THE POTENTIAL GLOBAL MARKET IN 2025 FOR SATELLITE SOLAR POWER STATIONS

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Abstract

Starting from hypothesis of moderate growth for energy demand through 2000/2025, we have computed the market of Large Electrical Power Plants (LEPP) in the range 24-40 TWh/yr suited for base-load electrical needs. For this purpose, we have developped a numerical model predicting the future demands for centralized and decentralized electrical energy according to geographical position. The input of this model are : the geographical distribution of population at the present time, the energy demand growth in the different world regions, the part of energy consumption used for electricity generation in each world region. The partition of electrical demand between centralized and decentralized needs is made according to the density of electrical consumption. We have used, as energy demand growth hypothesis, results from the reports of the Conservation Commission of the World Energy Conference (1977) and the work of the Case Western Reserve University. Our model leads to a world market for LEPP in 2020/2025 of 752/942 plants, which could be provided alternatively by Conventionnal Thermal Plants, Breeder Nuclear Reactors, Fusion Reactors or SSPS (Satellite Solar Power Station). Assuming a 50% market penetration factor for SSPS between 2000 and 2025, the number of SSPS to be built during this period amounts to 199/275.

Introduction

One of the most important problem of the next decades will unquestionnally be to face the prospect of a growing energy demand in a context of limited gas and petroleum reserves, and of environmental concerns. Among various alternate ways to contribute to future energy demand (coal, oil shales, fission and fusion nuclear energy, etc...) solar energy is receiving a special attention due to its large availability, cleanliness and public acceptance. The purpose of our work is to look at the prospects of using solar energy to supply an important part of world electrical demand in 2020/2025.

1. Problem of large scale solar electricity generation

Solar Energy is available for electricity generation on earth and in space. Ground solar electricity generation (GSEG) must work with the great variability of the solar energy input at earth surface, according to latitude, hour, season, weather. In order to provide a nearly constant power, it needs a storage (electrical, thermal or chemical) or to be complemented by a conventionnal generator (i.e in the "fuel saver" mode). Due to these limitations, GSEG will probably not be well suited to supply electricity to power grid in industrialized part of the world, but it will surely be well suited to provide in great part the electrical demand in area where extensive power grids do not exist, or where connection to the grid is not convenient. For these applications, the scale of GSEG extend from about 1 kW (individual housing, TV relay, etc...), to about 100 MW (demand of isolated medium scale town).

In order to compete on the centralized electricity market, solar electricity will thus have to rely on the concept introduced in 1968 by Peter Glaser [2]:the Satellite Solar Power Station (SSPS) working in geostationnary orbit with its panel constantly oriented towards the sun, has a nearly constant supply of solar energy (there is only a seasonnal variation of 5% due to earth orbit excentricity and satellite orbit inclination, and an eclipse problem up to 74 min per day 20 days apart of each equinoxe). The scaling of the microwave energy transmission link between space and earth points towards very large SSPS, in the range 3-5 GW. For these reasons, (constant level of production and large scale) the SSPS fits very well to the needs of big power grid for Large Electrical Power Plant (LEPP), in the range of production 24-40 TWh/year.

2. Future electrical demand

One can find in the litterature many very different assumptions and predictions for future energy demand [3] . We have put aside both the no-growth alternatives which we think unrealistic in view of the aspiration for a better life in most parts of the world, and the rapid growth models which we think also unrealistic due to the

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rising cost of energy production, and to the potential of energy conservation.

As a first choice, we have decided to conduct this work with two global models of energy demand growth :

a) the lower growth model of Case Western Reserve University (CWRU) [4]

b) the H 5 model of the conservation commission of the World Energy Conference (WEC), which is a model of quite fast economic development in an energy constrained world [5] . Both model predict a very moderate growth of energy demand, and we think our coming assessments of SSPS market could be considered as minimum. The CWRU and WEC analysis make use of repartitions of countries in10 world regions. There is some differences in the two set of regions, which are presented in Table 1. The regional energy demands in years 1980, 2000, 2025 for the CWRU model, and in year 1985, 2000, 2020 for the WEC model are respectively given in Table 2 and 3. There is some differences between the two set of predictions. The WEC model predicts a higher energy demand growth in developping countries, and a lower one in developped countries, than does the CWRU model. These differing views make the parallel use of the two models very interesting.

In order to obtain electrical demand from primary energy demand, one has to assess the part of primary energy used for electricity generation. This part has been a growing function of regional development,

Table 1 World regions

		CWRU	WEC
N.AMERICA	1	•	•
W.EUROPE	2	•	•
JAPAN	3	•	
JAP.,AUST., N.ZEALAND	3'		•
U.R.S.S. E.EUROPE	4	•	•
REST.DEV. COUNTRIES	5	•	
LAT. AMER.	6	•	• x
N.AFRICA M.EAST	7	•	
ARAB COUNTRIES	7'		• x
MAIN AFRICA	8	•	
AFRICA S. OF SAHARA	8'		• x
S./S.E.ASIA	9	•	• x
COM. ASIA	10	•	•
O.P.E.C.	11		•

x: without Opec

and thus of time. For computing regional electricity demand from CWRU primary energy data, we have assessed the value of this part in year 2000 and 2025 for each region, as shown in table 4. For the WEC data, we have used the set given in the WEC Conservation commission report [5] , for year 2000 and 2020 and the results are also shown in Table 5.

4. Future base load centralized electrical demand

Starting from regional electrical demand, the problem is to assess which part of this demand is to be satisfied by centralized means (that is by extended electrical grids) and which is to be satisfied by uncentralized means (diesel generators today and solar terrestrial power plants as their cost is becoming lower). Clearly, the problem cannot be solved on a regional basis, since density of energy consumption can vary greatly inside a world region. That is why we have divided each world region of CWRU and WEC into zones of 10° latitude x 10° longitude, in which we have computed, according to the 1978 population repartition, the electricity zonal demand (Ez), and then the zonal demand density (Dez) taking into account only the land area of each zone. The density Dez is the principal factor governing the economical advantage of using an electrical power grid with LEPP. If Dez is high, the cost of electrical distribution is small compared to LEPP investment, and the reverse situation arises if Dez is small. We have determined a critical density Dec under which the cost of distribution system of electricity supplied by a typical LEPP is higher than 50% the LEPP construction cost : Dec = 200 MWh/km2. Map. 3 shows the zones in which in 2025 Dez will be higher than Dec, and those in which the electricity density demand will be much higher (Dez > 1000 MWh/km2). We have assumed that the power grid supply is 90% of the electrical demand if Dez > Dec, and decreases proportionnaly to Dez under Dec. The LEPP produces the "base load" electricity in the grid (the peak-loads have to be satisfied in an other way), which we have estimated at 70% of total electrical demand. In any case, we assume there is no grid if the base load demand on it is smaller than 24 TWh/year, which we estimated as the minimum economical production for most alternate LEPP. Details of this model have been given else-where [6] Table 6 gives the numbers of LEPP needed in each region for CWRU data (year 2000 and 2025) and WEC data (year 2000 and 2020). With a LEPP park of 752 (WEC) or 942 (CWRU), the market for such large plants is clearly tremendous, particularly during the period 2000/2020-25 during which 394 (WEC) or 548 (CWRU) are to be built.

Table 2 Regional energy demand (MTEC)
Model WCRU

		1980	2000	2025
N.AMERICA	1	3566	5840	10830
W.EUROPE	2	2350	4020	7450
JAPAN	3	1020	2585	4040
JAP.,AUST., N.ZEALAND	3'			
U.R.S.S. E.EUROPE	4	2190	3540	7410
REST. DEV. COUNTRIES	5	200	330	630
LAT. AMER.	6	460	1045	3070
N.AFRICA M.EAST	7	200	705	3430
ARAB COUNTRIES	7'			
MAIN AFRICA	8	70	137	350
AFRICA S. OF SAHARA	8'			
S./S.E.ASIA	9	245	470	1180
COM. ASIA	10	570	1030	2130
O.P.E.C.	11			

Table 4 Regional electricity demand (TWh/yr)
Data WCRU

		2000		2025	
N.AMERICA	1	45%	7448	50%	15346
W.EUROPE	2	..	4989	..	10272
JAPAN	3	..	3927	..	5725
JAP.,AUST., N.ZEALAND	3'				
U.R.S.S. E.EUROPE	4	..	4453	..	10356
REST. DEV. COUNTRIES	5	30%	281	40%	715
LAT. AMER.	6	..	888	..	3480
N.AFRICA M.EAST	7	..	599	..	3888
ARAB COUNTRIES	7'				
MAIN AFRICA	8	20%	78	30%	298
AFRICA S. OF SAHARA	8'				
S./S.E.ASIA	9	..	266	..	1003
COM. ASIA	10	30%	876	40%	2415
O.P.E.C.	11				

Table 3 Regional energy demand (MTEC)
Model WEC

		1985	2000	2020
N.AMERICA	1	3423	4936	7357
W.EUROPE	2	2165	3315	4740
JAPAN	3			
JAP.,AUST., N.ZEALAND	3'	884	1340	2135
U.R.S.S. E.EUROPE	4	2584	4542	8466
REST. DEV. COUNTRIES	5			
LAT. AMER.	6	595	1230	4107
N.AFRICA M.EAST	7			
ARAB COUNTRIES	7'	129	221	479
MAIN AFRICA	8			
AFRICA S. OF SAHARA	8'	381	643	1289
S./S.E.ASIA	9	704	1166	2584
COM. ASIA	10	1156	1785	3349
O.P.E.C.	11	534	1224	3835

Table 5 Regional electricity demand (TWh/yr)
Data WEC

		2000		2020	
N.AMERICA	1	45%	6295	50%	10425
W.EUROPE	2	40%	3657	..	6536
JAPAN	3				
JAP.,AUST., N.ZEALAND	3'	45%	1372	..	2428
U.R.S.S. E.EUROPE	4	50%	6348	45%	10349
REST. DEV. COUNTRIES	5				
LAT. AMER.	6	25%	871	30%	3492
N.AFRICA M.EAST	7				
ARAB COUNTRIES	7'	..	142	..	370
MAIN AFRICA	8				
AFRICA S. OF SAHARA	8'	..	424	..	1022
S./S.E.ASIA	9	..	826	..	2196
COM. ASIA	10	20%	1012	..	2847
O.P.E.C.	11	..	697	..	3276

5. Potential SSPS market

We have not tried to compare from the economical point of view the various alternatives which could lead to LEPP at the beginning of the XXI st century, that is, in our opinion :

- Coal or oil shales thermal plants
- Breeder nuclear reactors
- Fusion reactors
- SSPS

The evaluations done in some references [7] to compare SSPS with the other options give all busbar electricity costs generally in the same very broad range (30/120 mills/kWh). But we think that such comparisons are premature due to the economical and technical uncertainties which affect forecasts not only for the fusion reactors and the SSPS, which are still at the concept level, but also for the Breeder and classical thermal plants.

We think that environmental and political questions will play a major role in the choice of the dominant LEPP technologies at the beginning of the XXI st century, and that, on these grounds, the SSPS competitors may suffer from some disadvantages :

- the environmental questions raised by the development of nuclear energy, and particularly by the Breeder reactor are well known (risk of major accident, radioactive wastes, diversion of plutonium, etc...).

- the fusion reactors, whose faisability is not yet established, will not be free from radioactive risks.

- the classical thermal plants produce large amounts of CO^2 which may lead to a dangerous "green-house" effect [7]

- Fusion, fission, and classical thermal plants reject about 150% more heat in the environment than they generate electricity (against only 10% for the rectenna which receives the microwave beam from the SSPS).

For these reasons, we think that the studies of the SSPS must focus on the environmental questions which can be raised by the SSPS (effects of microwaves on ionosphere, consequences of a very high rate of space launchings). The present evaluations are optimistic [8] but they are still clearly preliminary. If further studies give ground to the environmental advantages of SSPS, then the SSPS could very well take a substantial part of the LEPP market after year 2000, which seems to us the earliest period when the SSPS could be available.

We have computed the number of SSPS needed in two case of penetration on the LEPP market a) 10% b) 50% (in which case SSPS would be the dominant LEPP technology). For the 50% case, Map 1 and 2 shows the number of SSPS antennas to be built per zone between 2000 and 2025 (2020) for CRWU and WEC models. Table 7 gives the total number to be built for each region and world, in the two cases considered.

Table 6 Nb of lepp needed

		FROM CWRU		FROM WEC	
		2000	2025	2000	2020
N.AMERICA	1	132	272	109	184
W.EUROPE	2	96	188	70	121
JAPAN	3	60	102		
JAP., AUST., N.ZEALAND	3'			23	42
U.R.S.S. E.EUROPE	4	79	183	112	190
REST. DEV. COUNTRIES	5	2	10		
LAT. AMER.	6	6	60	7	62
N.AFRICA M.EAST	7	6	71		
ARAB COUNTRIES	7'			1	5
MAIN AFRICA	8	0	0		
AFRICA S. OF SAHARA	8'			0	2
S./S.E.ASIA	9	0	14	10	39
COM. ASIA	10	13	42	16	50
O.P.E.C.	11			10	57
		394	942	358	752

Table 7 SSPS market 2000/2025 (2020)

		10% NEW LEPP		50% NEW LEPP	
		CWRU	WEC	CWRU	WEC
N.AMERICA	1	14	8	70	38
W.EUROPE	2	9	5	46	26
JAPAN	3	4		21	
JAP., AUST., N.ZEALAND	3'		2		9
U.R.S.S. E.EUROPE	4	10	8	52	39
REST. DEV. COUNTRIES	5	1		4	
LAT. AMER.	6	6	6	27	28
N.AFRICA M.EAST	7	7		33	
ARAB COUNTRIES	7'		0		2
MAIN AFRICA	8	0		0	
AFRICA S. OF SAHARA	8'		0		1
S./S.E.ASIA	9	1	3	7	15
COM. ASIA	10	3	3	15	17
O.P.E.C.	11		5		24
		55	40	275	199

Conclusion

The faisability of building such large numbers of SSPS is strongly related to the capability of the interested countries to finance the initial investment, as in every solar energy system. Consequently the prospects of penetration look quite different if we consider Western countries or Developing Countries due to this investment funds availability. Also the Developing Countries may be reluctant to invest in imported technologies when they will strive to develop their own industry.

So if the implementation of SSPS at the level of 50% of the new LEPP seems possible for the western industrialized countries, this figure is rather unrealistic for developing countries and 10% could be a fair estimate.

Using the CWRU data, the number of SSPS would be 141 in Western countries and 14 in Devel.countries, reaching a total of 155. The WEC data lead to a dramaticaly smaller figure for Western countries : 73 and 9 in Developing Countries (excluding OPEC countries, where oil and natural gaz should still be prefered in the 2000-2025 period). The total is then 82. What is the weight in the world energy supply of about one hundred of SSPS ? (82 to 155). The average yearly production of an SSPS is, according to our model, 37 Twh/year. The corresponding primary energy would be 9 millions of tons of oil or 13 millions of tons of coal to be spent each year. So the park of 100 SSPS would save each year the equivalent of 900 millions of tons of oil (6660 millions barrels) or 1400 millions of tons of coal. This oil saving is about a quarter (25%) of the maximum anticipated world production of oil (around 4 billions of tons of oil). It is also possible to compute the weight of uranium which would be necessary to produce the same amount of electricity thanks to a PWR type reactor. The 100 SSPS save 70 000 tons of Uranium each year. The accumulated savings are also tremendous : from 2000 to 2030 (twenty years of system implementation at 5 SSPS/year and ten years of full operation), the accumulated oil saving would be 18 billions of tons of oil. (Savings of the same order of magnitude could be obtained by socialist countries if they choose SSPS as dominant LEPP technology).

A large SSPS park could thus relieve developed countries from the problems of oil and uranium ore exhaustions (in case Breeder reactors are not developed). One can also consider the possibility of a larger penetration on developing countries market through an international program, in which industrialized countries would provide funds and technology for an international agency providing electricity at low cost for energy poor countries.

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9. See for instance :

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10. See for instance :

- "Geosynchronous Satellite Solar Power" J.R. Williams in "Solar Energy for earth an AIAA assessment"
- Testimony of R.W. Taylor in "Solar Power from satellites" USGPO 1976

Map. 1 caption : zonal distribution of SSPS antennas needs in period 2000/2025 according to our model with CWRU primary energy data, in case of a 50% penetration factor on LEPP market.

Map. 2 caption : same as for Map. 1, but for 2000/2020 period, and WEC data.

Q. I wonder if you have given any thought to the cost influences?

A. I expect that we don't have to pay attention to this because the model and the data are self-consistent; that is, in this model the cost of energy is taken into account. The only thing we have to say is that the prices of the energy systems we consider are in the same order of magnitude as, say, a breeder reactor.

Q. I was considering the effect on development; might a lower cost of energy in a developed country further accelerate the gap between developing and developed nations?

A. This is an important factor. I don't think that the graph points toward a greater gap; on the contrary, I think it point towards a smaller one. This model points toward a rise in the use of energy in the underdeveloped countries which is faster than the rise in the developed countries.