SUMMARY

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Practical Proposals for Very Large Scale Photovoltaic Systems

Edited by Kosuke Kurokawa
Keiichi Komoto
Peter van der Vleuten
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Foreword

This book deals with the concept of very large scale photovoltaic power generation (VLS-PV) systems and represents the second report that has been prepared on this subject within the International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), Task 8: Very Large Scale Photovoltaic Power Systems. Under the leadership of Professor K. Kurokawa, and based on the previous conceptual work, the international project team has elaborated upon the subject with concrete case studies.

The current rapid growth of the photovoltaic market is dominated by grid-connected applications and the average size of these projects has recently increased. Starting from small scale system sizes in the kilowatt (kW) power range, systems of tens to hundreds of kW are now regularly realized. These photovoltaic systems are often mounted on or integrated within buildings and have reached system sizes up to a few megawatts (MW). In parallel, ground-based arrays on the order of 10 MW and more have been recently built. Through these projects, the photovoltaic sector has gained important experience in the design, construction and operation of photovoltaic systems in the MW range.

Surface and land availability will limit the greater size of photovoltaic systems in densely populated areas of the planet. On the other hand, enormous surfaces of high solar irradiation exist in arid or desert areas. These offer a large potential for photovoltaic systems beyond the size currently known, for which the term VLS-PV systems has been introduced. Such systems may seem unrealistic due to the current state of technology. However, this is precisely the origin of this report, aimed at exploring the detailed conditions for VLS-PV systems in selected regions.

The report provides a detailed analysis of technical, socio-economical and environmental aspects of VLS-PV systems for case studies in the Mediterranean, the Middle East, and the Asian and Oceania regions. Moreover, it includes a brief comparison with concentrated solar (thermal) power (CSP) systems and a first assessment on global climate impact.

I am confident that through its careful, detailed and thorough analysis, this report forms a comprehensive assessment of the concept of very large scale photovoltaic power systems. It should help to rationalize the discussion of this concept and to provide the basis for concrete feasibility studies and project proposals.

I would like to thank Professors K. Kurokawa and K. Komoto, as well as the whole Task 8 expert team for their dedicated effort in making this publication possible. I hope that this unique analysis will contribute to the advance of photovoltaics in new applications.

Stefan Nowak
Chairman, IEA PVPS

Preface

It is already known that the world's very large deserts present a substantial amount of energy-supplying potential. Given the demands on world energy in the 21st century, and when considering global environmental issues, the potential for harnessing this energy is of huge import and has formed the backbone and motive for this report.

The work on very large scale photovoltaic power generation (VLS-PV) systems, upon which this report is based, first began under the umbrella of the International Energy Agency (IEA) Task 6 in 1998. The new Task 8 – Very Large Scale Photovoltaic Power Generation Utilizing Desert Areas – was established in 1999.

The scope of Task 8 is to examine and evaluate the potential of VLS-PV systems, which have a capacity ranging from several megawatts to gigawatts, and to develop practical project proposals for demonstrative research towards realizing VLS-PV systems in the future.

For this purpose, in the first phase (1999–2002), key factors that enable the feasibility of VLS-PV systems were identified, and the benefits of VLS-PV applications for neighbouring regions were clarified.

In order to disseminate these possibilities, we published the first book entitled *Energy from the Desert: Feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems* in 2003. At the same time, we started the second phase of activity.

In the second phase (2003–2005), in-depth case studies on VLS-PV systems were carried out, and practical proposals for demonstrative research projects on pilot photovoltaic (PV) systems suitable for selected regions were outlined, which should enable sustainable growth in VLS-PV systems in the future. Practical projects for large scale PV system were also discussed.

'It might be a dream, but …' has been a motive for continuing our beloved study of VLS-PV. Now we have become confident that this is no longer a dream.

This report deals with one of the promising recommendations for sustainable development in terms of solving world energy and environmental problems in the 21st century.

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1. Introduction

1.1 OBJECTIVES

The scope of this study is to examine and evaluate the potential of very large scale photovoltaic power generation (VLS-PV) systems, which have capacities ranging from several megawatts to gigawatts, and to develop practical project proposals for demonstrative research towards realizing VLS-PV systems in the future.

Our previous report, *Energy from the Desert: Feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems*, identified the key factors enabling the feasibility of VLS-PV systems and clarified the benefits of this system's applications for neighbouring regions, the potential contribution of system application to global environmental protection, and renewable energy utilization in the long term. It is apparent from the perspective of the global energy situation, global warming and other environmental issues that VLS-PV systems can:

- contribute substantially to global energy needs;
- become economically and technologically feasible;
- contribute considerably to the environment; and
- contribute considerably to socio-economic development.

This report will reveal virtual proposals of practical projects that are suitable for selected regions, and which enable sustainable growth of VLS-PV in the near future, and will propose practical projects for realizing VLS-PV systems in the future.

1.2 CONCEPT OF VERY LARGE SCALE PHOTOVOLTAIC POWER GENERATION (VLS-PV) SYSTEMS

Solar energy is low-density energy by nature. To utilize it on a large scale, a massive land area is necessary. One third of the land surface of the Earth is covered by very dry desert and high-level insolation (in-coming solar radiation), where there is a lot of available space. It is estimated that if a very small part of these areas, approximately 4 %, was used for installing photovoltaic (PV) systems, the resulting annual energy production would equal world energy consumption.

A rough estimation was made to examine desert potential under the assumption of a 50 % space factor for installing PV modules on the desert surface as the first evaluation. The total electricity production would be 2 081 x 10^3 TWh (= 7,491 x 10^{21} J), which means a level of almost 17 times as much as the world primary energy supply (0,433 x 10^{21} J in 2002). These are hypothetical values, ignoring the presence of loads near the deserts. Nevertheless, these values at least indicate the high potential of developing districts located in solar energy-rich regions as primary resources for energy production.

Figure E1.1 shows that the Gobi Desert area in western China and Mongolia can generate as much electricity as the current world's primary energy supply. Figure E1.2 depicts an image of a VLS-PV system in a desert area

Three approaches are under consideration to encourage the spread and use of PV systems:

1 Establish small scale PV systems independent of each other. There are two scales for such systems: installing stand-alone, several hundred watt-class PV systems for private dwellings, and installing 2 to 10 kW-class systems on the roofs of dwellings, as well as 10 to 100 kW-class systems on office buildings and schools. Both methods are already being used. The former is employed to furnish electric power in developing countries, which is known as the solar home system (SHS), and the latter is used in Western countries and Japan.

2 Establish 100 to 1 000 kW-class mid-scale PV systems on unused land on the outskirts of urban areas. The IEA Photovoltaic Power Systems Programme (PVPS)/Task 6 studied PV plants for this scale of power generation. Systems of this scale are in practical use in about a dozen sites in the world at

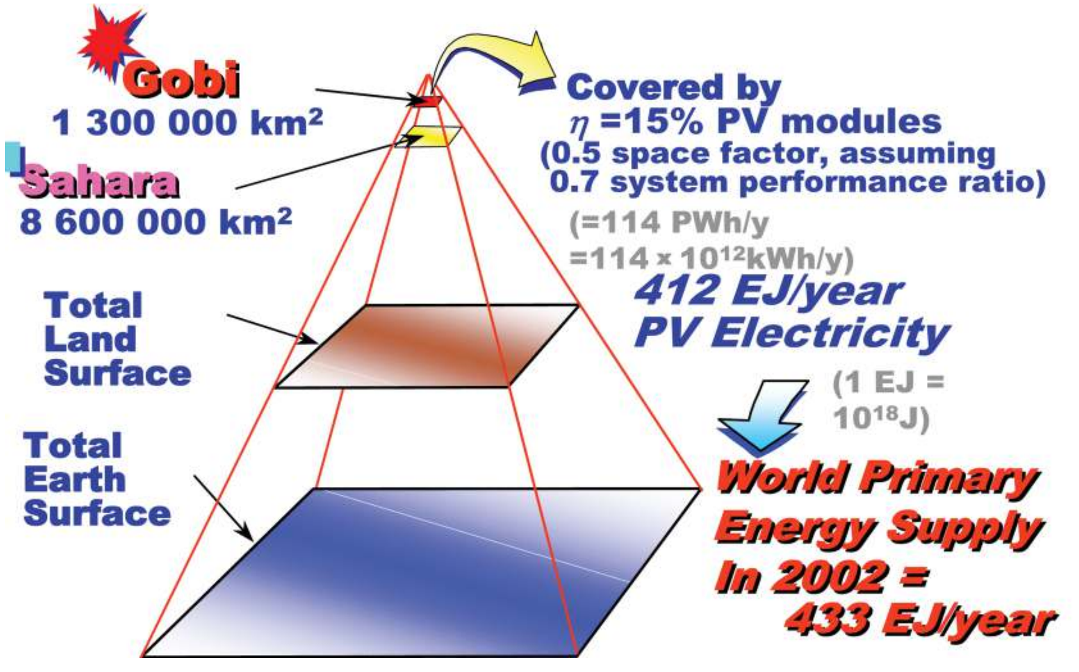

Figure E1.1 Solar pyramid

the moment; but their number is expected to increase rapidly in the early 21st century. This category can be extended up to multi-megawatt size.

3 Establish PV systems larger than 10 MW on vast barren, unused lands that enjoy extensive exposure to sunlight. In such areas, a total of even more than 1 GW of PV system aggregation can be easily realized. This approach enables installing a large number of PV systems quickly. When the cost of generated electric power is lowered sufficiently in the future, many more PV systems will be installed. This may lead to a drastically lower cost of electricity, creating a positive cycle between cost and consumption. In addition, this may become a feasible solution for future energy need and environmental problems across the globe, and ample discussion of this possibility is worthwhile.

The third category corresponds to VLS-PV. The definition of VLS-PV may be summarized as follows:

- The size of a VLS-PV system may range from 10 MW to 1 or several GW, consisting of one plant, or an aggregation of plural units distributed in the same district operating in harmony with each other.
- The amount of electricity generated by VLS-PV can be considered significant for people in the district, nation or region.
- VLS-PV systems can be classified according to the following concepts, based on their locations:
  – land based (arid to semi-arid deserts);
  – water based (lakes, coastal and international waters);
  – locality options: developing countries (lower-, middle- or higher-income countries; large or small countries) and Organisation for Economic Co-operation and Development (OECD) (countries).

Although the concept of VLS-PV includes water-based options, much discussion is required. It is not neglected here, but is viewed as a future possibility outside the major emphasis of this report.

The advantages of VLS-PV are summarized as follows:

- It is very easy to find land in or around deserts appropriate for large energy production with PV systems.
- Deserts and semi-arid lands are normally high insolation areas.
- The estimated potential of such areas can easily supply the estimated world energy needs by the middle of the 21st century.
- When large-capacity PV installations are constructed, step-by-step development is possible through utilizing the modularity of PV systems. According to regional energy needs, plant capacity can be increased gradually. It is an easier approach for developing areas.
- Even very large installations are quickly attainable in order to meet existing energy needs.
- Remarkable contributions to the global environment can be expected.
- When VLS-PV is introduced to some regions, other types of positive socio-economic impacts may be induced, such as technology transfer to regional PV

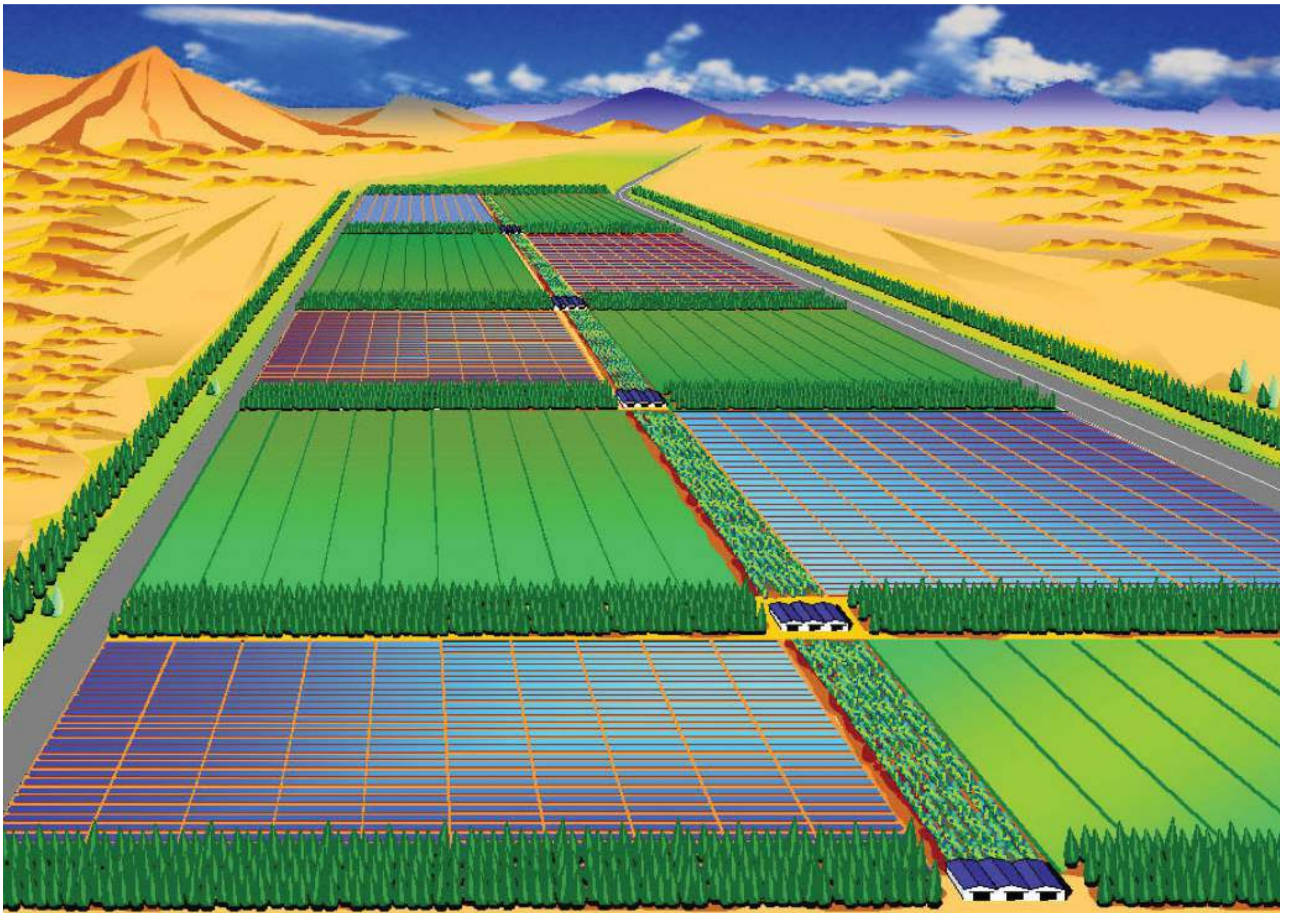

Figure E1.2 Image of a VLS-PV system in a desert area

industries, new employment and growth of the economy.

- The VLS-PV approach is expected to have a drastic influence on the chicken-and-egg cycle in the future PV market. If this does not happen, the goal of achieving VLS-PV may move a little further away.

VLS-PV systems are already feasible. A PV system with a capacity of 10 MW was installed and connected to the public grid in April 2006. Currently, a land-based VLS-PV concept is in its initial stage.

These advantages make VLS-PV a very attractive option and worthy of being discussed in the context of the 21st-century's global energy needs.

1.3 PRACTICAL APPROACHES TO REALIZE VLS-PV

Solar energy resources, PV technologies and renewable energy will help to realize important economic, environmental and social objectives in the 21st century, and will be a critical element in achieving sustainable development.

In order to advance the transition to a global energy system for sustainable development, it is very important to orient large and increasing investments towards renewable energy. If investments continue with business as usual, mostly in conventional energy, societies will be further locked into an energy system incompatible with sustainable development and one that further increases the risks of climate change.

In order to promote renewable energy and its diversity of challenges and resource opportunities (as well as the financial and market conditions among and within regions and countries) different approaches are required. Establishing policies for developing markets, expanding financing options and developing the capacity required are crucial in incorporating the goals of sustainable development within new policies.

As a result, increasing renewable energy use is a policy, as well as a technological, issue that applies directly to achieving VLS-PV.

VLS-PV is a major project that has not yet been experienced. Therefore, in order to realize VLS-PV, it is necessary to identify issues that should be solved and to discuss a practical development scenario.

When thinking about a practical project proposal for achieving VLS-PV, a common objective is to find the best sustainable solution. System capacity for suitable development is dependent upon each specific site with its own application needs and available infrastructure, especially access to long-distance power transmission, and human and financial resources.

From the technological viewpoint, it is important to start with the research and development (R&D) or pilot stage when considering overall desert development. In terms of commercial operation, the pilot or demonstration stage is more crucial.

The proposals developed in this report may motivate stakeholders to realize a VLS-PV project in the near future. Moreover, the practical project proposals, with their different viewpoints and directions, will provide essential knowledge for developing detailed instructions for implementing VLS-PV systems.

2. The Mediterranean region: Case study of very large scale photovoltaics

The economic conditions for VLS-PV systems in the Mediterranean region were examined. Originally focusing on the Sahara Desert-bordering countries of Morocco and Tunisia, Portugal and Spain were also included in order to compare the impact of recently approved PV feed-in tariffs with the 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 developer's perspective by determining PV electricity generation cost and potential revenues from electricity sales from 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.

As taken from experience with already realized MW systems, a stationary (non-tracking, flat-plate) large scale PV installation can, to date, be realized at around 4 010 EUR/kW. The value 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 to 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. For annual cost, 20 years' linear depreciation and 100 % loan financing at a 5 % interest rate serve as model parameters, which, of course, need to be adapted for concrete project proposals. No investment for land was considered here, and the estimated land rental cost is included in the 2 % annual operation and maintenance cost. The total annual cost per kW was assumed to be equal to 480 EUR/kW at all locations.

PV electricity generation costs in the analysed Mediterranean countries are between 30,2 and 47,6 EUR cents/kWh, as shown in Table E2.1. As expected, the generation cost for PV calculated is distinctly higher than the price level of conventional electricity drawn from the grid in all places. In this context, it is impor-

Figure E2.1 The Mediterranean regions within the case study

Table E2.1 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

Country	Site	Annual global irradiation (kWh/m²/year)	Annual energy yield (kWh/kW/year)	Generation cost for PV (EUR cents/kWh)	Conventional grid electricity price level (EUR cents/kWh)	Feed-in tariff rate (EUR cents/ kWh)
Morocco	Casablanca	1 772	1 337	35,9	~8–12	None
	Quarzazate	2 144	1 589	30,2		
Tunisia	Tunis	1 646	1 219	39,4	~2–5	None
	Gafsa	1 793	1 339	35,8		
Portugal	Porto	1 644	1 312	36,6	~12	~55 <5 kW
	Faro	1 807	1 360	35,3		~31–37 >5 kW
Spain	Oviedo	1 214	1 008	47,6	~9	41,44 <100 kW
	Almeria	1 787	1 372	35,0		21,62 >100 kW

tant to note that the assumed 100 % loan financing makes up a substantial proportion of the generation cost. Generation costs below 20 EUR cents/kWh result for almost all sites, without including the financing cost and the 7 % safety reduction in the annual energy yield. This confirms that PV generation costs are not too far 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 with increasing mass production.

Although the lowest generation cost of 30,2 EUR cents/kWh is reached in Quarzazate, this is not low enough to become attractive for a buyback scheme in Morocco, even considering that the general electricity price level is comparatively high there. Tunisia has a centralized electricity industry with a low price level, making the situation for PV even more difficult. Morocco and Tunisia have no specific legal framework to support PV electricity generation and no existing feed-in tariff. Therefore, the economic feasibility for VLS-PV is low in these Northern African countries if based on achieving income from electricity sales to consumers or on the grid alone – that is, not considering any investment subsidies.

Portugal and Spain also have much lower prices for conventional electricity 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 whether large systems can also be economically operated under special circumstances. Answering this question requires a closer look at the conditions in these Southern European countries.

In summary, we expect the best conditions for VLS-PV to develop in Spain on an intermediate time scale of 2 to 5 years, even though there are now several larger projects proposed in Portugal. Concrete realization of VLS-PV projects depends upon successful negotiation between project developers, PV and electricity industries, and politicians with regard to acceptance, sustainability and incentives in every single project.

Generally, VLS-PV as a centralized electricity source needs to compete with conventional electricity sources and other centralized renewable energy sources (RES), such as solar-thermal and wind energy, which are also proposed and implemented strongly in the studied region, in addition to decentralized small scale PV. Lower investment costs, 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.

3. The Middle East region: A top-down approach for introducing VLS-PV plants

A top-down approach to providing solar electricity to any given region must address the following five questions:

1 How much land area is available for the harvest of sunshine, and how much electricity could this resource provide?
2 How much electricity is required?
3 What kind of technology should be used, and how much of it would be needed for the task?
4 At what rate should the technology be introduced?
5 What monetary resources would be required and how could these resources be provided?

This study provides a set of answers for the principal electricity-consuming countries in the Middle East.

First, we studied the current electricity requirements and land availability of all countries in the region, with the specific aim of being able to provide some 80 % of their total electricity needs with solar energy within 36 years. For all of the major electricity-producing countries, it was concluded that land area considerations should present no obstacles to such aims.

Second, we studied *existing* concentrator photovoltaic (CPV) technology at the system component level, considering the expected costs involved in their mass production. These costs included the VLS-PV plants and the necessary mass production facilities for

Table E3.1 Land area, electricity requirements and solar electricity potential in the Middle East

Country	Land area (km^2)	Electricity production in 2002 (TWh)	Solar electricity potential by technology			
			Static, 30° tilt (TWh y^{-1})	One-axis tracking (TWh y^{-1})	Two-axis tracking (TWh y^{-1})	Concentrator photovoltaic (CPV) (TWh y^{-1})
Bahrain	665	6,9	43,5	46,3	22,1	32,4
Cyprus	9 240	3,6	604,3	643,1	306,8	450,0
Egypt	995 450	81,3	65 102,4	69 283,3	33 048,9	48 478,4
Iran	1 636 000	129,0	106 994,4	113 865,6	54 315,2	79 673,2
Iraq	432 162	34,0	28 263,4	30 078,5	14 347,8	21 046,3
Israel	20 330	42,7	1 329,6	1 415,0	675,0	990,1
Jordan	91 971	7,3	6 014,9	6 401,2	3 053,4	4 479,0
Kuwait	17 820	32,4	1 165,4	1 240,3	591,6	867,8
Lebanon	10 230	8,1	669,0	712,0	339,6	498,2
Oman	212 460	9,8	13 894,9	14 787,2	7 053,7	10 346,8
Qatar	11 437	9,7	748,0	796,0	379,7	557,0
Saudi Arabia	1 960 582	138,2	128 222,1	136 456,5	65 091,3	95 480,3
Syria	184 050	26,1	12 036,9	12 809,9	6 110,5	8 963,2
Turkey	770 760	123,3	50 407,7	53 644,9	25 589,2	37 536,0
UAE	82 880	39,3	5 420,4	5 768,4	2 751,6	4 036,3
Yemen	527 970	3,0	34 529,2	36 746,7	17 528,6	25 712,1

Table E3.2 Expected economic benefits to Israel of VLS-PV plant introduction during the first 36 years

Interest rate	3 % /year
Yearly added solar power	1,5 GW
Yearly added six-hour storage power	0,5 GW
Credit line capacity required for the entire project	9 781 MUSD
Interest paid	3 397 MUSD
Loan repaid after	21 years
Total solar power installed	46,5 GW
Total storage power installed	15,5 GW
Electricity price after five years, when solar electricity sales start	9 US cents/kWh
Electricity price after 22 years, when all debts are paid off	5,5 US cents/kWh
Land area required for installation	558 km^2
Fraction of total national land area	2,7 %
Yearly manpower requirements for solar production	4 500 jobs
Yearly manpower requirements for solar operation	11 625 jobs
Yearly manpower requirements for storage production	1 500 jobs
Yearly manpower requirements for storage operation	3 875 jobs
Headquarters and engineering	1 395 jobs
Total number of jobs after 36 years	22 895 jobs

their manufacture. It was concluded that, in Israel, VLS-PV plants would cost no more than 850 USD/kW, and that production facilities, capable of an annual throughput of 1,5 GW collectors and 0,5 GW storage, would cost approximately 1 170 MUSD.

Third, we studied the kind of investment that would be necessary to create a production facility in four years, the first VLS-PV during the fifth year, and one successive new VLS-PV plant every year thereafter. Assuming an open credit line being made available by the government (or investors) at a 3 % real rate of interest, it was concluded that, in the Israeli case:

- the credit line would reach its maximum value in the 13th year;
- the maximum required credit would be equal to the cost of approximately ten fossil-fuelled plants;
- the credit-line *plus interest* would be fully paid off by electricity revenues after 21 years;
- by that time, revenues would be sufficiently high to enable both the continued annual production of VLS-PV plants with no further investment, *and* the decommissioning and replacement of old plants after 30 years of service.

It is important to point out that after the initial investment has been paid off, the price of electricity no longer depends upon any factors related to its generation. It becomes a purely arbitrary figure that can be fixed at any desired level. For our examples, we arbitrarily fixed it at 5,5 US cents/kWh. However, if it is deemed desirable to continue installing VLS-PV plants at the rate of one per year, then the price of electricity can be lowered to a figure enabling the annual net revenue from sales to precisely cover the cost of one new VLS-PV plant. Similarly, if it becomes necessary to replace old plants after 30 years of service, it is sufficient to fix the electricity price during the 29th year at a level covering the cost of constructing two new VLS-PV plants the following year, etc. Simple arithmetic shows that in both of these examples, the required electricity price will be less than the 9 US cents/kWh that we have adopted for our calculations.

In the fourth part of this study, we repeated the Israeli calculations for the other major electricity producers in the region, making certain simplifying assumptions that were specified in each case. Given uncertainties surrounding local electricity prices, labour costs, and production/consumption growth rates, our results for these countries should be regarded as indicative rather than definitive.

A number of far-reaching conclusions can be drawn from the results of this study. First, VLS-PV plants can yield electricity at costs fully competitive with fossil fuel. Second, one may think in terms of typically 80 % of a country's entire electricity requirements coming from solar energy within a period of 30 to 40 years. Third, VLS-PV plants turn out to be *triply renewable*. In addition to the normal sense in which solar is deemed to be a renewable energy, the revenues from this top-down approach would be sufficient to completely finance the continued annual construction of VLS-PV plants *and* the replacement of 30-year-old VLS-PV plants with new ones *without* the need for any further investment.

In conclusion, the present top-down study strongly indicates that VLS-PV could directly compete with fossil fuels as the principal source of electricity for any country in the Middle East, and an investment scheme has been suggested for implementation.

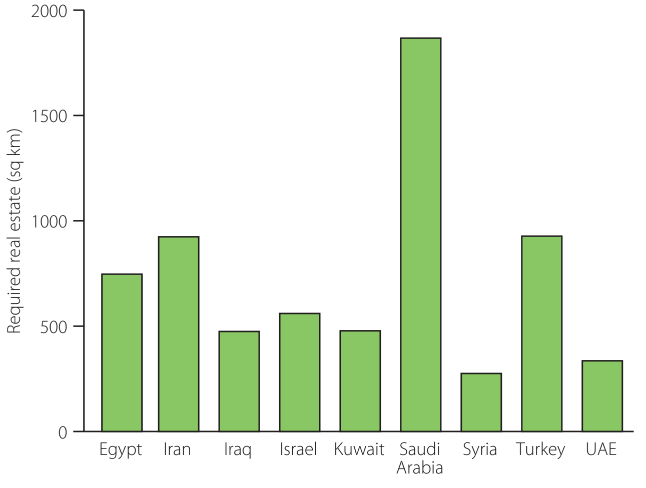

Figure E3.1 Land requirement for providing 80 % of each country's electrical requirements

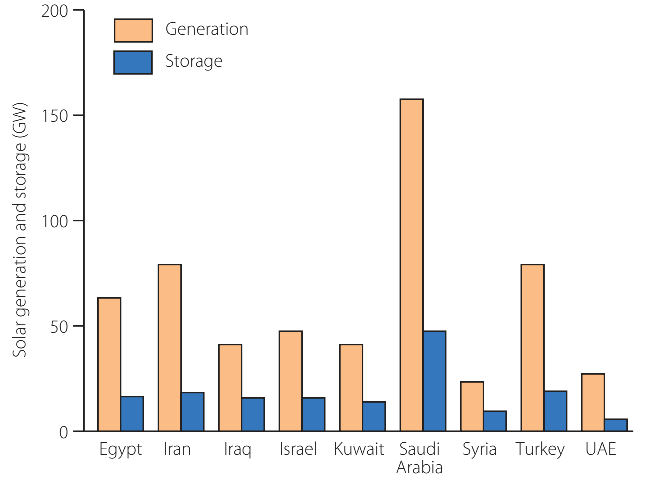

Figure E3.2 Total solar generating and storage capacity at the end of 36 years

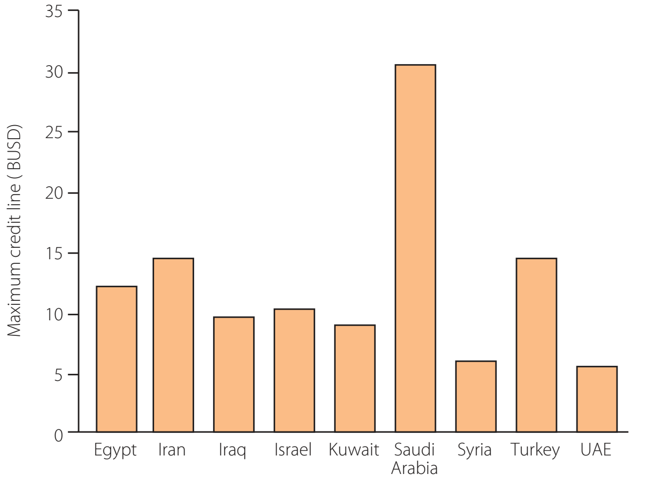

Figure E3.3 Maximum credit line required at 3 % real interest

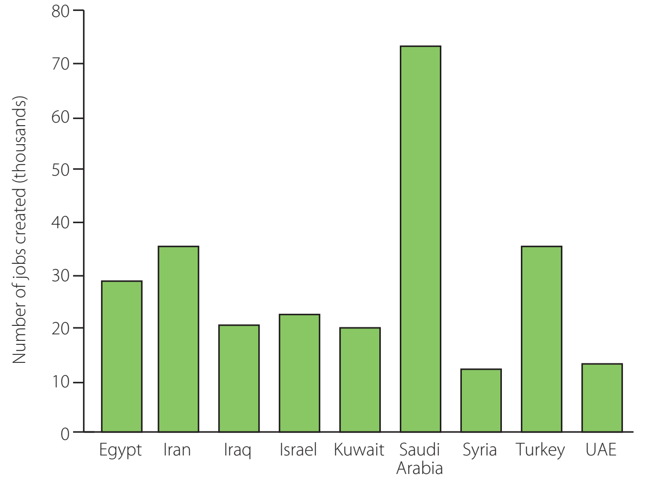

Figure E3.4 Total number of jobs created

II

4. The Asian region: Project proposals of VLS-PV on the Gobi Desert

4.1 DEMONSTRATIVE RESEARCH PROJECT FOR VLS-PV IN THE GOBI DESERT OF MONGOLIA

Mongolia has the vast Gobi Desert area in the southern and south-east parts. There are two types of electricity users in Mongolia, nomadic families and users of the electricity network. While electrification using PV for nomadic families has occurred, an existing electricity network supports Mongolian economic activity.

The electricity networks (transmission lines) have been constructed only in specific regions, such as those centring on Ulaanbaatar, the capital of Mongolia. The transmission lines have basically been constructed along a railway connecting Atlanbulug with Zumiin Uud through Ulaanbaatar – the borders in the north and south-east. The railway is playing a very important role in Mongolian economic activity. Therefore, these areas along the railway and transmission lines are expected to further develop in the future. However, electricity for the areas is generated by coal at Ulaanbaatar, worsening the atmospheric environment around Ulaanbaatar. As a result, installing large scale carbon-free renewable electricity such as the VLS-PV system may contribute both to protecting against air pollution and supporting regional development.

The VLS-PV scheme is a project that has not been carried out before. In order to achieve VLS-PV, a sustainable development scheme will be required. There are many technical and non-technical aspects that should be considered. Therefore, we will propose a demonstrative research project in the areas along the railway and discuss a future possibility for VLS-PV in the Gobi Desert, in Mongolia. The proposed project will include three phases as follows (see Table E4.1 and Figure E4.1). The potential sites in the Gobi Desert area along the railway were identified using long-term

Table E4.1 Proposed projects for VLS-PV development in Mongolia

	Location	Capacity	Demands
First stage: R&D/pilot phase	Sainshand	1 MW	Households and public welfare (significant level compared to the peak demand and electricity usage in Sainshand city)
Second stage: demonstration phase	Four sites along the railway: 1 Sainshand 2 Zumiin Uud 3 Choir 4 Bor-Undur	10 MW/site (total: 40 MW)	Industry (surpasses the peak demand and almost equivalent to electricity usage around these locations)
Third stage: deployment phase	Five sites along the railway: 1 Sainshand 2 Zumiin Uud 3 Choir 4 Bor-Undur 5 Mandalgobi One site between Oyu–Tolgoi and Tsagaansuvrage	100 MW/site (sub-total: 500 MW) and 500 MW (total: 1 GW)	Power supply (almost double the peak demand and significant level compared to electricity usage in Mongolia)

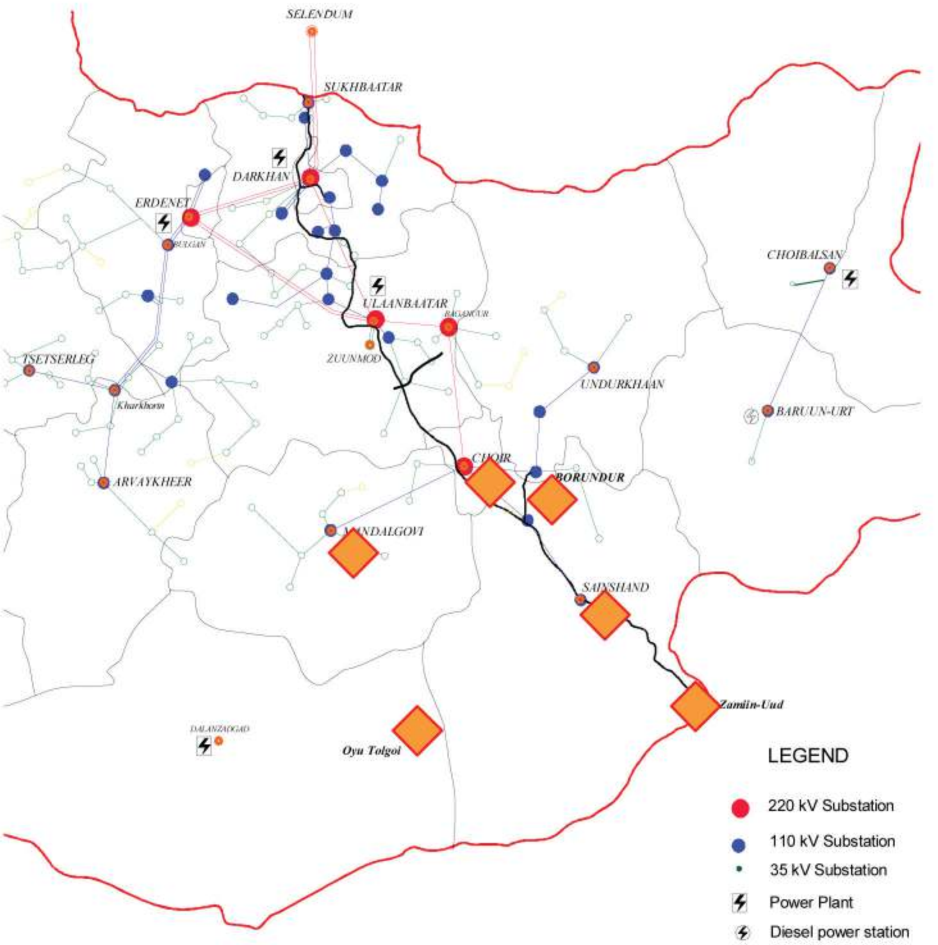

Figure E4.1 Location of VLS-PV system

meteorological observation data conducted over the last 30 years. Grid access, as well as favourable market, economic, climatic and weather conditions, prevail in southern Mongolia – hence the choice of the candidate sites for the development of the VLS-PV system in the Gobi.

It is expected that the first phase will take four to five years. The project site will be Sainshand and the capacity of the PV system will be 1 MW. The assumed demands are households and public welfare needs in the region. The project has benefits beyond electricity. Apart from the creation of jobs and employment, the tourism industry will also benefit. In the second phase, 10 MW PV systems will be installed in Sainshand, Zumiin Uud, Choir and Bor-Undur, where they are located along the railway lines. These sites are important cities and the scale is classified as medium-large scale in Mongolia. The total capacity of PV systems installed will reach 40 MW, and the demands assumed are to supply industry sectors, such as mining, located in the sites' neighbourhoods. The project will then be shifted to the third phase, which is the deployment phase. In this stage, 10 MW PV systems will be enhanced to 100 MW VLS-PV systems, and one new 100 MW system will be constructed in Mandalgobi. Besides these 100 MW VLS-PV systems, another 500 MW VLS-PV system will be constructed in between Oyu Tolgoi and Tsagaansuvraga, which are located in Umnugobi and Dornogobi provinces.

Renewable energy development is a promising way for social development and is one of the most important policies in Mongolia. Two documents, the Law for the Promotion of Renewable Energy and a proposal for a Utilization and National Renewable Energy Programme, have recently been drafted and submitted to the government for the approval of parliament. Final approval of these two documents will positively affect taxes and other funding that will assist in the development of VLS-PV systems.

4.2 FEASIBILITY STUDY ON 8 MW LARGE SCALE PV SYSTEM IN DUNHUANG, CHINA

Energy shortages and environmental pollution have become the bottleneck of social and economic development in China. Improving the current structure of energy supply and promoting utilization of renewable energy are effective solutions for these problems. The photovoltaic power generation system involves clean energy without greenhouse gas emissions. In China,

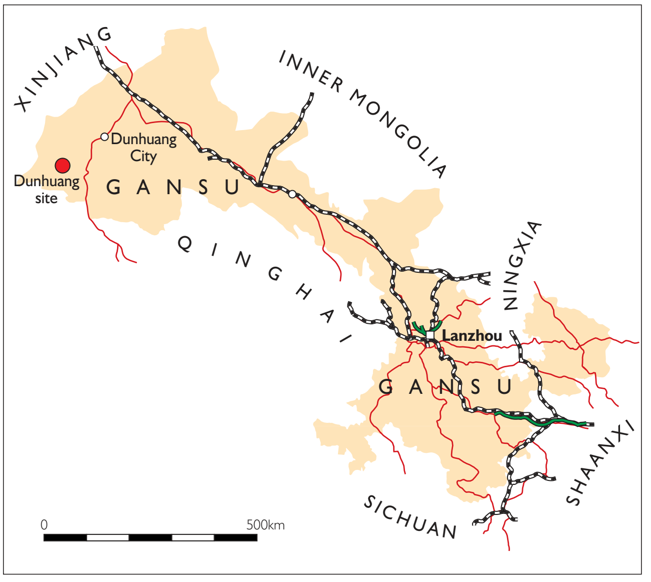

Figure E4.2 Location of Dunhuang, Gansu

there are huge lands in the Gobi Desert and elsewhere that provide the possibility of large scale PV systems on very large scale applications. Only when PV is used for large scale applications can costs be reduced to the level of those associated with traditional electric power.

The Gobi area in Gansu is about 18 000 km². This area can be used to build 500 GW VLS-PV, which is more than the whole power capacity in China today. The targeted place for 8 MW large scale photovoltaic power generation (LS-PV) in the Gobi Desert is at Qiliying, 13 km from Dunhuang city. The latitude is N-40° 39’, with a longitude of E-94° 31’ and an elevation of 1 200 m. It is only 5 km from Qiliying to the 6 000 kVA/35 kV transformer station, so it will be not cost that much to build a high voltage transmission line.

The 8 MW PV system will be divided into eight sub-stations of 1 MW each. Each 1 MW sub-station will feed the generated electricity to a high voltage grid (35 000 V) through a 1 000 kVA transformer. Each 1 MW sub-station will be divided into five channels with

Table E4.2 Capital investment for 8 MW LS-PV system (1 yuan = approximately 0.12 USD)

	Investment (million yuan)	Share (percentage)
Equipment	277,02	85,91
PV module	236,8	73,43
Inverter	34,2	10,61
Transformer	3,52	1,09
Test and monitoring	2,5	0,78
Civil construction	15,56	4,83
Transportation and installation	7,35	2,34
Feasibility study and preliminary investment	7,0	2,17
Miscellaneous	15,36	4,65
Total	322,47	100

200 kW each, as shown in Figure E4.3. Each 200 kW PV channel will be equipped with a grid-connected inverter to convert the DC power from the PV into three-phase AC power for the primary of the 1 000 kVA transformer.

Each 1 MW sub-station and each 200 kW channel will be independent. Such design offers the advantages of being easier for troubleshooting and maintenance, being flexible for potential investors, and allowing various types of PV systems to be installed and compared.

The system efficiency is assumed to be 0,77. Using the efficiency and the annual in-plain irradiation facing south with a 40° tilted angle, the annual output is calculated to be 13 761 MWh/year.

Total capital investment is 322,47 million yuan (approximately 38,7 MUSD), and 86 % of total investment is for PV system equipment, such as PV modules, inverters and transformers, as shown in Table E4.2. However, it is expected that 96,74 million yuan (approximately 11,6 MUSD; 30 % of the total capital) will be a grant provided by the central government of China, and the real required capital will be 225,73 million yuan (approximately 27,1 MUSD).

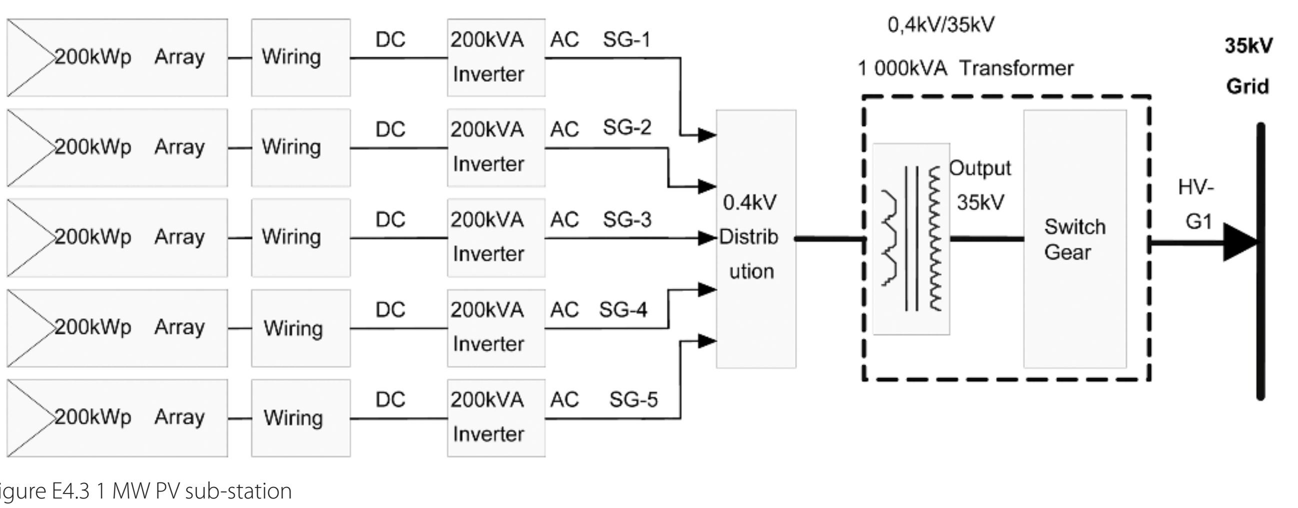

Figure E4.3 1 MW PV sub-station

The Gansu grid company will guarantee 1,683 yuan/kWh (0,202 USD/kWh) as the feed-in tariff and the annual income for the PV system will be 23,16 million yuan (approximately 2,78 MUSD): 13,761 MWh/year x 1,683 yuan/kWh. The tariff purchased by the grid company will be added on to all the electricity consumed in Gansu Province and the electricity consumption in Gansu Province was 340×10^8 kWh in 2002. Therefore, the additional tariff will be 0,006 8 yuan/kWh (0,000 82 USD/kWh): 23,16 million yuan/340 x 108 kWh. For a family consuming 2 kWh/day, the annual consumption will be 730 kWh, and they will only need to pay 5 yuan/year (0,6 USD/kWh) in addition.

The proposed 8 MW LS-PV plant in Dunhuang city is considered the first pilot project in China with the Great Desert Solar PV Programme proposed by the World Wide Fund for Nature (WWF) and an expert group. The development of further large scale PV systems in other regions is also being discussed. It has been proposed that 30 GW of solar PV power generation capacity could be developed by 2020 if government incentive policies are developed and are in place. This could enable China to become a leading country in solar power development in the world.

5. The Oceania region: Realizing a VLS-PV power generation system at Perenjori

Perenjori is a small township approximately 350 km north-east of Perth in the wheat belt of Western Australia and situated at E-116,2° longitude and S-29° latitude. The required land to set up a VLS-PV power generation project can be obtained at a reasonably low price or leased for 30 to 50 years from local farmers. The land is flat and suitable for mounting the structure or installing solar PV power generation projects.

Several issues arise in terms of achieving a very large scale solar photovoltaic power generation project at Perenjori. Although the Great Sandy Desert receives more solar radiation than Perenjori, the overall economy of setting up the project and generation costs will be less at Perenjori due to its location to enough loads and the availability of the local grid.

At present, the load is almost negligible; but there is a strong interest in promoting the mining industry in the region provided that sufficient and good quality power is available for mining activities. A number of mining companies have also shown interest in setting up their mining operations in the Perenjori regions, and there will be a load of the order of 1 GW over the next 10 to 15 years.

The size of a VLS-PV system may range from 10 MW (pilot) to 1 or several GW (commercial), consisting of one plant or an aggregation of a number of units, distributed in the same region and operating in harmony with one another. Figure E5.2 gives a rough idea how a VLS-PV project can be realized in a circular distance of 100 km of Perenjori over the next 15 years, aggregating to a capacity of over 1 GW.

What will be feasible is to install several stand-alone solar PV systems as per the load requirement of each individual mining operation in the region. Then, when three to four projects have been set up in the region, they can be interconnected by creating a small local grid.

A project for installing a 10 MW pilot power generation system will be proposed as the first step for a VLS-PV system at Perenjori. The estimated project cost of a 10 MW PV power generation project at Perenjori will be of the order of 60 MAUD (approximately 45,6 MUSD), with the following cost breakdowns as shown in Table E5.1. Almost 70 % of the project cost comprises PV modules only.

The generation cost of the pilot project of 10 MW, after availing of a 50 % subsidy from the government, will be approximately 14 AUD cents/kWh (0,11 USD/kWh) under the Mandatory Renewable Energy

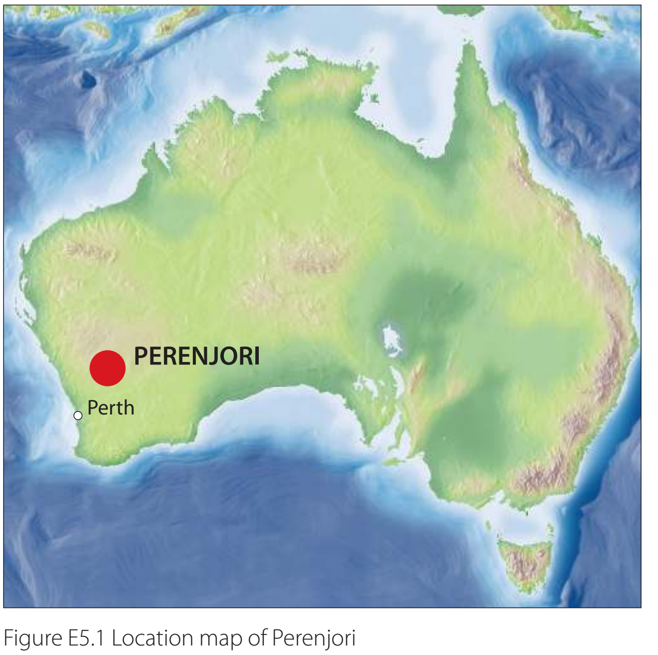

Figure E5.1 Location map of Perenjori

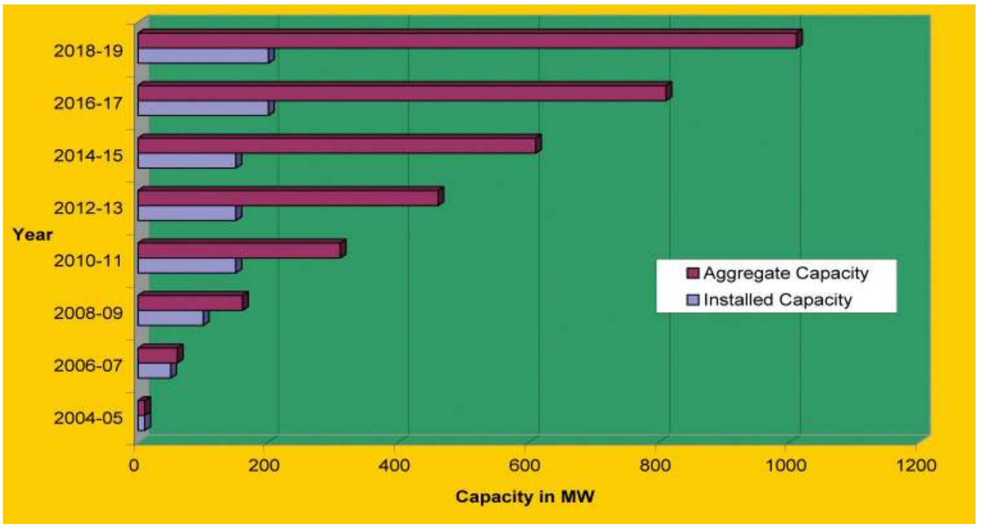

Figure E5.2 Possible scenario to realize VLS-PV at Perenjori

Table E5.1 Estimated project cost for 10 MW PV power generating system (1 AUD= approximately 0,76 USD)

Components	Unit cost	Total cost (AUD)
PV modules	4,4 AUD/Watt	44 000 000
Mounting structure with single-axis tracking	10 % of modules	4 400 000
Inverter(s)	125 000	5 000 000
Transformers and cabling	4 % of modules	1 760 000
Installation and commissioning	7 % of modules	3 080 000
Land	Lump sum	500 000
Miscellaneous, including transportation to site	Lump sum	1 260 000
Total		60 000 000

Target (MRET) of the federal government of Australia, which is very much comparable with the cost of power generation from a diesel power project. At a price of 36 AUD cents/litre (0,27 USD/litre), diesel fuel is available to the mining companies in Perenjori; the cost of power generation from diesel power projects comes to about 12 AUD cents/kWh (0,09 USD/kWh). Therefore, the mining companies would be interested in purchasing power from the proposed pilot project of 10 MW, and the installation of a diesel-based power project as a backup has been suggested.

Prior to setting up the pilot project, arrangements must be made by the project developers to sell the power to the mining operators. The power purchase agreements (PPAs) should be signed for the whole lifetime of the project. The Shire of Perenjori and Mid West Development Commission would play an important role in negotiating the terms and conditions of the PPAs, and their assistance would be necessary to attract project developers for this project, as well as for other projects to be installed later on.

6. Desert region community development

In this report, the following issues are researched and investigated:

- the possibility of utilizing VLS-PV in desert areas;
- a sustainable scenario for installing VLS-PV systems;
- modelling of sustainable society with solar photovoltaic generation and greening in desert;
- specific problems of VLS-PV systems in desert areas;
- the use of solar PV generation with regard to elemental technology/systems for sustainable agriculture;
- sustainable agriculture utilizing other regional renewable energy options.

Figure E6.1 depicts a desert community development that aims to achieve an ideal community. Agriculture and tree planting can be facilitated with plentiful renewable energy, and electricity is used by neighbouring cities. The community must have the potential to appeal to other people through the following themes:

- *Sustainable PV stations: sustainable energy production*. Here, the VLS-PV system is the main feature, using sunshine and wind, along with wind power and other renewable energy. At night, electricity comes from battery storage instead of from the grid.
- *Sustainable farming*. Utilizing soil and water conservation technology, we will conserve and rehabilitate the landscape. This may not be difficult to achieve with PV support because the main reason for desertification is human activity relating to energy needs. Conservation and rehabilitation will take plant and animal ecology into account.
- *Sustainable community*. Statistical and scenario analyses are used to develop an ideal community. In order to sustain regional society, in addition to the facilities and technology needed, education and training are provided.
- *Remote sensing*. Remote sensing technology has the potential to find suitable places in which to implement VLS-PV and wind power systems. It can generate data on soil and water required for sustainable agricultural production.
- *Desalination*. Renewable energy power can operate a desalination system, which will supply drinking and irrigation water.
- *Effect of PV station on forest, grassland and farmland*. Proper operation of a water pump and desalination system can provide good quality water and remove salt from the groundwater. This can enhance crop yields and reduce the use of fuelwood. Renewable energy-driven greenhouse agriculture can produce high quality and high product yields.
- *Effect of PV station on the local community*. PV stations can go beyond supplying electricity to local communities to producing more employment in the region. This would also increase local incomes through selling electricity. PV structures can also protect houses from strong winds.
- *Effect of forest, grassland and farmland benefits on local community*. Agriculture can supply food to communities and leads to wind protection effects and employment. People in local communities can obtain more income by selling products.
- *Technology*. Implementing a subsurface drainage system may save groundwater quality, and desalination equipment protects soil from damage due to salinization.

In sum, this virtual community is ideal, but is based on the existence of a good groundwater supply and a power grid near the community.

Nevertheless, agriculture in the desert is difficult even though arid and semi-arid regions are better suited for solar irradiation. While there is occasionally more than enough sunshine, it diminishes easily. Rain-fed

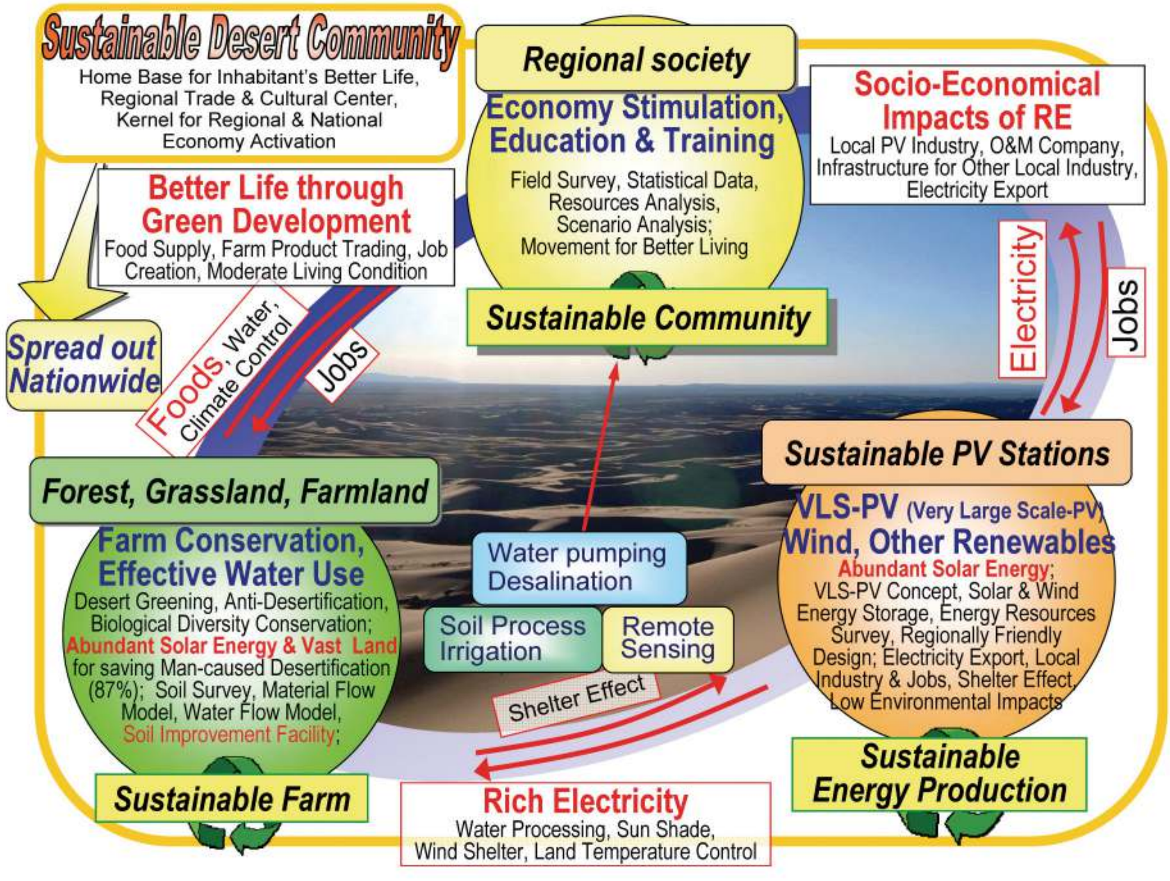

Figure E6.1 Framework of desert community development and research topic

agriculture is limited by low precipitation. Although irrigated agriculture has been maintained in some areas, it often causes soil degradation, largely through improper water distribution, and inadequate irrigation practice and quality.

Figuring out the appropriate amount and quality of irrigation water, including groundwater behaviour, is important. Controlling water quality for irrigation, as well as controlling the amount of irrigation using pumps, is also necessary. Although this is easy to achieve in developed countries, arid and semi-arid regions still have problems due to the cost of improving water distribution through pumping. In this report we suggest realistic proposals for using PV systems to drive the energy necessary to control the quality and quantity of irrigation water.

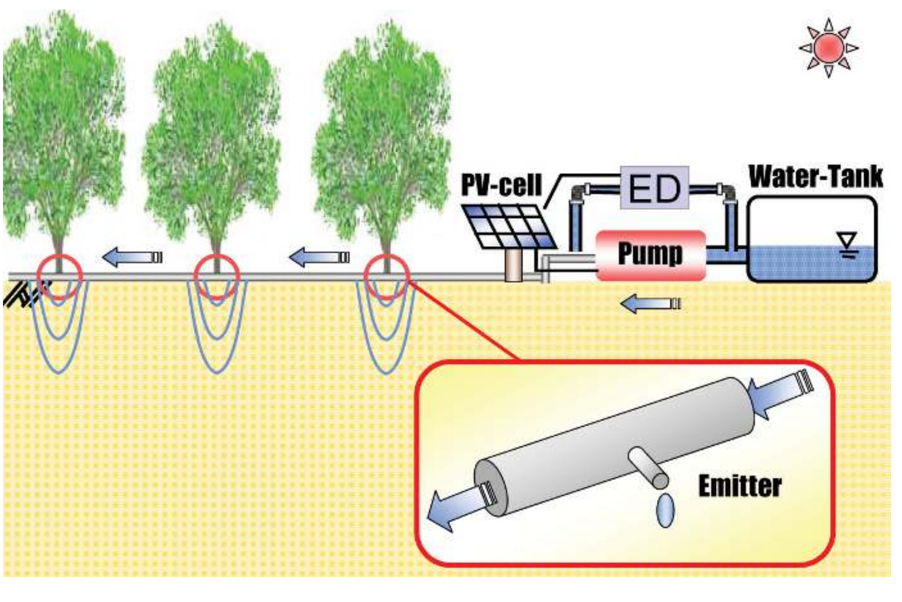

Figure E6.2 Desalinized drip irrigation system

Implementing a PV system in an arid or semi-arid region also has the potential of introducing electricity as an alternative energy source for wood used as fuel. This is significant for forest conservation purposes. PV systems also protect water recourses by reusing desalinized groundwater. In the past, water was desalinized through distillation, using solar heat; but this required a huge area to desalinize salty water because the distillation rate of solar heat is quite low. Considerable amounts of low saline water are available when we use a PV system to generate electricity to drive a desalinization system, such as reverse osmosis (RO) or electro-dialysis (ED). Figure E6.2 depicts a drip irrigation system with a desalination system that introduced PV as an energy resource.

In order to achieve the sustainable development of desert region communities, it is important to consider technology innovation and to protect the community and its environment. Maintaining community food production is a further important issue.

Agriculture is inevitable for food supply and lack of appropriate knowledge of agriculture often leads to soil degradation and wasting water, thus worsening desertification. In this report, we propose different types of irrigation systems using PV to save soil and water in arid and semi-arid areas. In addition, it is advisable to provide an impact assessment of the climactic results of introducing VLS-PV into a desert region since a PV system will affect quality of life and food production in arid and semi-arid regions.

7. Conclusions and recommendations

7.1 GENERAL CONCLUSIONS

The scope of this report is to examine and evaluate the potential of VLS-PV systems, which have a capacity ranging from several megawatts to gigawatts, and to develop practical project proposals for demonstrative research towards realizing VLS-PV systems in the future.

It is apparent that VLS-PV systems can contribute substantially to global energy needs, are economically and technologically feasible, and can contribute considerably to environmental and socio-economic development. With the objective of ensuring these contributions and outlining the actions necessary for realizing VLS-PV in the future, this report has developed concrete project proposals.

When thinking about a practical project proposal for achieving VLS-PV, a common objective is to find the best sustainable solution. System capacity for suitable development is dependent upon each specific site with its own application needs and available infrastructure, especially access to long-distance power transmission, and human and financial resources

Although the impacts expected by VLS-PV will differ in each region, depending upon the local situation, and upon any options and concerns, there are several conclusions in common.

Background

- World energy demands will increase as world energy supplies diminish due to trends in world population and economic growth in the 21st century. In order to save conventional energy supplies while supporting growth in economic activity, especially within developing countries, new energy resources and related technologies must be developed.
- The potential amount of world solar energy that can be harnessed is sufficient for global population needs during the 21st century. It has been forecast that photovoltaic technology shows promise as a major energy resource for the future.
- Much potential exists in the world's desert areas. If appropriate approaches are found, they will provide solutions to the energy problem of those countries that are surrounded by deserts.

Technical aspects

- It has already been proven that various types of PV systems can be applied for VLS-PV. PV technologies are now considered to have reached the necessary performance and reliability levels for examining the feasibility of VLS-PV.
- To clarify technical reliability and sustainability, a step-by-step approach will be required to achieve GW scale. This approach is also necessary for the sustainable funding scheme.
- Technology innovation will make VLS-PV in desert areas economically feasible in the near future.
- Global energy systems, such as hydrogen production and high temperature super-conducting technology, as well as the higher conversion efficiency of PV cells and modules, will make VLS-PV projects more attractive.

Economic aspects

- The economic boundary conditions for VLS-PV are still unsatisfactory at current PV system prices without supporting schemes, so that lowering the investment barrier, additional support, and/or higher feed-in tariffs for large systems are still required.

- VLS-PV using flat-plate PV modules or CPV modules produced using mass production technologies are expected to be an economically feasible option for installing large central solar electric generation plants in or adjacent to desert areas in the future as a replacement for central fossil-fuelled generating plants.
- Intelligent financing schemes such as higher feed-in-tariffs in developed countries, and international collaboration schemes for promoting large scale PV or renewable energy in developing countries will make VLS-PV economically feasible.
- For the sustainable development of VLS-PV, initial financial support programmes should be sufficient to completely finance the continued annual construction of VLS-PV plants and the replacement of old VLS-PV plants by new ones, eliminating the need for any further investment after the initial financing is repaid.

Social aspects

- Renewable energy development is a promising way of ensuring social development and is one of the most important policies in developing countries.
- VLS-PV projects can provide a pathway to setting up PV industry in the region, while the existence of a traditional and strong PV industry will provide an additional factor contributing to an economic and political environment that favours the application of PV.
- International collaboration and institutional and organizational support schemes will lead to the success of VLS-PV projects in developing countries.
- Developing VLS-PV will become an internationally attractive project, making the region and/or country a leading country/region in the world.
- When we think about developing VLS-PV, we should be careful to consider the social sustainability of the region – for instance, in terms of complementing agricultural practices and desert community development.

Environmental aspects

- In light of global environmental problems, there is a practical necessity for renewable energy, and it is expected to be an important option for the mid 21st century.
- A proper green area coupled with VLS-PV would positively impact upon convective rainfall, rather than produce a negative impact due to a rise in sensible and surface heat flux. It would also decrease dust storms, as well as reduce and mitigate CO_2 emissions.

7.2 REQUIREMENTS FOR A PROJECT DEVELOPMENT

VLS-PV is anticipated to be a very globally friendly energy technology, contributing to the social and economic development of the region in an environmentally sound manner.

However, concrete realization of VLS-PV projects depends upon successful negotiation between project developers and PV and electricity industries, and must have the support of government regarding its acceptance, sustainability and economic incentives.

In order to make negotiations successful and to establish a VLS-PV project, approaches required for project development are as follows:

- Clarify critical success factors on both technical and non-technical aspects.
- Demonstrate technical capability and extendibility.
- Demonstrate economic and financial aspects.
- Show local, regional, and global environmental and socio-economic effects.
- Assess, analyse and allocate project risks such as political and commercial risks.
- Find available institutional and organizational schemes.
- Provide training programmes for installation, operation and maintenance.
- Develop instructions or a guideline for these approaches.

7.3 RECOMMENDATIONS

There are strong indications that VLS-PV could directly compete with fossil fuel and with existing technology as the principal source of electricity for any country that has desert areas. This could be accomplished by finding an investment scheme and by getting institutional and organizational support for its implementation.

In addition, the technology innovations regarding PV and global energy systems in the future will make VLS-PV economically and technologically attractive and feasible.

The following recommendations are outlined to support the sustainable growth of VLS-PV in the near future:

- Discuss and evaluate future technical options for VLS-PV, including electricity network, storage and grid management issues, as well as global renewable energy systems.
- Analyse local, regional and global environmental and socio-economic effects induced by VLS-PV systems from the viewpoint of the whole life cycle.
- Clarify critical success factors for VLS-PV projects, on both technical and non-technical aspects, based on experts' experiences in the field of PV and large

scale renewable technology, including industry, project developers, investors and policy-makers.

- Develop available financial, institutional and organizational scenarios, and general instruction for practical project proposals to realize VLS-PV systems.
- The International Energy Agency (IEA) PVPS community will continue Task 8 activities. Experts from the fields of grid planning and operation, desert environments, agriculture, finance and investment should be involved.
- The IEA PVPS community welcomes non-member countries to discuss the possibility of international collaboration in IEA PVPS activities.