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CASE STUDY OF VERY LARGE SCALE PV IN THE MEDITERRANEAN REGION

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ABSTRACT: The economic feasibility of very large scale photovoltaic power generation (VLS-PV) is examined within the framework of Task 8 of IEA-PVPS: PV from the Desert for the four Mediterranean countries Morocco, Tunisia, Portugal and Spain. Key geographical and socio-economic parameters are analyzed, including the legislative supporting framework like recently approved PV feed-in tariffs in order to determine the boundary conditions for a practical implementation of VLS-PV. The evaluation of PV generation cost for different sites and possible revenues from electricity sales indicates a clear ranking of the economic feasibility presently in favour of the southern-European countries. The regional status of VLS-PV is discussed reviewing also existing projects and proposals.
Keywords: Large Grid-connected PV systems, Economic Analysis, Mediterranean Region

I INTRODUCTION

Very Large Scale PV Systems (VLS-PV) can contribute considerably to global energy needs, to the environment, to socio-economic development and at the same time become economically and technologically feasible [1]. This work was performed within the framework of Task 8 of IEA-PVPS: PV from the Desert and examines the economic conditions for VLS-PV systems in the Mediterranean region. Originally focusing on the Sahara desert bordering countries Morocco and Tunisia, Portugal and Spain were included to compare the impact of recently approved PV feed-in tariffs with less-supportive framework environments in Northern Africa.

Two sites were selected for each country, one more affected by marine climate influences with lower irradiation, and one representing a higher irradiated desert-like location. The study was performed from a professional project developers point of view by determining PV electricity generation cost and potential revenues from electricity sale of VLS-PV systems to customers, either to consumers on a standard electricity price level or to grid operating entities on a feed-in tariff basis.

II GENERAL CONDITIONS

2.1 Country profiles

Morocco, located in north-western Africa, has a 29.7 Mill. population living mainly in the fertile north-western coastal regions. Casablanca with 3.1 Mill. inhabitants is the leading industrial, commercial and financial centre of the country including an important port. The income per capita was 1,532 € in 2002. The annual horizontal global radiation input of Morocco increases from north to south and from west to east. The lowest intensities of about 1,700 kWh/m²*a are found in the north. In the lee of the Grand Atlas and in the Sahara desert the annual radiation input is above 2,100 kWh/m²*a, e.g. in Quarzazate. Further key data are compiled in Table I.

Tunisia, located in northern Africa, has a population of 9.9 Mill. people, mostly concentrated in a narrow strip along the Mediterranean coast in the north. The most important urban area is the capital region of Tunis with 1.8 Mill. inhabitants. The income per capita was 2,200 € in 2002 which is the highest of all countries in North Africa apart from Lybia. The annual horizontal global radiation increases from about 1700 kWh/m²*a in the north at Tunis to intensities of more than 2100 kWh/m²*a in the south in the Sahara desert.

Portugal, located in far south-western Europe on the western side of the Iberian Peninsula, has 10.2 Mill. people population concentrated in the plains along the Atlantic Coast. The most important urban areas are the capital region of Lisbon with 1.9 Mill. inhabitants and the region of Porto. The income per capita was 12,500 € in 2002. The annual horizontal global radiation increases from about 1,500 kWh/m²*a in the north-west over 1,760 kWh/m²*a in Lisbon to Europes highest 1,900 kWh/m²*a in the Algarve and Alentejo regions in the south.

Spain occupies the greater part of the Iberian Peninsula. With about 40.8 Mill. people it is the third-biggest of the northern-mediterranean countries at a high 80% urbanisation rate. Apart from the capital Madrid (3 Mill.), large areas of the centre of Spain are scarcely populated. The average income per capita was 17,100 € in 2002. In Spain, the annual horizontal global radiation increases from about 1,200 kWh/m²*a in the north towards the best solar conditions along the southern Costa del Sol with a radiation of about 1,800 kWh/m²*a e.g. in Almería.

	Morocco (2002)	Tunisia (2003)	Portugal (2002)	Spain (2002)
Population (Mill.)	29.7	9.9	10.2	40.8
Area (km²)	446,550	163,610	92,040	505,960
Population density (1/km²)	67	61	111	81
GDP per capita (€)	1,532	2,200	12,500	17,100
Energy consumption per capita (toe)*	0.48	0.83	2.52	3.24
Total energy consumption (Mtoe)	14.3	8.2	25.7	132.2
Total electricity production (TWh)	17.2	11.8	46.1	246.1
Electricity price level (€-cent/kWh)	~8-12	~2-5	~12	~9
Annual solar radiation (kWh/m²*a)	1,700 - 2,100	1,700 - 2,100	1,500 - 1,900	1,200 - 1,800
Feed-in tariff for renewable electricity	No	no	yes	Yes
Cap for PV (MWp)	---	---	150	150
PV industry	No	no	small	large

Table I: Key data of the Mediterranean countries. *1 toe = 1 ton oil equivalent = 11,630 kWh = 11.63 MWh

2.2 Evaluation with respect to VLS-PV

Based on geographic data all countries under consideration offer favourable conditions for the implemtation of VLS-PV. The population density is comparatively low and there are ample areas with suitable geographic conditions (low poulation and vegetation, smooth slopes). We have visited several possible sites of 200-300 ha land size required for an 100 MWp-scale PV system. The irradiation is highest with 1,700-2,100 kWh/m²*a in Morocco and Tunisia, but also southern Portugal and Spain offer regions with up to 1,900 kWh/m²*a annual global irradiation.

In the economic key data there are stronger differences between the two groups of northern African and southern European countries, see Figure 1: The latter exhibit distinctly higher gross domestic product and energy consumption per capita than the former, leading to the conclusion that the economic power of Portugal and Spain might be favourable to afford the economic support required for market introduction of renewable energy sources (RES) in general and PV in particular on a large scale. Also, the pressure to introduce RES might be higher at higher energy and electricity consumption from an environmental responsibility point of view. The existence of a traditional and strong PV industry in Spain and on a smaller scale also in Portugal provides an additional factor contributing to the economic and political environment favouring the application of PV.

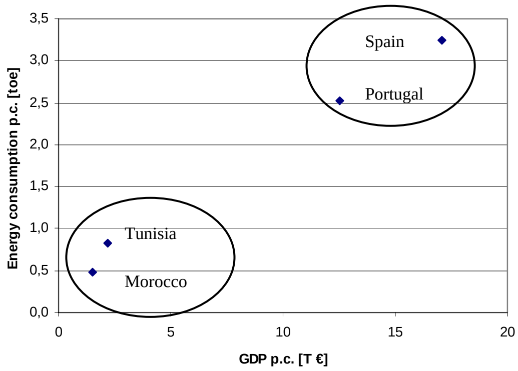

Figure 1: Relation GDP p.c. – Energy consumption p.c.

Interesting to note, these assumptions are reflected by the fact that both Portugal and Spain have passed long-term national plans for the development of renewable energies and PV in particular, which is not the case in Morocco and Tunisia. Also in the latter countries there is an increasing application of PV, but more in the way of small, off-grid rural solar home and village PV systems. The existence of feed-in tariff legislation for grid-connected PV (and other RES) in Portugal and Spain is consistent with these general remarks and provides favourable framework conditions for VLS-PV in principle, based on the presently valid assumption that unsupported generation cost for PV electricity is not low enough to compete with conventional grid electricity prices yet. The actual 150 MWp cap for PV in both Portugal and Spain leaves capacity for large-scale systems, which renders worth-while to perform the closer calculations of economic feasibility for large PV systems.

III ECONOMIC FEASIBILITY OF VLS-PV SYSTEMS

3.1 PV elecrticity generation cost

As taken from experience within the project team with already realized MWp ystems, a stationary (non-tracking, flat-plate) large-scale PV installation can to date be realized at around 4,010 €/kWp as represented in Table II. 4,000 €/kWp therefore serves as a fair approximation for the following calculations including a limited overhead cost of 8%. Note that this overhead does not yet include a further 6-8% capital acquisition cost which is typically required if the project is sold to private or fund investors, a frequently-encountered way of project financing at present. Three quarters of the system cost amounts to the PV modules, the module prices thus being the main parameter for future cost reduction.

The annual cost is represented in Table III. 20 years linear depreciation and 100% loan financing at 5% interest rate serve as model parameters which of course need to be adapted for a concrete project proposal. In our model financing forms a major contribution to annual cost. No investment for land was taken into account here, instead the estimated land renting cost is included in the 2% annual operation and maintenance cost.

The annual global irradiation and annual energy yield were calculated using PVS [2] for two locations per country as shown in Table IV. A virtual stationary PV system was used as input for the program. The irradiation represented is the annual global radiation onto a horizontal surface for the given site. The specific energy yield per kWp represented is the output of the computer program PVS for optimum orientation (south) and inclination (in most cases 30°) multiplied by a factor of 0.93, i.e. including a 7% safety reduction.

The generation cost for PV shown in Table IV was then determined by division of the total annual cost per kWp (assumed to be equal to 480 €/kWp*a at all locations, see Table III) and the annual energy yield.

PV modules	2,950 €/kWp
Mounting racks (material cost)	210 €/kWp
Inverter (assumed N*300-400 kVA)	280 €/kWp
Cables (incl. both DC and AC)	45 €/kWp
Transformer (to 10-20 kV grid level)	58 €/kWp
Installation (labour and auxiliary matl.)	120 €/kWp
Permit fees, infrastructure, transportation	50 €/kWp
Installed system cost (net)	3,713 €/kWp
8% overhead (project development, attorney and bank fees, and similar)	297 €/kWp
Total system cost (net investment)	4,010 €/kWp

Table II: Cost structure for stationary VLS-PV systems in the >MWp range.

Depreciation (linear over 20 years)	200 €/kWp*a
Interest (100% financing @ 5% p.a.)	200 €/kWp*a
Operation and maintenance (2% p.a.)	80 €/kWp*a
Total annual cost (net value)	480 €/kWp*a

Table III: Annual cost per kWp for a total system cost of 4,000 €/kWp.

The investment for tracking systems is higher than the one for stationary systems because of the high cost of the electromechanical structure as compared with stationary mounting racks. Also the operation and maintenance cost is higher because of moving parts, resulting in total annual cost per kWp of 25-30% (depending on the exact type) above the one for stationary systems. The energy yield gain of a single-axis azimutal tracking system amounts to 30-35 % over a south oriented fixed sytem in the Mediterranean region according to experience within the group. Effectively this gives a slight economic advantage of tracking systems. Because this difference does not influence the conclusions of the study substantially, we restrict the following discussion to the stationary system results.

Country	Site	Annual global irradiation (kWh/ m^2*a)	Annual energy yield (kWh/kWp*a)	Generation cost for PV (€-cent/kWh)	Conventional grid electricity price level (€-cent/kWh)	Feed-in tariff rate @ system size (€-cent/kWh)
Morocco	Casablanca	1772	1337	35.9	~8-12	None
	Quarzazate	2144	1589	30.2		
Tunisia	Tunis	1646	1219	39.4	~2-5	None
	Gafsa	1793	1339	35.8		
Portugal	Porto	1644	1312	36.6	~12	~55 <5 kWp
	Faro	1807	1360	35.3		~31-37 >5 kWp
Spain	Oviedo	1214	1008	47.6	~9	41.44 <100 kWp
	Almeria	1787	1372	35.0		21.62 >100 kWp

Table IV: Solar irradiation, energy yield and PV electricity generation cost data compared with the conventional electricity price level and local feed-in tariff rates for stationary systems at two representative sites in four Mediterranean countries.

3.2 Main results and discussion

PV electricity generation costs in the analyzed Mediterranean countries are between 30.2 and 47.2 €-cent/kWh. As a result of the method of determination, the generation cost is inversely following the irradiation conditions.

As expexted, the generation cost for PV calculated with the described parameters is distinctly higher than the price level of conventional electricity drawn from the grid in all places. In this context it is important to note that the assumed 100% loan financing makes up a substantial proportion of the generation cost. Without inclusion of financing cost and without the 7% safety reduction on the annual energy yield generation cost below 20 €-cent/kWh results for almost all sites (data not shown). This confirms that PV generation cost is not hopelessly above the conventional price line and could reach or even fall below this line after a price decrease of PV modules which is already anticipated by foreseeable advances in technology and economy of scale at increasing mass production [3].

If the generation costs are compared to local feed-in tariffs, the results indicate a clear ranking of the economic feasibility.

Although the lowest generation cost of 30.2 €-cents/kWh is reached in Quarzazate, this is not low enough to become attractive for a buy-back scheme in Morocco even taken into account that the general electricity price level is comparatively high in this country. Tunisia has a centralized electricity industry with low price level, making the situation for PV even more difficult. Morocco and Tunisia have no specific legal framework to support electricity generation by PV and no existing feed-in tariff. Therefore the economic feasibility for VLS-PV is low in these northern-African countries if based on the concept of achieving income from electricity sales to consumers or to the grid alone, i.e. not considering any investment subsidies.

Also in Portugal and Spain the prices of conventional electricity are much lower than the calculated PV electricity generation cost. In these countries however, smaller systems appear to be economically feasible with the available feed-in tariffs in higher-irradiation sites. The exciting question for VLS-PV is if also large systems could be economically operated under special circumstances. To answer this question requires a closer look at the conditions in these southern-European countries.

IV A CLOSER LOOK AT PORTUGAL AND SPAIN

4.1 VLS-PV in Portugal

The main problem in Portugal related to grid-connected PV is the low transparency of both legislation and administration related to PV electricity feeding into the grid. This statement amounts to the height and total capacity cap of the feed-in tariff, as well as the approval procedure for applicable systems. The original values of 41 €-cent/kWh (for systems <5 kWp) and 22.4 €-cent/kWh (>5 kWp) were subject to a complicated inflation-correction formula. In 2004 the respective values were ~55 and ~32 €-cent/kWh. Only recently in the February 2005 the feed-in tariff for large systems (>5 kWp) was increased to 37 €-cent/kWh, together with lifting the cap from 50 to 150 MWp. This was exciting because large-scale systems could be economically feasible with these values. Few weeks later, however the rate was apparently decreased again to 31 €-cent/kWh rendering an economic operation impossible for our parameters. The political attitude towards PV is generally positive in Portugal, but this is not clearly valid for large-scale PV, possibly because the presence of PV industry is only small in this country.

Interesting to note, the world´s largest PV system proposals known to the authors, prototypes of real VLS-PV are waiting for their approval under the described uncertain circumstances in Portugal. The first one is the 64 MWp project "AMPER" proposed by BP Solar for a site close to the community of Moura in Alentejo region of southern Portugal [4]. The second one is an 116 MWp project. According to our impressions, no clear time scale is visible for either one of these projects. The realization of more than one VLS-PV project would furthermore require another lifting of the 150 MWp cap, which can not be safely expected.

4.2 VLS-PV in Spain

The stated feed-in tariffs for PV are valid since 2004. They represent an important improvement, because now the higher tariff rate is available for systems up to 100 kWp (before only up to 5 kWp). We do not comment here on further details as duration of the feed-in tariff payment, possible alternative rates and/or accumulation with additional investment subsidies [5,6]. Important to note, it is clear from practical experience that in many cases the application of feed-in tariffs is a well-organized procedure in Spain with only limited administrative hurdles. The attidude is clearly positive towards PV, possibly because of the stronger presence of PV industry in Spain.

This fact has already led to a number of MWp-scale PV systems under the former tariff conditions by combining many systems with <5 kWp to one MWp system. One example is the "HUERTAESOLAR" system concept realized by AeSol in several locations of Arguedas, Navarra. Another prominent project under the increased tariff legislation is the "SOLTEN" proposal for Tenerife, with plans to combine 150 lots of 100 kWp systems to one 15 MWp system, with even larger systems under consideration [7]. Also for Spain, the implemtation of VLS-PV on a larger scale would require a further lifting of the present 150 MWp cap.

Other than Portugal we expect that Spain will follow the German example and improve the legislation stepwise by lifting further and eventually removing both the permitted maximum system size as well as the cap. Such a development could lead to very attractive conditions for VLS-PV in Spain in future, thus winning back European leadership in this field.

V SUMMARY AND CONCLUSIONS

The economic boundary conditions for VLS-PV are still non-satisfactory at present PV system prices without supporting schemes like feed-in tariff legislation. The lack of such supporting schemes renders VLS-PV presently improbable in Morocco and Tunisia. The boundary conditions in Portugal and Spain are generally more favourable because of the existence of feed-in tariff schemes with sufficiently large caps. However, also in these countries the generation cost of PV electricity exceeds the conventional electricity price level and the feed-in tariffs applicable for larger systems in nearly all of the cases studied, with the possible but uncertain exemption of Portugal. The example of Spain shows that the application of intelligent financing schemes will most probably lead to VLS-PV in the very near future there.

In summary, we expect the best conditions for VLS-PV to develop in Spain on an intermediate time scale of 2-5 years, even though there are at present some larger projects proposed in Portugal. Concrete realisation of VLS-PV projects depends on successful negotiation between project developers, PV and electricity industry and policy (acceptance, sustainability, incentives …) in every single project.

Generally, VLS-PV as a centralized electricity source is in the need to compete with conventional electricity sources and other centralized RES like solar-thermal [8] and wind energy also proposed and implemented strongly in the studied region, other than decentralized, smaller-scale PV. Lower invest, additional support and/or higher feed-in tariffs for large systems are required in addition to intelligent financing schemes in order to make VLS-PV economically feasible in the considered Mediterranean region on a larger scale.

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