TRANS-CSP

Trans-Mediterranean Interconnection for Concentrating Solar Power

Executive Summary

by

German Aerospace Center (DLR)
Institute of Technical Thermodynamics
Section Systems Analysis and Technology Assessment

Study commissioned by

Federal Ministry for the Environment,
Nature Conservation and Nuclear Safety
Germany

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DLR

"The sun-belt and the technology belt can become very powerful when they begin to understand themselves as a community: a community of energy, water and climate security; a community for their common future."

H.R.H. Prince El Hassan Bin Talal

President of the Club of Rome

Address for World Energy Dialogue,

Hannover Messe, April 2006

Introduction

Competitiveness, compatibility with society and the environment, security of supply and international cooperation are considered main pillars for sustainability in the energy sector. For each of the 30 countries[1] shown in Figure 1, electricity scenarios from the year 2000 to 2050 were developed that show a consistent transition to a sustainable supply that is inexpensive, compatible with the environment and based on diversified, secure resources.

Sustainable power in Europe (EU) can be based to a great extent on renewable generation including solar electricity import from the Middle East and North Africa (MENA). A well balanced mix of renewable energy sources with fossil fuel backup can provide affordable power capacity on demand.

The transfer of solar electricity from MENA to Europe can initiate an understanding of a common EUMENA region, starting with a partnership and free trade area for renewable energy, and culminating in what H.R.H. Prince El Hassan Bin Talal, President of the Club of Rome, called a "Community for Energy, Water and Climate Security" at the World Energy Dialogue at the Hannover Technology Fair in April 2006.

The TRANS-CSP study comprises a comprehensive data base on the present and expected demand for electricity and firm power capacity, quantifies the available renewable energy resources and their applicability for power, provides scenarios of the electricity supply system until 2050, and evaluates the resulting socio-economic and environmental impacts for each of the analysed countries. The executive summary at hand gives the aggregated results for Europe as a whole, while individual country data is given in the annex of the full study report.

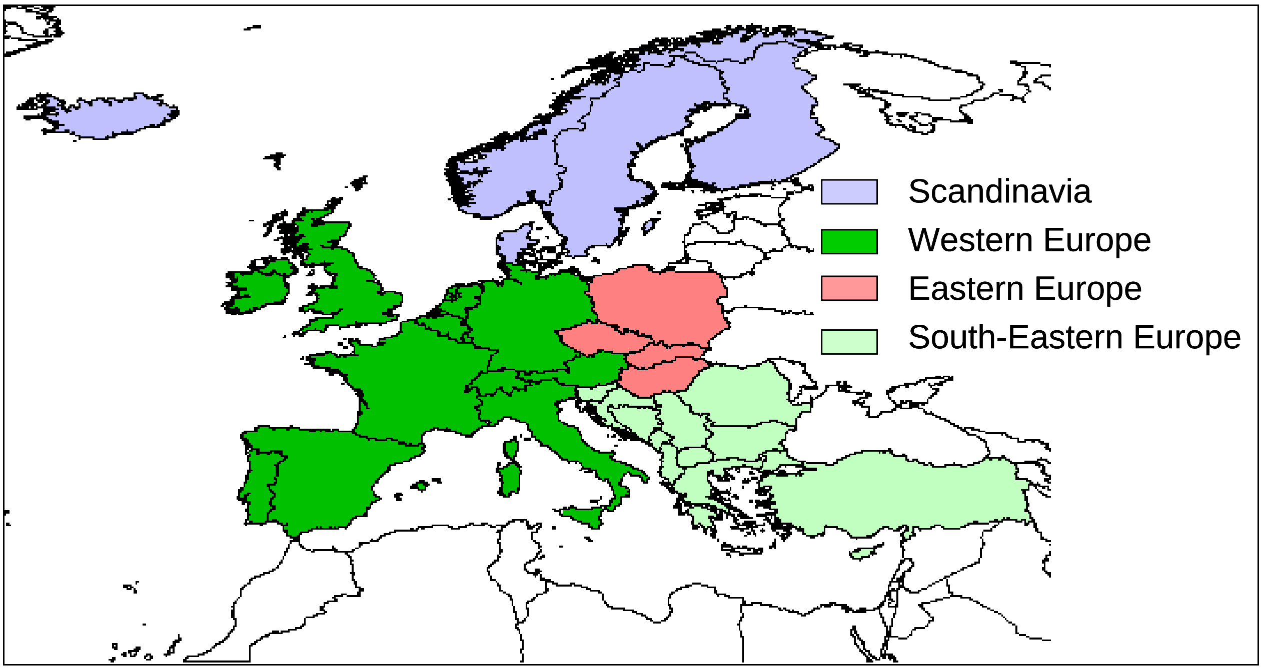

Figure 1: A total of 30 countries in Europe were analysed in the TRANS-CSP study

[1] TRANS-CSP covers: Iceland, Norway, Sweden, Finland, Denmark, Ireland, United Kingdom, Portugal, Spain, France, Belgium, Netherlands, Luxembourg, Germany, Austria, Switzerland, Italy, Poland, Czech Republic, Hungary, Slovakia, Slovenia, Croatia, Bosnia-Herzegovina, Serbia-Montenegro, Macedonia, Greece, Romania, Bulgaria, Turkey, www.dlr.de/tt/trans-csp. The MENA countries and some Southern European countries were analysed within the MED-CSP study, www.dlr.de/tt/med-csp, quantifying the opportunities of the Mediterranean region.

Main Results of the TRANS-CSP Study

The TRANS-CSP study analyses the renewable electricity potentials in Europe and their capability to provide firm power capacity on demand. The concept includes an interconnection of the electricity grids of Europe, the Middle East and North Africa (EUMENA) and evaluates the potential and benefits of solar power imports from the South. The conventional electricity grid is not capable of transferring large amounts of electricity over long distances. Therefore, a combination of the conventional Alternate Current (AC) grid and High Voltage Direct Current (HVDC) transmission technology will be used in a Trans-European electricity scheme based mainly on renewable energy sources with fossil fuel backup. The results of the TRANS-CSP study can be summarized in the following statements:

- A well balanced mix of renewable energy sources backed by fossil fuels can provide sustainable, competitive and secure electricity for Europe. For the total region, our scenario starts with a reported share of 20 % renewable electricity in the year 2000 and reaches 80 % in 2050. An efficient backup infrastructure will be necessary to complement the renewable electricity mix, providing firm capacity on demand by quickly reacting, natural gas fired peaking plants, and by an efficient grid infrastructure to distribute renewable electricity from the best centres of production to the main centres of demand.
- If initiated now, the change to a sustainable energy mix leads to less expensive power generation than a business as usual strategy in a time span of about 15 years. Imported fuels with escalating cost will be increasingly substituted by renewable, mostly domestic energy sources. The negative socio-economic impacts of fossil fuel price escalation can be reversed by 2020 if an adequate political and legal framework is established at time. Feed-in tariffs like the German or Spanish Renewable Energy Acts are very effective instruments for the market introduction of renewables. If tariff additions are subsequently reduced to zero, they can be considered a public investment rather than a subsidy.
- Solar electricity generated by concentrating solar thermal power stations in MENA and transferred to Europe via high voltage direct current transmission can provide firm capacity for base load, intermediate and peaking power, effectively complementing European electricity sources. Starting between 2020 and 2025 with a transfer of 60 TWh/y, solar electricity imports could subsequently be extended to 700 TWh/y in 2050. High solar irradiance in MENA and low transmission losses of 10-15 % will yield a competitive import solar electricity cost of around 0.05 €/kWh.
- Carbon emissions can be reduced to 25 % compared to the year 2000. 1 % of the European land will be required for the power mix, which is equivalent to the land used at present for transport and mobility.
- European support for MENA for the market introduction of renewables can attenuate the growing pressure on fossil fuel resources that would otherwise result from the economic growth of this region, thus helping indirectly to secure fossil fuel supply also in Europe. The necessary political process could be initiated by a renewable energy partnership and a common free trade area for renewable energies in EUMENA and culminate in a Community for Energy, Water and Climate Security.

The TRANS-CSP study provides a first information base for the design of a political framework that is required to initiate and realise such a scheme.

Chapter 1 (Solar Electricity Transfer) describes the technical options of transferring solar electricity from MENA to Europe via hydrogen, through the conventional alternating current (AC) grid and by a possible future high voltage direct current (HVDC) infrastructure.

The transport of solar energy via hydrogen over a distance of e.g. 3000 km would in principle be possible, but 75 % of the generated renewable electricity would be lost by the involved conversion, transport and storage processes. Consequently, this option was disregarded.

The transfer capacities of the conventional AC grid are rather limited, and even considering that the MENA countries would empower their regional electricity grid to Central European standards and would create additional interconnections all around the Mediterranean Sea, the transfer would still be limited to about 3.5 % of the European electricity demand. Over a distance of 3000 km, about 45 % of the generated solar electricity would be lost by such a transfer.

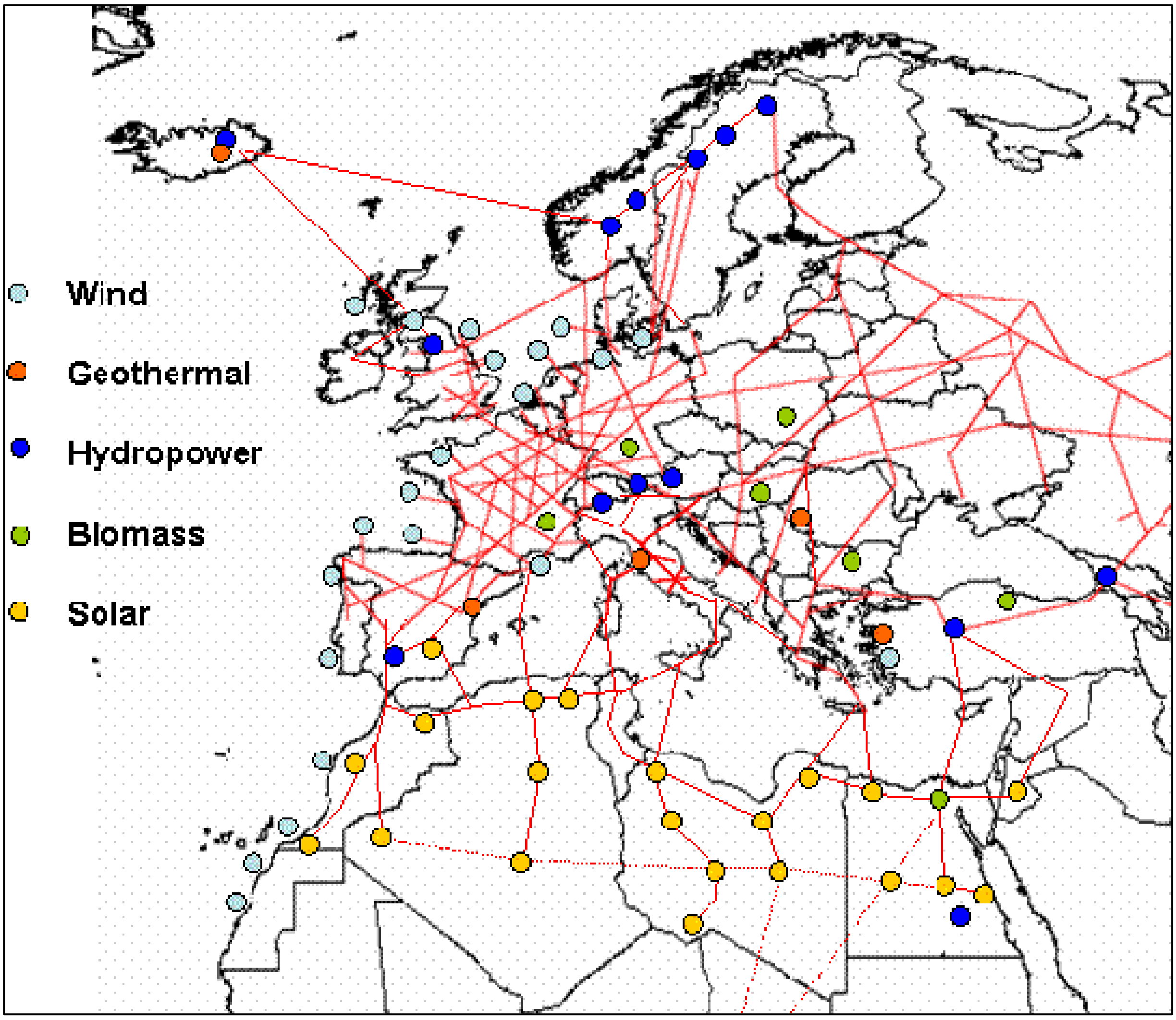

Figure 2: Vision of an EUMENA backbone grid using HVDC power transmission technology as "Electricity Highways" to complement the conventional AC electricity grid.

HVDC technology is becoming increasingly important for the stabilisation of large electricity grids, especially if more and more fluctuating resources are incorporated. HVDC over long distances contributes considerably to increase the compensational effects between distant and local energy sources and allows to compensate blackouts of large power stations through distant backup capacity. It can be expected that in the long term, a HVDC backbone will be established to support the conventional European electricity grid and increase the redundancy and stability of the future power supply system.

As a spin-off effect of this development, the import of solar electricity from MENA will become an attractive diversification of the European power generation portfolio. Solar and wind energy, hydropower, geothermal power and biomass will be generated in regions of best performance and abundance, distributed all over Europe and MENA through a highly efficient HVDC grid on the upper voltage level, and finally delivered to the consumers by the conventional interconnected AC grid on the lower voltage level (Figure 2). Analogue to the network of interstate highways, a future HVDC grid will have a low number of inlets and outlets to the conventional AC system as it will primarily serve long distance transfer, while the AC grid will have a function analogue to country roads and city streets.

Only 10 % of the generated electricity will be lost by HVDC transmission from MENA to Europe over 3000 km distance. In 2050, twenty power lines with 5000 MW capacity each could provide about 15 % of the European electricity demand by solar imports, motivated by their low cost of around 5 €-cent/kWh (not accounting for further cost reduction by carbon credits) and their high flexibility for base-, intermediate- and peak load operation.

Year		2020	2030	2040	2050
Transfer Capacity GW		2 x 5	8 x 5	14 x 5	20 x 5
Electricity Transfer TWh/y		60	230	470	700
Capacity Factor		0.60	0.67	0.75	0.80
Turnover Billion €/y		3.8	12.5	24	35
Land Area	CSP	15 x 15	30 x 30	40 x 40	50 x 50
km x km	HVDC	3100 x 0.1	3600 x 0.4	3600 x 0.7	3600 x 1.0
Investment	CSP	42	143	245	350
Billion €	HVDC	5	20	31	45
Elec. Cost	CSP	0.050	0.045	0.040	0.040
€/kWh	HVDC	0.014	0.010	0.010	0.010

Table 1: Main indicators of the total EUMENA High Voltage Direct Current (HVDC) interconnection and Concentrating Solar Power (CSP) plants from 2020 – 2050 according to the TRANS-CSP scenario. In the final stage in 2050, lines with a capacity of 5 GW each will transmit about 700 TWh/y of electricity from 20 different locations in the Middle East and North Africa (MENA) to the main centres of demand in Europe.

Chapter 2 (Scenario for Sustainable Electricity) demonstrates the capability of a well balanced mix of renewable and fossil energy sources to provide secure, inexpensive and sustainable electricity for the supply of each of the European countries. Renewable energy can provide the necessary amount of clean energy to achieve the targets for climate stabilisation and reduce the consumption of fossil fuels to the rare times when renewable energy supply and electricity demand do not coincide. The strategy of reducing fossil energy use to peaking power allows for firm capacity on demand and at the same time reduces the consumption of fossil fuels that are a very valuable, ideally stored form of energy that should be exclusively used for that purpose.

Europe has plenty renewable energy sources for power generation (Figure 3). Their total economic potential amounts to about 145 % of the expected future electricity demand. This suggests that the coverage of the demand by 100 % should be achievable within a time span of 50 years. However, 60 % of this potential comes from wind and solar energy, both fluctuating resources that can provide electricity, but almost no firm power capacity on demand (Table 2). Moreover, the potentials are not distributed uniformly, but are concentrated in typical regions, e.g. hydropower in Scandinavia and the south central mountains, solar energy in the south, wind energy at the northern coasts and geothermal energy in South and Eastern Europe. Therefore, only 80 % of the power mix of the year 2050 will be derived from renewable sources.

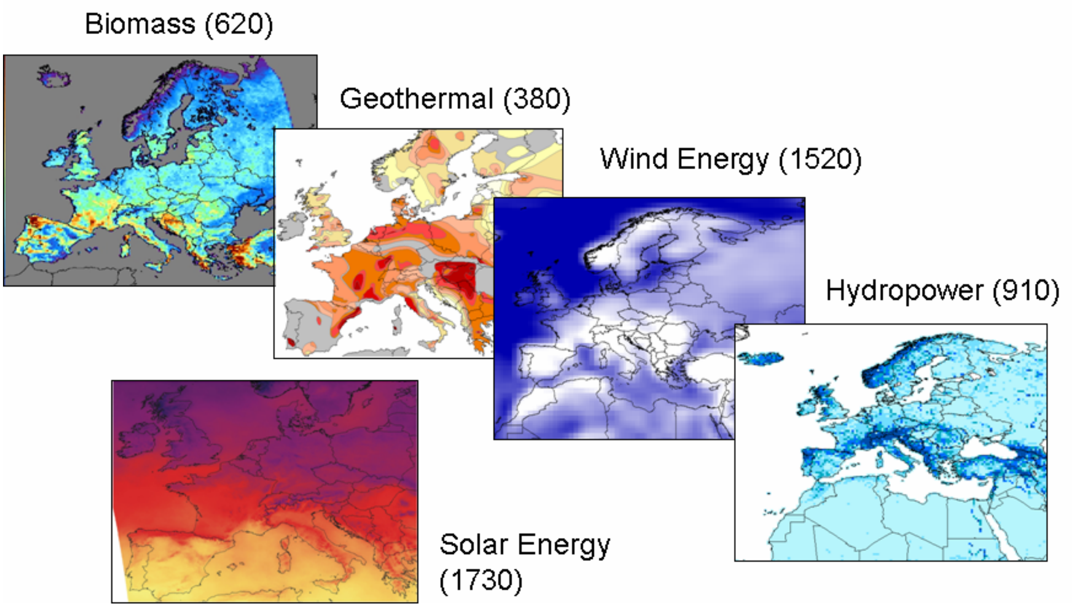

Figure 3: Renewable energy resource maps for the European region. Please refer to the main report for the colour code and references. The numbers give the economic electricity potential in TWh/y. Solar energy includes both CSP and PV potentials within the analysed European countries. All renewables sum up to 5160 TWh/y. The total future electricity demand of the analysed countries amounts to about 4000 TWh per year.

An efficient backup infrastructure will be necessary to complement the renewable electricity mix, on one side to provide firm capacity on demand by quickly reacting, natural gas fired peaking plants, and on the other side by an efficient grid infrastructure that allows to distribute renewable electricity from the best centres of production to the main centres of demand. The best solution is a combination of HVDC electricity highways and the conventional AC grid. On the lower voltage level, decentralised structures will also gain importance, combining e.g. PV, wind and micro-turbines operating together just like one, virtual power plant. Such a grid infrastructure will not be motivated by the use of renewables alone. In fact, its construction will probably take place anyway, with the purpose to stabilize the growing Pan-European grid, to provide higher security of supply, and to foster competition. Using fossil energies exclusively for backup purposes will reduce their consumption to a sustainable level and will reduce the quickly escalating cost of power generation. Fossil fuels will be used to provide firm capacity, while renewables will serve to reduce fossil fuel consumption.

	Unit Capacity	Capacity Credit *	Capacity Factor **	Resource	Applications	Comment
Wind Power	1 kW – 5 MW	0 – 30 %	15 – 50 %	kinetic energy of the wind	electricity	fluctuating, supply defined by resource
Photovoltaic	1 W – 5 MW	0 %	5 – 25 %	direct and diffuse irradiance on a tilted surface	electricity	fluctuating, supply defined by resource
Biomass	1 kW – 25 MW	50 - 90 %	40 – 60 %	biogas from the decomposition of organic residues, solid residues and wood	electricity and heat	seasonal fluctuations but good storability, power on demand
Geothermal (Hot Dry Rock)	25 – 50 MW	90 %	40 – 90 %	heat of hot dry rocks in several 1000 meters depth	electricity and heat	no fluctuations, power on demand
Hydropower	1 kW – 1000 MW	50 - 90 %	10 – 90 %	kinetic energy and pressure of water streams	electricity	seasonal fluctuation, good storability in dams, used also as pump storage for other sources
Solar Updraft	100 – 200 MW	10 to 70 % depending on storage	20 to 70 %	direct and diffuse irradiance on a horizontal surface	electricity	seasonal fluctuations, good storability, base load power
Concentrating Solar Thermal Power	10 kW – 200 MW	0 to 90 % depending on storage and hybridisation	20 to 90 %	direct irradiance on a surface tracking the sun	electricity and heat	fluctuations are compensated by thermal storage and (bio)fuel, power on demand
Gas Turbine	0.5 – 100 MW	90 %	10 – 90 %	natural gas, fuel oil	electricity and heat	power on demand
Steam Cycle	5 – 500 MW	90 %	40 – 90 %	coal, lignite, fuel oil, natural gas	electricity and heat	power on demand
Nuclear	> 500 MW	90 %	90 %	uranium	electricity and heat	base load power

Table 2: Some characteristics of contemporary power technologies. * Contribution to firm power and reserve capacity. ** Average annual utilisation.

Several renewable power technologies can also operate as base load and peaking plants: geothermal (hot dry rock) systems that are today still in a phase of research and development, hydropower plants with large storage dams available in Norway, Iceland and the Alps, most biomass plants and concentrating solar power plants in MENA, using the high annual solar irradiance of that region, the possibility of solar thermal energy storage for overnight operation and the option of backup firing with fuels. CSP in Europe is bound to significant seasonal fluctuations, and firm peaking power can only be provided with a considerable fossil fuel share. Due to a higher solar irradiance, the cost of CSP is usually lower in MENA than in Europe. Therefore, there will be a significant market for CSP imports to complement the European sources and provide firm power capacity at competitive cost (Figure 4).

A requisite of the electricity mix is to provide firm capacity and a reserve of about 25 % in addition to the expected peaking load (Figure 5). Before significant CSP imports start in the year 2020, this can only be provided extending the capacity and fuel consumption of natural gas fired peaking plants. In our scenario, the consumption of natural gas doubles with respect to the starting year 2000, but is then brought back to the initial level, after introducing in 2020 increasing shares of import CSP, geothermal power and hydropower from Scandinavia by HVDC interconnections. As shown in Figure 3, the European renewable energy sources that could provide firm capacity are rather limited from the point of view of their potentials. Therefore, CSP imports will be useful to reduce both the installed capacity and the fuel consumption of gas fired peaking plants and to provide firm renewable power capacity.

Except for wind power that is already booming today, and hydropower that is already introduced, renewable energy will hardly become visible in the electricity mix before 2020. At the same time, the fade out of nuclear power in many European countries and a stagnating use of coal and lignite due to climate protection will imply increasing pressure on natural gas resources, increasing their consumption as well as their installed capacity. As described above renewables will primarily reduce fuel consumption until 2020, but hardly substitute power capacities. Therefore, the total installed capacity will grow faster than the peaking load (Figure 5). Due to the growth of consumption and the substitution of nuclear power, fossil fuel consumption for power generation in Europe cannot be reduced before 2020. Fuel oil for electricity will fade out in 2030, nuclear power will follow after 2040. The consumption of gas and coal will be reduced by 2050 to a compatible and affordable level.

The electricity mix of the year 2000 depends mainly on five resources, most of them limited and imported, while the mix of 2050 will be based on ten energy sources, most of them domestic and renewable (Figure 4). Thus, the TRANS-CSP scenario responds to the European Strategy for Sustainable, Competitive and Secure Energy declared by the European Commission in the corresponding Green Paper and Background Document, aiming at higher diversification and security of the European energy supply.

Chapter 3 (Policies and Finance) discusses the political and financial issues of a strategy following the TRANS-CSP scenario. Industry and private investors need a reliable political and legal framework to introduce and expand renewables in the power market. It can be stated that many countries are already on that track, with a large portfolio of instruments to foster renewable energy market introduction in many countries. The present share of renewables on global power investment of 25 % and industrial production growth rates of up to 60 % per year speak a clear language. Most successful instruments seem to be the feed-in tariffs like the German and Spanish Renewable Energy Acts that provide a fixed premium or revenue for renewable electricity that is individually adapted to the requirements of each technology and granted for the total economic lifetime of the plants.

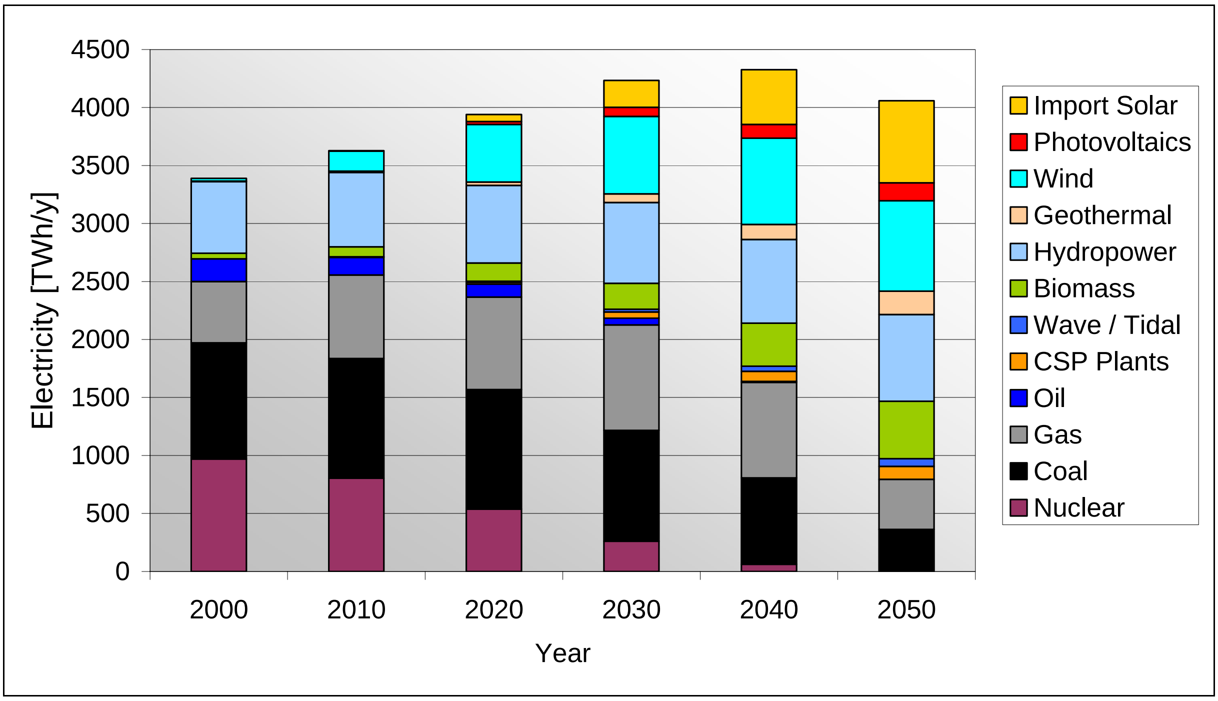

Figure 4: TRANS-CSP scenario of gross electricity production and import for the analysed European countries until 2050. The import of other than solar electricity to the region is negligible.

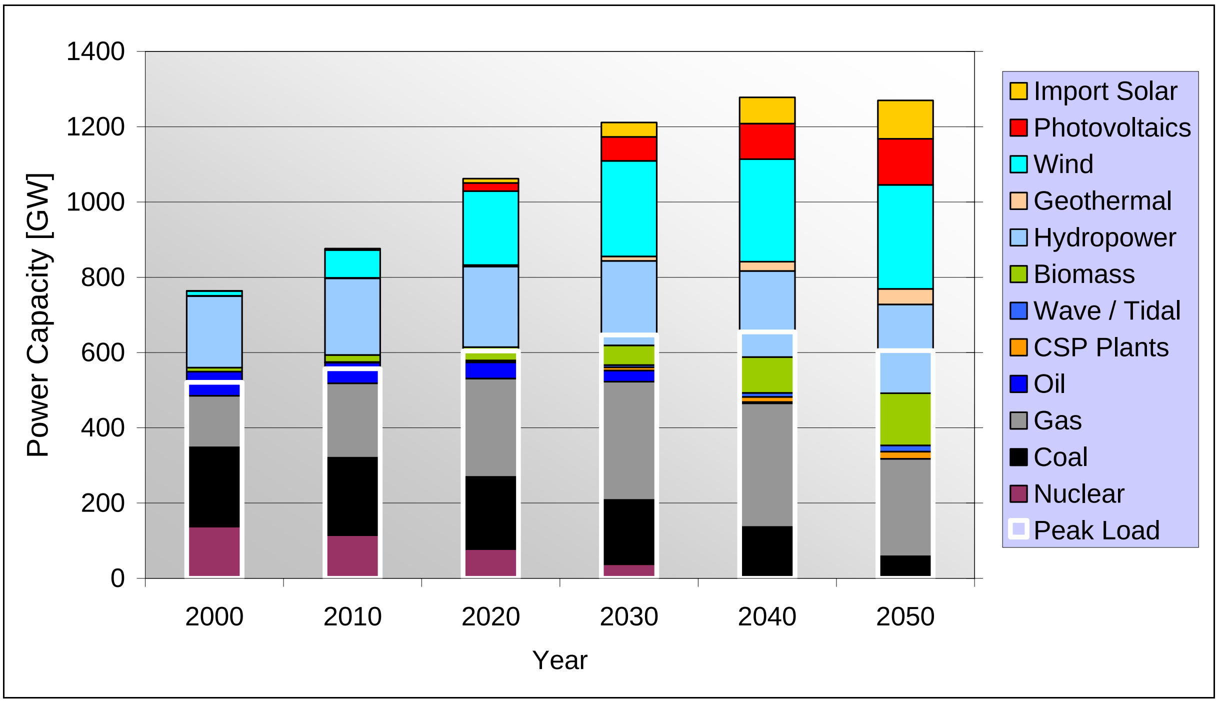

Figure 5: TRANS-CSP scenario for the total installed power capacities and peak load for the analysed European countries until 2050.

Renewable energy feed-in laws provide long term, guaranteed power purchase agreements with local utilities. Private investments under such a scheme are usually provided at interest rates that are 50 % lower than those in the conventional power sector, thus effectively reducing the cost of market introduction of renewables. Feed-in tariffs (for new plants) are subsequently reduced year by year, thus motivating intensive research and development for cost reduction. Although such instruments are already effective in some European countries, adequate policies have been adapted only by a few, and there is still a long although promising way to achieve a European standard.

The situation is quite different in public research, development and demonstration policies (RD&D). In this sector, there is a strong contradiction between the allocation of funds and the awareness of the necessities of a sustainable energy future. More than 50 % of the energy RD&D budget supports the existing nuclear / fossil energy mix, while poorly 8 % are dedicated to the different forms of renewable energy. Present energy subsidies give a similar picture: 90 % are granted to fossil and nuclear energy, while only 10 % are dedicated to the total renewable energy portfolio. Moreover, there is a fundamental difference between public funding of renewables and the subsidization of fossil or nuclear energy: the first supports new technologies in the phase of market introduction that still require public investment to achieve further cost reduction, while the second artificially prolongs the life of a supply scheme that is clearly beyond its economic summit. Table 3 compares a renewable with a fossil-nuclear strategy for energy security. Looking at those facts, it is difficult to find any reason at all for persisting in the present fossil-nuclear energy strategy of many European countries. A third option, the combination of renewables with nuclear plants must be disregarded too, due to the simple fact that nuclear plants can only operate economically if they run at constant power.

Electricity Mix dominated by Renewable Energy with Fossil Fuel Backup	**Electricity Mix dominated by Nuclear Power and Fossil Fuels**
Power on demand by a well balanced mix of renewable and fossil energy sources	Power on demand by using ideally stored forms of energy like uranium, coal, oil and gas
Supply based on many, mostly unlimited resources	Supply based on few, mostly limited resources
Domestic sources dominate the electricity mix	Energy imports dominate the electricity mix
Low vulnerability of decentralised generation	High vulnerability of large central generation units
Low hazardous waste, recyclable materials	Disposal of nuclear waste and CO_2 unsolved
Low risk of contamination or major accidents	Risks of plutonium proliferation and nuclear accidents
Requires public investment over limited time span	Requires long-term continuous subsidisation
Low environmental impact	Climate change, pollution and nuclear radiation
Intrinsic trend to lower cost and less price volatility	Intrinsic trend to higher cost and price volatility
Requires a change of structures and thinking	Fits to present structures and thinking
Based on proven and demonstrated technologies	Requires major technological breakthroughs: o Safe fission and breeder technology o Commercial fusion reactor o Carbon capture and sequestration (CCS)
=> Low risk strategy	**=> High risk strategy**

Table 3: Comparison of a renewable power strategy in Europe with a nuclear – fossil energy mix

Chapter 4 (Socio-Economic Impacts) analyses the societal consequences of our scenario, especially in terms of wealth creation, energy economy and security of supply. The TRANS-CSP concept addresses those issues in a unique way. As described before, the diversification of resources and empowering of the electricity grid will increase the European security of power supply. Import dependency will be reduced through the improved use of domestic renewable energy (Figure 6). A growing pressure on natural gas resources will be avoided.

In contrast to the common belief that for every wind park a backup power plant must be installed, the analysis shows that the need of peaking plants is relatively constant although the share of fluctuating sources (PV and wind) increases. Fact is that the necessary peaking capacity is already there, with the purpose to cover the fluctuations of demand. No extra capacities are needed as long as the fluctuating renewable energy share is smaller than the existing peaking capacity, which is the case in our scenario. Wind and PV plants cannot considerably reduce the required installed capacity of conventional power plants, but they will reduce their consumption of fossil fuels. Establishing a well balanced mix of technologies and sources, fossil peaking capacities will remain, while fossil and nuclear base load plants will be subsequently replaced.

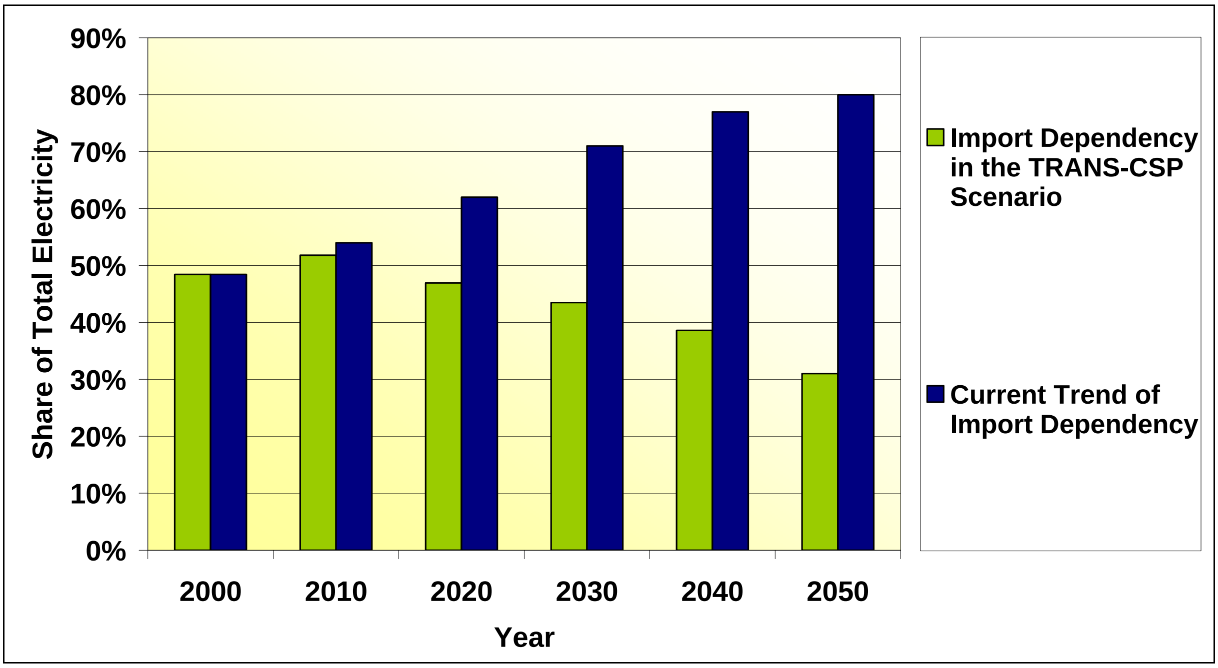

Figure 6: Import dependency inclusive CSP import in the TRANS-CSP scenario compared to the current trend of import dependency in the EU.

The International Energy Agency has calculated a reduction of 0.5 % of the Gross Domestic Income, an inflation of 0.6 % and a loss of 400,000 jobs in the OECD for a rise of the oil price of 10 $/barrel. However, the oil price escalated from 25 $/barrel in 2000 to over 60 $/barrel today, and all other primary fuels including uranium followed this trend, causing a proportionally stronger socio-economic impact. A further rise to 120 $/barrel within the next twenty years is not outside the range of expert expectations. On the other hand, the development of renewables has created over 150,000 new jobs in Germany alone, and its stabilising effect on the electricity cost was recently confirmed by one of the major German utilities.

As shown in Figure 7 for the example of Spain, the introduction of renewables will also add to the average cost of power generation, and thus to the negative impacts of electricity cost escalation. However, during the first twenty years, this impact is relatively small, because the share of renewables is small, too. Most of the cost escalation is due to fuel prices and to new power plant capacity investments. By 2020 most renewables will be cheaper than conventional power, and from that point, the renewable energy shares and their stabilising impact on the electricity cost will become much more noticeable. This demonstrates the danger of policy decisions based on short term scenarios that simply overlook the unique chance of abandoning the present trend of cost escalation, not in the short term – because the necessary investments must still be done – but in the medium and long term. Individual cost learning curves for the different power technologies are shown in Figure 8. To become effective in time, they will require an adequate political and legal framework that allows for the implementation of the necessary power capacities to achieve the related economies of scale.

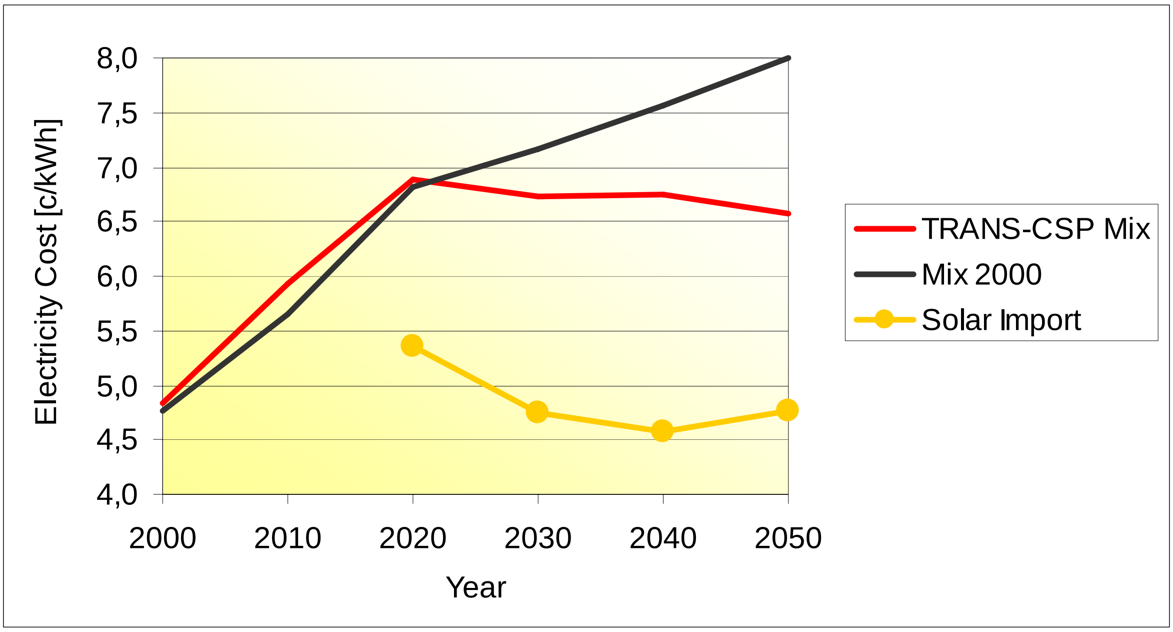

Figure 7: Average cost of electricity from new plants within the TRANS-CSP scenario and within a conservative scenario based on the electricity mix of the year 2000, in comparison to the cost of electricity imports from MENA for the example of Spain. For other countries please refer to the annex of the report.

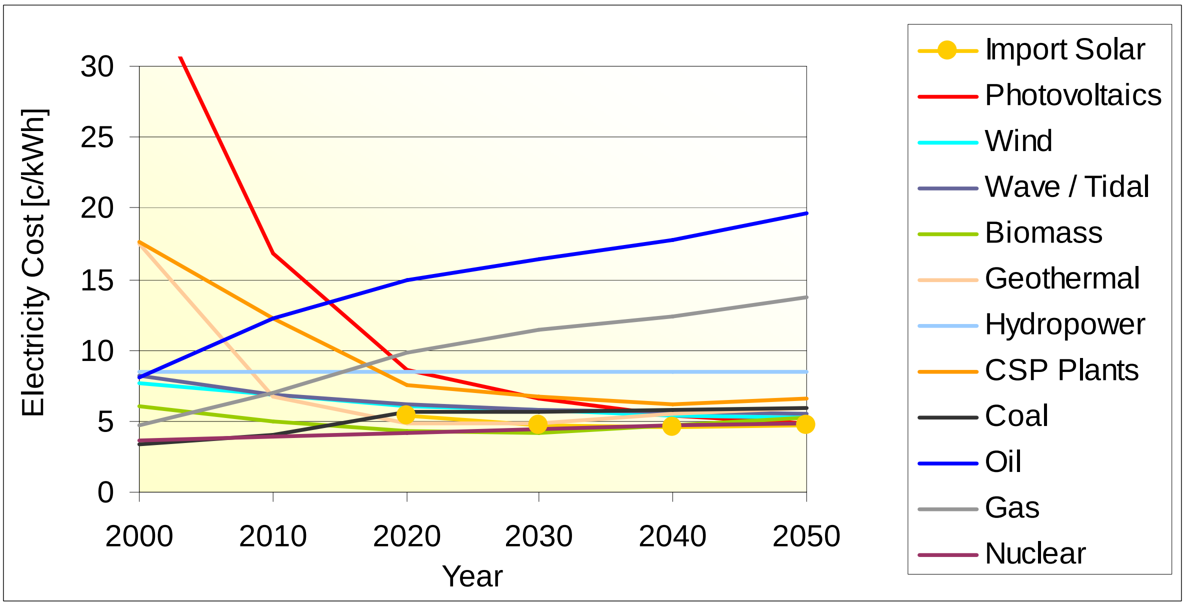

Figure 8: Electricity generation cost of new power plants. In the medium term, renewables are the least cost option for power. The curve “Import Solar” starts in 2020.

Chapter 5 (Environmental Impacts) looks at the emission of carbon dioxide and other pollutants, the energy amortisation time, land use and visibility of the renewable energy mix, and to the specific impacts of the scheduled HVDC overhead lines and submarine cables on the environment and biosphere.

Carbon emissions are effectively reduced to values that are considered as compatible with the goal of stabilising the CO_2 content of the atmosphere at 450 parts per million, as stated by the International Panel on Climate Change. Starting with 1400 million tons of carbon dioxide per year in the year 2000, the emissions are reduced to 350 Mt/y in 2050, instead of growing to 2350 Mt/y in a business as usual case. The final per capita emissions of 0.59 tons/cap/y are acceptable in terms of a maximum total emission of 1-1.5 tons/cap/y that has been recommended by the German Scientific Council on Global Environmental Change (WBGU).

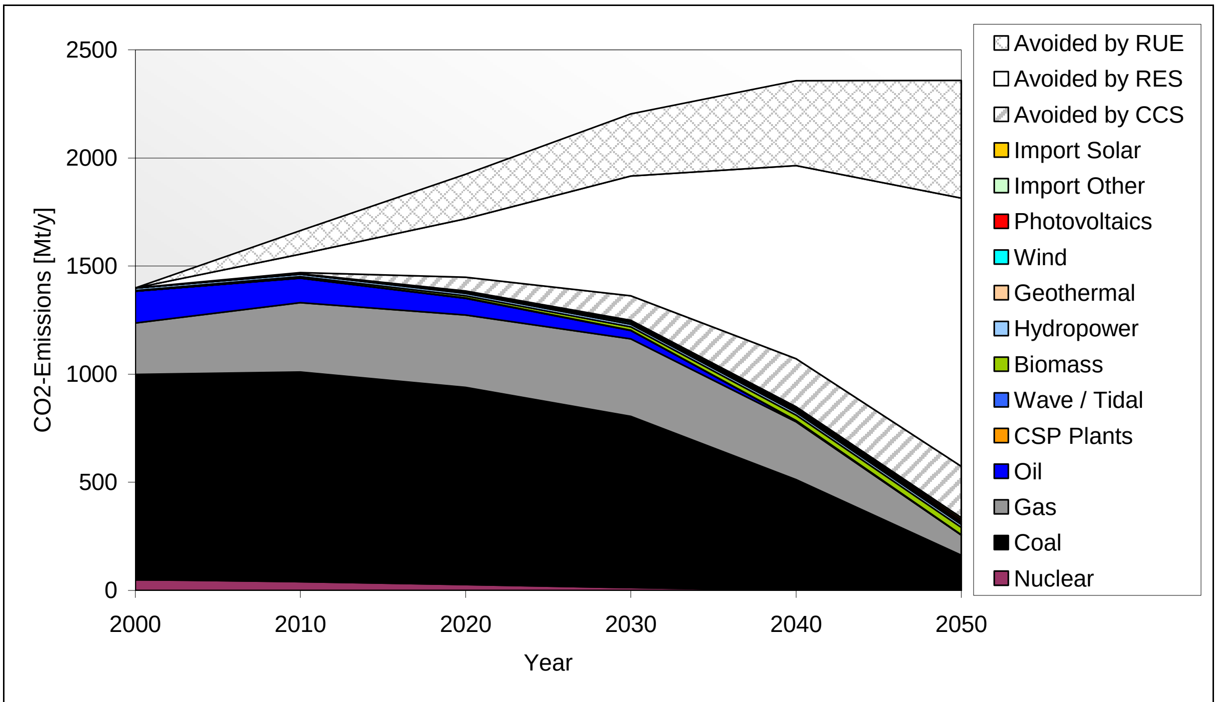

Figure 9: CO_2-emissions from electricity generation in million tons per year for all countries of the TRANS-CSP scenario and emissions avoided by Rational Use of Energy (RUE 22 %), Renewable Energy Source (RES 66 %) and by Carbon Capture and Sequestration (CCS 12 %) with respect to an electricity mix equivalent to that of the year 2000. For single countries please refer to the Annex.

The land used for the renewable energy infrastructure scheduled for 2050 amounts to roughly 1 % of the total land area, which is comparable to the land presently used for the transport and mobility infrastructure in Europe.

Using a geographic information system (GIS) three exemplary HVDC lines were analysed connecting very good sites for CSP generation in MENA with three major European centres of demand. The GIS was programmed to minimize cost, environmental impacts and visibility of the power lines, and we found that the resulting impacts are in an acceptable range. In general, the environmental impacts of HVDC lines are much lower than those of comparable AC overhead lines using conventional technology. Altogether, the TRANS-CSP scenario shows a way to reduce significantly the negative environmental impacts of power generation in Europe, and could also serve as a model for global application.

The full **TRANS-CSP Study Report** can be found at the website:

http://www.dlr.de/tt/trans-csp

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