation is critical as the demand will exceed the renewable water resources of those countries by more than 50%. With Libya and Egypt this is almost a factor of 2 because both countries have already reached their limit today. This demand can only be covered by a very efficient water management and the installation of considerable capacities for the desalination of seawater will be unavoidable. If this is done using fossil fuels, the situation may become even worse due to its negative effect on the climate, and the use of nuclear power would create other serious hazards. An increased dependency on those fading resources would not be sustainable in any way.

Combined power generation and seawater desalination by CSP can break that vicious circle. It will provide both electricity and water at an acceptable price and without endangering the environment, and create additional income from the export of surplus solar electricity. It will also not run into the trap of a future fuel scarcity or cost escalation. If only 5% of the required water were generated by such plants, North Africa could export about 40 billion kWh/y of solar electricity by 2025. However, the maximum potential is much larger and it is only limited by demand, not by the available resources. Using this concept for the industrial and agricultural development of desert areas will thus create additional jobs and many other benefits for the North African societies.

Economics of concentrating solar power

With today's technology, a 100 MW solar-thermal plant with 8 hours thermal storage will require:

- 4 km^2 of land
- 25 000 tonnes of steel
- 12 000 tonnes of glass
- 30 000 tonnes of storage medium
- 20 000 m^3 of concrete.

This would involve 4000 20 t trucks or 2000 railway wagons for transport. This means an investment of €400 million, 1000 jobs during construction and 100 jobs during the 25 years of operation (Geyer, 2002).

With costs of €200–250 per square metre for the turnkey installed collector field, electricity from CSP is today somewhat more expensive than from conventional power plants. The technology must still run through a learning curve to become competitive within the next decade (Figure 9), with a realistic perspective of achieving collector costs of less than €100/m^2. Preferred financing (as established by the German and by the Spanish Renewable Energy Acts), emission trading and support from the GEF will help to activate start-up funding. A global market initiative for CSP (GMI-CSP) initiated by the German Federal Ministry for the Environment as result of the Johannesburg Conference is presently developing a strategy to achieve further opportunities for project development and finance, building the bridge from the pioneer phase to future green electricity markets and emission trading by preferential financing in subsidised

	Morocco	Algeria	Tunesia	Libya	Egypt	North Africa
Electricity Demand 2000 GWh/y	14,500	23,500	9,500	18,000	64,500	130,000
Electricity Demand 2025 GWh/y	23,500	39,000	15,500	30,000	106,000	214,000
Electricity Deficit 2025 GWh/y	**9,000**	**15,500**	**6,000**	**12,000**	**41,500**	**84,000**
Water Demand 2000 Mm?/y	13,100	6,100	2,500	5,300	70,000	97,000
Water Demand 2025 Mm?/y	33,000	11,000	5,000	11,000	130,000	190,000
Water Demand / Sources 2000	55%	35%	50%	120%	95%	80%
Water Demand / Sources 2025	135%	65%	102%	205%	180%	150%
Water Deficit 2025 Mm?/y	**8,500**	**0**	**100**	**5,500**	**57,000**	**71,000**
Max. CSP Electricity Potential by 2025 GWh/y	233,000	15,000	6,100	143,000	1,570,000	1,900,000
Max. CSP Water Potential by 2025 Mm?/y	8,600	0	100	5,500	57,000	71,000
Max. CSP Capacity Potential by 2025 MW	31,000	2,000	800	19,000	209,000	260,000
CSP Electricity Scenario by 2025 GWh/y	**18,750**	**6,000**	**3,750**	**18,750**	**67,500**	**114,750**
CSP Export to Europe by 2025 GWh/y	**9,750**	**0**	**0**	**6,750**	**26,000**	**42,500**
CSP Water Scenario by 2025 Mm?/y	**666**	**0**	**100**	**666**	**2,396**	**3,828**
CSP Capacity Scenario by 2025 MW	**2,500**	**800**	**500**	**2,500**	**9,000**	**15,300**
Per cent of electricity deficit 2025	**208%**	**39%**	**63%**	**156%**	**163%**	**137%**
Per cent of water deficit 2025	**8%**	**-**	**100%**	**12%**	**4%**	**5%**

Table 1 The growing demand for power and water in North Africa and the economic potential of CSP, including export of solar electricity to Europe

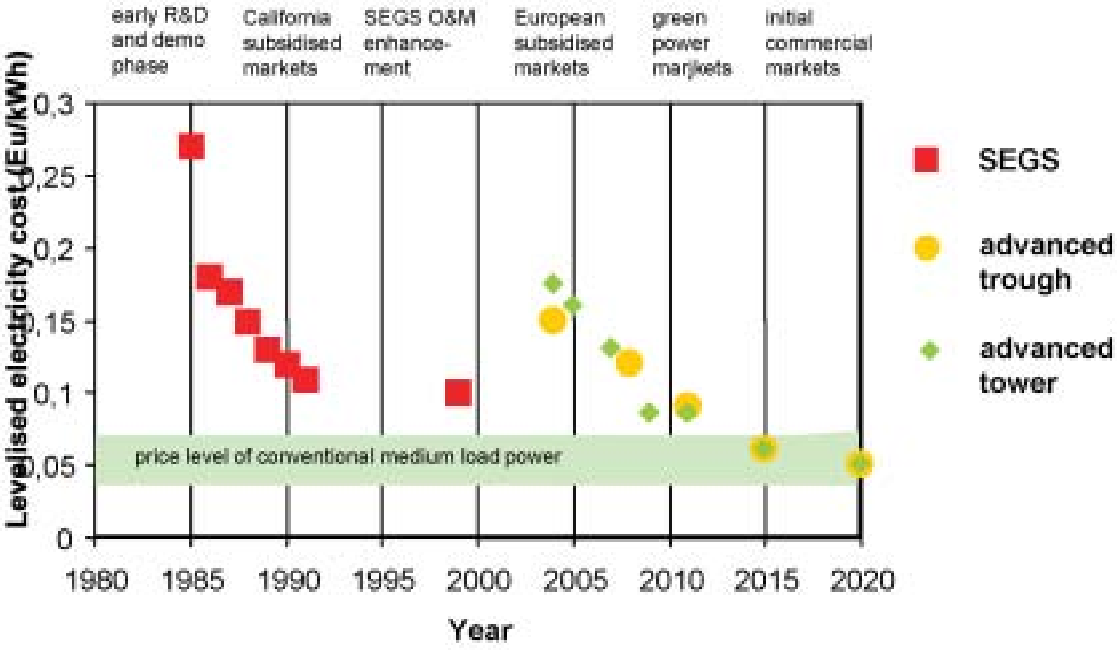


Figure 9 The cost learning curve from the pioneer phase to international green power markets has to be bridged by subsidised markets in the OECD countries. Demonstrated costs of the Californian Solar Electricity Generating Systems and projected costs of advanced trough and tower technologies. (Source: DLR, SolarPaces, EUREC

> With adequate financing, CSP will achieve full cost competitiveness within the next 10–15 years

markets supported by the OECD countries. Whilst such a market has already been established by the Renewable Energy Act of Spain, a similar world wide scheme, but supported by the OECD, is under consideration within the GMI-CSP.

The Renewable Energy Act in Spain provides a premium of about €0.12/kWh for solar electricity from CSP that adds to the merchant price of €0.035–0.040/kWh. This may be sufficiently attractive to start the first European projects by 2004. Under the solar radiation conditions of Spain (2000 kWh/m^2/year), in the medium term, solar electricity costs of 6–8 cents/kWh may be achieved. Under better radiation conditions (2700 kWh/m^2/year or more) and in hybrid operation, costs can be in the range of 8–10 cents/kWh today, with medium term opportunities to reach 4–6 cents/kWh.

Under very good radiation conditions (2700 kWh/m^2/year or more), and using hybrid combined power and desalination systems, costs as low as 2–4 cents/kWh can be expected. However, even lower costs have been reported for conventional plants with subsidised fuel prices. Therefore, initial support for the market introduction of CSP is required. The ATHENE concept, developed within a study for the German Federal Ministry for the Environment, proposes an OECD-supported mechanism that provides long term power purchase agreements to CSP projects in order to reduce their financial risk and with that their capital cost. The start-up funding could be realised in terms of preferential finance between 2005 and 2020 including revenues from emission trading. The total support needed within 15 years for the worldwide market introduction of CSP would be, for example, in the range of only 50% of the subsidies that Germany has to spend every year for power generation from German coal, or 4% of the total sum spent on subsidies for nuclear power plant development and operation in Germany during the past 30 years. Full stand-alone cost competitiveness is expected within a ten year period at a total of 5000 MW of worldwide installed capacity, if a global market initiative is started now.

Conclusions

During the first decades of the 21st century, fossil energy carriers will still play the main role in the world's energy supply. However, these resources will have to be used in a much more efficient way than today. The share of renewable energy sources will continue to increase until, after the initial market introduction phase, large scale renewable technologies will make up a significant and growing fraction of the newly installed power plant capacity. 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.

CSP technology for electricity generation is ready for the market. With adequate start-up financing, CSP will quickly run through its learning curve and achieve full cost competitiveness within the next 10 to 15 years. After that, there will be no further additional cost on the emission reduction by CSP. Moreover, the problem of sustainable water resources and development in arid regions is addressed in an excellent way, making use of highly efficient, solar powered co-generation systems.

During the introduction phase, strong political and financial support from the responsible authorities is still required and many barriers must be overcome. To achieve this, the German Federal Ministry for the Environment together with UNEP and GEF have started a Global Market Initiative for CSP (GMI-CSP) with an international executive conference of decision-makers from industry, policy and finance in Palm Springs, California in October 2003. ■

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Franz Trieb has worked in the field of renewable energies since 1983. After the implementation of a hydrogen storage for an autonomous renewable energy system at the University of Oldenburg, Germany, he conducted a two-year postgraduate course ‘Renewable Energy’ at the National University of Tacna, Peru. Since 1994, he has been project manager at the Institute of Technical Thermodynamics of the German Aerospace Center (DLR), working on solar energy resource assessment by satellite remote sensing, market strategies for concentrating solar power and renewable energy scenarios.