PROSPECTS FOR SPACE POWER WORK IN EUROPE

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ABSTRACT

The paper presents a strategic approach to assess the importance of space solar power for securing the increasing energy demand of Europe. Based on European particularities, like its high and increasing energy import dependence and the strong engagement to significantly reduce its emission of greenhouse gases (GHG), the effort of the recently created European Network on Space Solar Power, lead by the European Space Agency (ESA), are described.

INTRODUCTION

Reliable energy supply, meeting the ever increasing demands, are of fundamental importance for prosperous and peaceful worldwide development. While the industrial revolution from the mid 19th century until the first decades of the 20th century was based on coal burning, the development of the 20th century until now relies mainly on oil and gas burning, with a relatively small nuclear portion since the 1970s.

Taking into account the environmental impact of the use of fossil sources and the unequal distribution of oil and gas, leading to strong dependence on relatively few supplier regions, growth of the 21st century should be based on the use of renewable and GHG emission free energy sources.

As a consequence, terrestrial renewable power sources receive at least in some countries the necessary interest. Space based systems, solar power satellites, on the other hand are still widely considered as too unrealistic to receive substantial support. Taking into account the respective specificities and the current trends, the space and terrestrial systems are widely complementary and can both play an important role in obtaining clean and reliable energy supply for the 21st century.

EUROPE'S ENERGY SITUATION

Current situation

The European Union represents about 16% of the world energy market. In 2000, it imports about half of its energy need and represent in total terms the largest energy-importing region in the world.
Within Europe, national energy profiles remain very different due to differences in economic structures, local resources, taxes and policy priorities. Regionally, oil is the most important energy source although its share is falling since 30 years, contrary to gas, the share of which constantly increased over the same period. Coal production and use has fallen since the 1970 and is now used mainly for electricity production.[1]

Europe's energy projections

European Unions's economy is assumed to grow at 1.9% annually until 2030, accompanied by an annual increase of the total primary energy demand of 0.7%. While the share of coal will continue to decrease, the one of gas will attain the level of oil around 34% by 2030. Non-hydro renewable energy sources are expected to more than double their share from 4 to 9%, equalling the nuclear share that – based on current projections about power plant construction – would decrease from today 15 to 8% in 2030.[1]

MOTIVATIONS FOR RESEARCH ON SPS

In parallel with the increasing demand, Europe's non-renewable energy reserves are diminishing and their extraction becomes less and less economically viable. As a consequence, the European Commission identified an increasing use of renewable energies as a strategic objective that could address the two main problems: 1. energy dependence and 2. environmental and climatic changes caused by greenhouse gases.

Europe's energy dependence

The result of the two trends is that Europe's total energy dependence is most likely to rise from today 50% to about 60 to 70% in 2030.[2] The enlargement of the Union does not alter this picture significantly, the trend being valid for entire Europe. The consequent potential vulnerability is furthermore enhanced by the dependence on few suppliers, essentially the Russian Federation (gas), OPEC countries (oil), North Africa (gas) and Norway (oil and gas).

Europe's commitment to decrease its emission of greenhouse gases

The European Union is responsible for 14% of the worldwide man-caused CO_2 emissions. At the Kyoto Conference in 1997, it undertook to reduce its greenhouse gas emissions by 8% until 2008/2012 compared to 1990. The current trend however is a 5% increase, calling for substantial action.[2]

Non-terrestrial use of solar power satellites

The scope of the study will not be restricted to aspects of solar power satellites for the supply of energy for terrestrial uses. Considerations shall also be given to the possibility for delivering energy to spacecraft either in Earth bound orbits or on interplanetary travel as well as to lunar or Martian outposts.

SPS RESEARCH WORK IN EUROPE

European Network on Solar Power Satellites

The European Union has identified research on sustainable energy as one of its priority research areas for the 6th Framework Programme.[3] In order to focus the different European activities on SPS, a European Network on Solar Power Satellites was established in August 2002, following an initiative of the Advanced Concepts Team of the European Space Agency. One of the goals is to position research on the space option of renewable energies in the context of research on sustainable development in Europe. For this purpose, a first meeting was held in Paris on August 28, 2002, gathering representatives from European research institutes, agencies and industry engaged in research on SPS.

The latest study related to solar power satellites in Europe was performed by the German Space Agency DLR under an ESA contract in 1999.[4] Since several years, the research group at French La Réunion performs in addition to system level studies, unique experiments on wireless power transmission.[5,6] Research on SPS in Europe's major space industries is kept on a stand-by level since some years. Complementary to these system level approaches, European laboratories are pushing technology in many SPS critical domains like high efficient multi layer solar cells, thin film solar cells, low mass μ-wave guides, high efficiency μ-wave generators, large extremely lightweight structures etc.

The current initiative by ESA aims to coordinate and focus these activities. The fist meeting of the Network has established a preliminary roadmap (Figure 1) for the organisation of European efforts:

Roadmap

In a first phase, a computerised SPS model will be developed, enabling the objective comparison of technical characteristics of different architecture concepts. In parallel, the legal aspects of space solar power activities will be assessed, both providing the frame for a short system architecture trade-off study, to be concluded by mid 2003.

The system level trade-off study will identify in addition to a reference design the critical technical points of the system that need further research.

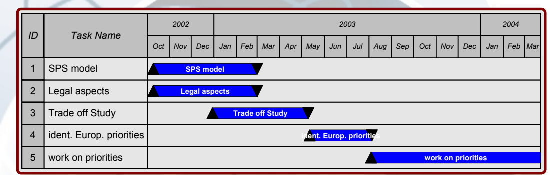

Figure 1: Proposed European SPS roadmap.

While past studies have put forward excellent technical solutions, it seems that there is still much room for new and innovative concepts, capable of improving the return/investments ratio and lowering the technical and operational risk. Considering furthermore the fast technological progress since the last major SPS study, the NASA lead "Fresh Look Study" in 1997[7], it is therefore reasonable to reconsider advantages and drawbacks of different concepts. Based on the existing legal framework and clear decision criteria, a system architecture level trade-off study will define a preliminary SPS design. The timeframe for this study is the first half of 2003.

European SPS reference architecture

In parallel to the identification of a reference SPS architecture that will serve as reference for other ongoing research, the study will identify some technical domains where European laboratories are internationally on the leading edge. Several studies on SPS until now have shown that there are no technical showstoppers for SPS to being developed.[4,7,8,9,10]

On the other hand, some of the conclusions of these past studies are also that 1. embarking in an SPS endeavour still bears high technological risks, 2. critical technical issues need more research; 3. the total cost of investment are very high compared to the first return, 4. the advantages of the SPS compared to terrestrial solar plants are not obvious, 5. SPS can only be considered as an international effort, 6. launching costs have to decrease by at least an order of magnitude (construction of SPS itself would certainly decrease launching costs; sometimes compared to the chicken-egg problem).

Identification of key areas

The next step after the system architecture level trade-off study will consist in enhanced research on two to three key areas. For this stage, prior international coordination leading to a reasonable repartition of tasks would be highly advantageous. Without reconsidering the entire model, these efforts that should start by mid 2003 would address points 1 and 2 above by gradually lowering specific technological risks. The entire SPS model would be kept and updated continuously at the system level.

Without anticipating the outcome of the trade-off study, the work already performed at La Réunion on wireless power transmission by microwaves, was acknowledged during the first Network meeting as important research area.

This phase will then proceed from the pure study level to actual experimental setups, most probably first on ground and subsequently on a small scale in space. Such small scale demonstrator missions should take as much as possible advantage of existing infrastructure, e.g. WPT to or from the ISS. As stated above, one of the major drawbacks of SPS are the high development costs. The success of this phase will therefore depend highly on the ability to show actual spin offs and dual use possibilities.

Economic aspects

Contrary to the approach chosen by the Fresh Look Study, economic aspects will be taken into consideration at a later stage, when domain specific, technical research will have lowered the technical risks and established a technically viable concept. The reason for this approach is that the emphasis of entire approach is given to the system and subsystem technical aspects and not to the system architecture development.

Nevertheless, the work on the space system will be guided by the constraint that is has to be advantageous or at least competitive to terrestrial alternatives, that will be part of the study.

As a second constraint, the total energy balance and the energy payback times of different system architecture level concepts will be considered.

COMPARISON WITH TERRESTRIAL SOLUTIONS

A preliminary order of magnitude for terrestrial alternatives is given by estimations on cost and efficiencies of a North African solar power station described in the next paragraph. For this assessment a region in the scarcely populated areas somewhere in the western Saharan desert is taken. Contrary to the space options all the technologies listed for this comparison are proven and already available.

North African Solar Thermal Power Plant

The assessment is based on a delivered capacity of 500 GW in Europe, which is about 55% of the projected total installed electricity generation capacity of the EU in 2030 and 76% of the additional capacity foreseen to be installed between 2000 and 2030. The cumulative investment for this additional capacity is estimated at 531 B€.[1]

The plant would use solar thermal conversion, since at South European and North African latitudes, direct irradiance is about 25% higher than diffuse irradiance. While photovoltaic systems can use also diffuse irradiance, solar thermal plants need the direct part. Between the two major concepts for solar thermal plants, the parabolic trough collectors would probably be preferred over the power tower concept, due to the large area.

The basic concept of parabolic trough systems is that sunlight is concentrated about 80 times onto a central metal absorber pipe in the line of focus, where water (or special thermal oils) is heated up to 400°C. The generated steam drives a turbine and an electrical generator before condensing and returning into the cycle.

The averaged daily solar irradiance at the west Saharan latitude is about 280 W/m^2. Current solar thermal power plants in the US and Spain operate around an efficiency of 16%[11,14]. The 16% are the result of about 45% efficiency of the parabolic toughs and 35% for the steam engine. (Figure 2)

These values are average values, peak values are significantly higher. Projected near-term improvements to 20% seem realistic and are taken as basis for this assessment.

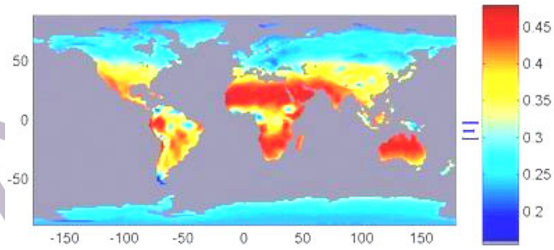

Figure 2: Efficiency of solar thermal troughs (data: EZMW and NCEP)[12,13,14]

For the electricity transport to Europe, high voltage direct current (HVDC) cables are considered. HVDC cables are currently the most cost effective power lines over distances exceeding about 800 km. This assessment is based on 2500 km power lines corresponding to the distance between Western Sahara and central west Europe. The reported losses would be in the order of 10% (at full load, the transmission losses are highest and about 4%/1000km, adding 0.6% for the HVDC stations).

Adding up the efficiencies of the different steps and considering the losses, a total receiver surface equivalent to a circle of about 56 km radius (9900 km^2) would be necessary to deliver 500 GW$_e$ to Europe.*

Today, nine solar thermal power plants have been installed, covering a total surface of about 7 km^2 and delivering around 800 GWh per year. The first plant installed 1984 in the Mojave Desert in California produced at 0.27 \$/kWh while the ones installed in 1991 managed to produce at rates as low as 0.12 \$/kWh.[15]

The current cost of HVDC power transmission lines is about 70 €/(kW$_e$/1000km) for land lines and 716 €/(kW$_e$/1000km) for sea lines, which amounts to about 100 B€ total line installation cost for the described case.[16] The HVDC stations at both end of the line add another 63 B€ (based on 60 €/kW$_e$). Adding the cost of the power plant itself, 2130 B€ for the solar field and 470 B€ for the thermal power plant (based on the assumption of 215 €/m^2 for the solar field[17] and 850 €/kWh for the thermal plant and not taking into account capital cost), these numbers provide an upper limit of 2770 B€† for any comparable space based power plant. These numbers are based on real data of existing trough power plants.[18] Applying the projected cost reduction for troughs as well as expected realistic performance improvements[19], the total cost would be reduced to 1475 B€ (solar field 57%, thermal plant 32%, transmission 7%, HVDC stations 4%). These numbers are in reasonably good agreement with previous published results.[20]

At a smaller scale, in order to deliver 10 GW$_e$ to Europe, receiver surface equalling a circle of 7.1 km radius would be required, totalling about 30 B€ (solar field: 17 B€, thermal plant: 9 B€, transmission 2 B€, HVDC stations 1 B€).

The main parameters of the comparison are summarised in Table 1.

Table 1: Summary of terrestrial solar thermal plant option.

	conservative	advanced		
energy delivered	500		10	[GW$_e$]
solar irradiance	280			[W/m^2]
total plant efficiency	0.20	0.25		
transmission distance	2500			[km]
solar field size	9921	7874	157	[km^2]
solar field size radius	56	50	7	[km]
solar field cost	215	107	107	[€/m^2]
	2133	842	17	[B€]
thermal plant cost	850			[€/kW$_e$]
	472	472	9	[B€]
power transmission cost	97	97	2	[B€]
HVDC station cost	63	63	1	[B€]
total cost	**2766**	**1475**	**30**	**[B€]**

The location at the Western Sahara is up to 30 longitude degrees east of central Europe, thus enabling some overlap of the production time with high demand time. A more detailed assessment is necessary to determine the best role of such a power supply in the future European power network, whether baseload or peak power consumption is targeted and how the integration with existing conventional sources would be most effective.

* This represents 0.1% of the Sahara desert size and 3.7% of the size of West Sahara (population density < 2 persons/km^2)

† Based on a lifetime of 30 years, the electricity prize would be 2.11 €cts/kWh. The inclusion of capital cost would raise this figure to about 3-4 €cts/kWh.

These estimations are preliminary in order to give reference orders of magnitude, they are not taking into account energy storage facilities (that would probably increase the efficiency and the cost per kWh), capital, maintenance and operation cost. In addition to the evident environmental benefits, financial benefit due to trade with GHG emission rights as laid down in the Kyoto protocol and the subsequent international conferences on the subject are not taken into consideration at this stage.

CONCLUSIONS

The present paper has outlined the institutional and technical frame within which the European Network for Solar Power Satellites will conduct its research activities. A roadmap was presented, highlighting the priorities of the ESA lead effort. For the purpose of a first comparison and the establishment of a potential economic frame, a preliminary assessment of a terrestrial solar power plant is given.

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