Assessment of an integrated space-terrestrial, solar-based Euro-Asian energy system

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SCOPE

Within the next 15 to 20 years a significant portion of the Worldwide and especially European power plants will reach their definitive end-of-life and will have to be replaced. As a consequence, the discussion about the most appropriate energy system for this 21^{st} century is gaining political and public interest.

At the same time, the general public attributes the increasing frequency of natural disasters more and more to greenhouse-gas caused climate changes. Health problems caused by air pollution show the limitations of fossil fuel based traffic increases in metropolitan areas. The increasing European energy-import dependence on few supplier regions, additionally alerts strategic planers and incites to look for viable, sustainable, affordable and realistic alternatives.

This paper tries to contribute to this debate in showing the potential of solar based solutions — space as well as terrestrial ones — for the long-term, larger European energy context.

To this extent, a comparison of space and terrestrial solar power solutions is presented, not in order to trade them off, but to show their complementarities and their combined potential. While the initial focus is on the wider European context, the integration of space solar power plants with terrestrial ones extends to an Asian-European cooperation in which the space asset equally enhances terrestrial plants in Europe and east Asia.

A first attempt to optimise the complex interaction between orbital parameters, transmission frequency and size of the terrestrial and space plants is presented.

SPACE AND TERRESTRIAL SOLAR PLANTS

It is believed that space solar power plants are likely to be preceded by large-scale terrestrial solar power plants. These will stimulate the renewable solar energy market, lower production costs and most importantly offer existing and functioning terrestrial receiver infrastructures to space solar power plants. The terrestrial infrastructure will consist not only of the actual receiving site, but also the power management and power distribution system to consumer centres.

In order to take maximum advantage of terrestrial plants, some orbits and transmission wavelengths are more suitable than others. In this assessment, the most recent European, US and Japanese SPS designs are taken as basis for the space component. Backed by the recent advances in laser power transmission, laser systems receive particular attention, since they also offer better integration potentials into ground solar power plants.

The study takes particular attention to clearly distinguish between state of the art and advanced technologies, both for terrestrial and space solar power solutions.

The actual electricity needs, measured as hourly European averages for typical winter month days and typical summer month days of the year 2001 were taken as basis, extrapolating the daily consumption profile to the expected values in 2020.

Different supply scenarios are envisaged, from pure peak load power supply stations to large base-load power provider plants. In both cases, local storage needs are required in the case of sole terrestrial plants — even at most favourable North-west Sahara locations, since especially during winter months the late evening peak demand could not be satisfied.

As local storage technology, the most advanced and less cost intensive underground hydrogen cavern storage solution was chosen. This solution then was traded off against space augmentation systems, that are able to drastically reduce or even remove the need of local storage capacities.

In a first assessment of a terrestrial 5 GW_e plant, the cost for overdimensioning and storage would increase the actual minimal costs by about a factor of $9-10$, from 11 to 109 B€. More advanced/optimistic cost estimates are in the order of 7 and 57 B€ for the terrestrial system without and with storage respectively. The

Table 1: Cost estimates of 5 GW terrestrial plant options. (all values in B€; incl. capital costs)

		PV		trough	
		cons.	adv.	cons.	adv.
without storage		12	7	11	7
with storage	*min*	119	52	109	57
	max	157	60	148	65
H_2 plant	*min*	127	54	118	59
	max	165	62	156	67

total cost for a 5 GW_e SPS system was estimated (including optimistic launch costs) by NASA during the Fresh Look Study at about 64 B€, including the ground site costs.

INTEGRATION INTO A HYDROGEN BASED ECONOMY

The present study further elaborates on the integration of such a space-terrestrial sustainable power generation system into an economy in transition from fossil fuel based energy vectors to a hydrogen energy vector. The overproportional increase of electricity demand compared to the total worldwide energy demand increase is expected to be further enhanced by the introduction of hydrogen as additional, storable energy vector, compliant with the requirements of the transport energy. The first larger hydrogen networks are expected to be operational in metropolitan areas, trying to alleviate the increasing health burden from fossil fuel based transportation systems.

The study looks at the potential for production of solar hydrogen at terrestrial solar plants augmented by space assets. It also looks that the advantages of hydrogen delivery instead of electricity delivery.

Table 1 shows the preliminary cost estimates for conservative and advanced solar terrestrial plants without local storage, with local storage and for a hydrogen plant.

SPS Orbits

For the space segment, three different orbits are studied in more detail:

Option 1 sun-synchronous repeating Molniya orbit;

Option 2 high elliptic nearly sun-synchronous Molniya orbit with a 1 year phase drift;

Option 3 high repeating circular orbit.

The main orbital parameters of the three options are summarized in Tab. 2. Access times are calculated respecting maximum steering angles of 30° and transmission possibility only during full solar exposure of the space plants' solar arrays.

The advantages and drawbacks of the three options are studied and fed into an optimisation process, taking into account the orbital parameters, the size, mass and cost of the space segment as well as the location, size and subsequently the access times of the terrestrial solar plants. In a first iteration, two plant locations are studied: A location in the western Sahara desert(26°N, 14°E) with an averaged daily solar irradiance of $280\,W/m^2$ ($2,455\,kWh/a$) and a plant in the Chinese-Mongolian Gobi desert, located at 40°N and 112°E with $1,700\,kWh/m^2a$. Such a plant would be able to serve the fast growing relatively close Chinese as well as the Japanese electricity/hydrogen market.

The optimisation of the combined terrestrial and space born system is carried out through an innovative advanced global optimisation algorithm that extensively explore the solution space in search for optimal combinations of the design parameters both for the space segment and for the ground segment: orbital parameters, sizing of the space and ground units, location of the terrestrial plant, etc. This global algorithm blends together the properties of systematic techniques such as branching and interval analysis and of heuristic methods as evolution programming for an improved search of several potentially optimal solutions.

Table 2: Orbital parameters of three options.

	option 1	option 2	option 3	
apogee alt.	$7,838.35$	$39,954.48$	$20,182.46$	km
perigee alt.	523.50	500.00	$20,182.46$	km
eccentricity	0.3464	0.7414	0	
inclination	116.57	63.4	98.0	*degree*
argum. of perig.	270	270	0	*degree*
lon.asc.node	202.82	314.96	9.0	*degree*

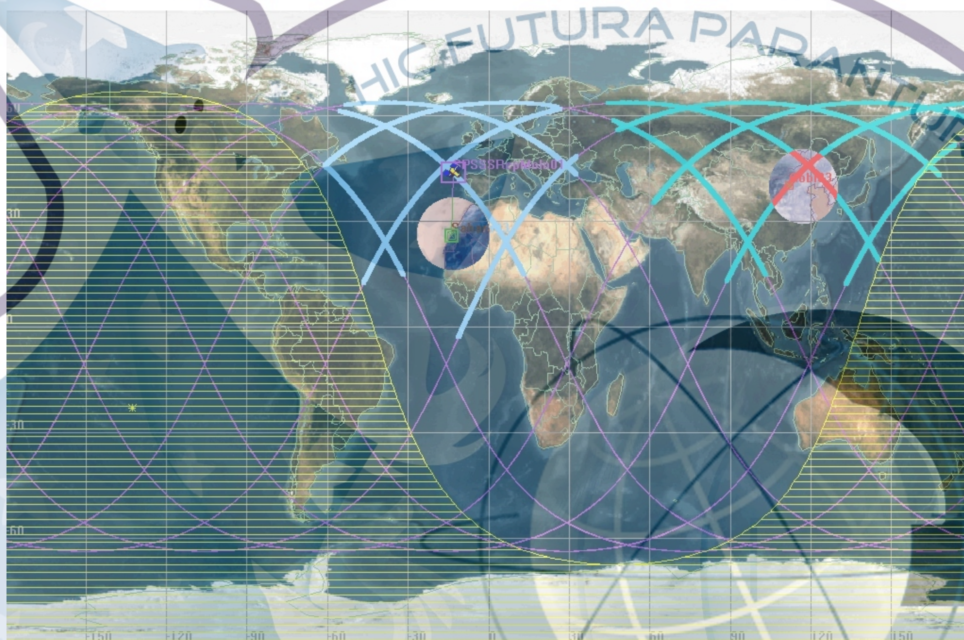

Fig.1: Option 1 Molniya orbit. (region of ground-stations inverted, January 21 : 00 GMT, solar irradiated areas marked with horizontal lines, access periods in bold)

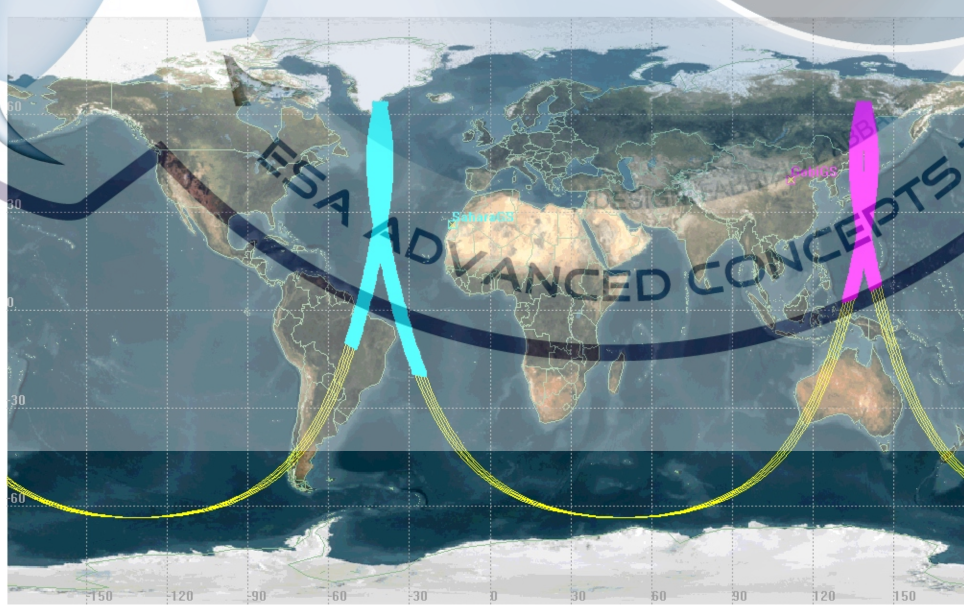

Fig.2: Option 2 Molniya orbit (January).