A NEW KNOWLEDGE HOW TO MAKE THE VERY LARGE SCALE PVS HAPPEN ON THE DESERT!

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ABSTRACT: In 2003, IEA PVPS Task8 published their report titled "Energy from the Desert" concerning Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems on deserts. Through their 5 year really international, collaborative works, the book showed that VLS-PV, ranging from several mega watts to giga watts, is not a simple dream story but becomes realistic in near future. For the past 3 years since then, specialists in the task have studied and proposed more detailed, practical, demonstrative R&D approaches toward the realization of VLS-PV in different regions in the world deserts: e.g., the Mediterranean region, the Middle East, Asia and Oceania. These new works will be published soon as the Second Phase Report of Task VIII titled "Energy from the Desert - Practical Proposals for Very Large Scale Photovoltaic Systems" and their essences are to be released at the conference right before the publication.
Keywords: Large Grid-connected PV system, Sustainable, Desert, VLS-PV

1 INTRODUCTION

In 2003, IEA PVPS Task8 published their report titled "Energy from the Desert" concerning Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems on deserts. Through their 5 year real, collaborative works, the book showed that VLS-PV, ranging from several megawatts to gig watts, is not a simple dream story but becomes realistic in near future. For the past 3 years since then, specialists in the task have studied and proposed more detailed, practical, demonstrative R&D approaches toward the realization of VLS-PV in different regions in the world deserts: e.g., the Mediterranean region, the Middle East, Asia and Oceania. These new works will be published soon as the Second Phase Report of Task VIII and their essences are to be released at the conference right before the publication.

A series of these international works have been activated as the Second Phase of IEA PVPS Task VIII among 10 countries and 2 observer countries: Japan (OA), Canada, Germany, Israel, Italy, Korea, the Netherlands, Spain, U.S.A., Australia, Mongolia (obs.) and China (obs.). It is well known that the team of this Task has been studying on a wide range of scope by really mutual-collaborative approaches as a whole.

The major studies have been made as follows:

(1) The Mediterranean region studies include 8 cases in 4 countries, i.e., Morocco, Tunisia, Portugal and Spain.

(2) In the of Middle East, 4 types of technologies, which are fixed tilt array, 1-axis tracking, 2-axis tracking and concentrated PV, have been examined for 17 countries: Bahrain, Cyprus, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, UAE and Yemen.

(3) In Asian region, the Gobi desert in both Mongolian and Chinese territories, LCA models have been formulated for cost, energy payback and CO_2 emission. 2 type of arrays, fixed and one-axis, are designed assuming m-Si, a-Si, CdTe and CIS modules. Power transmission cost has also been estimated for the distance of 100 km.

(4) More detailed study was made for 8 MW pilot stage at Dunhuang in the Gansu Gobi of China. Gansu Gobi can accept nearly 500 GW VLS-PV.

(5) Step-by-step sustainable approach was taken to evaluate the possibility of VLS-PV at Perenjori in western Australian desert. Up to around 2020, 1 GW PV aggregate will be realised gradually from multi-megawatt scale to 200 MW annual installations approximately.

(6) Another consideration of socio-economic model has been given for villages around the Gobi. It includes various kinds of flows into and out of villages, e.g., energy delivery, physical distribution and money to make the whole social system sustainable.

(7) Remote sensing technology by utilizing satellite images has clarified actually utilisable land area on world deserts. Sand dunes, mountains, forest and water surface are all omitted from the surface of deserts by their nature of morphology and spectroscopy. Only stiff and flat lands are selected as appropriate VLS-PV site candidates as summarised in the table.

2 DEFINITION AND ADVANTAGES OF 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.

- 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

3 MEDITERRANEAN REGION CASE STUDIES

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 Euros/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 Euros/kW at all locations.

PV electricity generation costs in the analysed Mediterranean countries are between 30,2 and 47,6 Euro-cents/kWh, as shown in Table 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 important to note that the assumed 100 % loan financing makes up a substantial proportion of the generation cost. Generation costs below 20 Euro-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 Eurocents/ 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-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 VLSPV 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 realisation

Table 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/m^2/y^{-1})	Annual energy yield (kWh/kW/y^{-1})	Generation cost for PV (Euro-cents/kWh)	Conventional grid electricity price level (Euro-cents/kWh)	Feed-in tariff rate (Euro-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

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.

4 MIDDLE EAST REGION CASE STUDIES

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

- How much land area is available for the harvest of sunshine, and how much electricity could this resource provide?
- How much electricity is required?
- What kind of technology should be used, and how much of it would be needed for the task?
- At what rate should the technology be introduced?
- 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 as shown in Table 2, 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 their manufacture. It was concluded that, in Israel, VLSPV plants would cost no more than US$850/kW, and that production facilities, capable of an annual throughput of 1,5 GW collectors and 0,5 GW storage, would cost approximately US$1 170 million.

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 as shown in Table 3:

- 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.

Table 3 Expected economic benefits to Israel of VLS-PV plant introduction during the first 36 years

Interest rate	3	% y−1
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	US$ million
Interest paid	3 397	US$ million
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

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 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 topdown 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

Table 4 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)

investment, surrounding local electricity prices, labour costs, and production/consumption growth rates, our results for these countries should be regarded as indicative rather than definitive.

5   VLS-PV PROJECT ON THE GOBI DESERT

5.1 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 4). The potential sites in the Gobi Desert area along the railway were identified using long-term 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, 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 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 substations 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 200 kW each, 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.

Table 5 Capital investment for 8 MW LS-PV system (1 yuan = approximately USD0.12)

	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	322,4	7 100

Total capital investment is 322,47 million Chinese 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 5. However, it is expected that 96,74 million yuan (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. The Gansu grid company will guarantee 1,683 yuan/kWh as the feed-in tariff and the annual income for the PV system will be 23,16 million yuan: 13,761 MWh/year × 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: 23,16 million yuan/340×10^8 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 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.

6 OCEANIAN CASE STUDY

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.
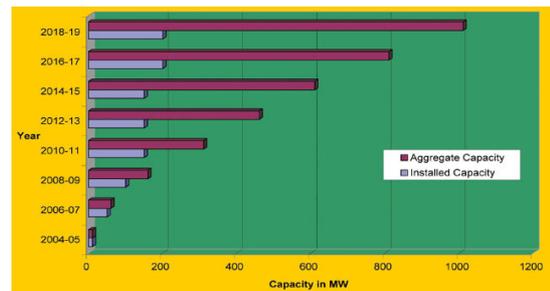

Figure 1 Possible scenario to realise VLS-PV at Perenjori

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 1 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.

Table 6 Estimated project cost for 10 MW PV power generating system (Aus$1 = approximately US$0.76)

Components	Unit cost	Total cost (Aus$)
PV modules	4,4 Aus$/W	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

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 Aus$60 million, with the following cost breakdowns as shown in Table 6. 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 Australian cents/kWh under the Mandatory Renewable Energy 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 cents/litre, diesel fuel is available to the mining companies in Perenjori; the cost of power generation from diesel power projects comes to about 12 cents/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.

7 DESERT COMMUNITY DEVELOPMENT

A region, where the VLS-PV is introduced, should also be sustainable as well in socioeconomic issues. By the Phase I studies [1], sustainable scenario was developed in order to maintain sustainable economical effects to the regional society year by year by introducing local PV module assembly factory lines and by supplying most of modules to VLS-PV constantly every year. This approach assures local job creation and income by purchasing electricity. Some part of electricity can be also utilised for agricultural development in the desert area. Especially, the presence of electricity in agricultural field seems to be a new kind of motif and this approach can provide useful means for agricultural people, for instance, in order to avoid soil property deterioration caused by careless irrigation.

Figure 2 illustrates a desert community development that aims to achieve an ideal community. Agriculture and tree planting can be facilitated with plentiful renewable energy. The electricity can also be fed to neighbouring communities. The modelling for the desert community
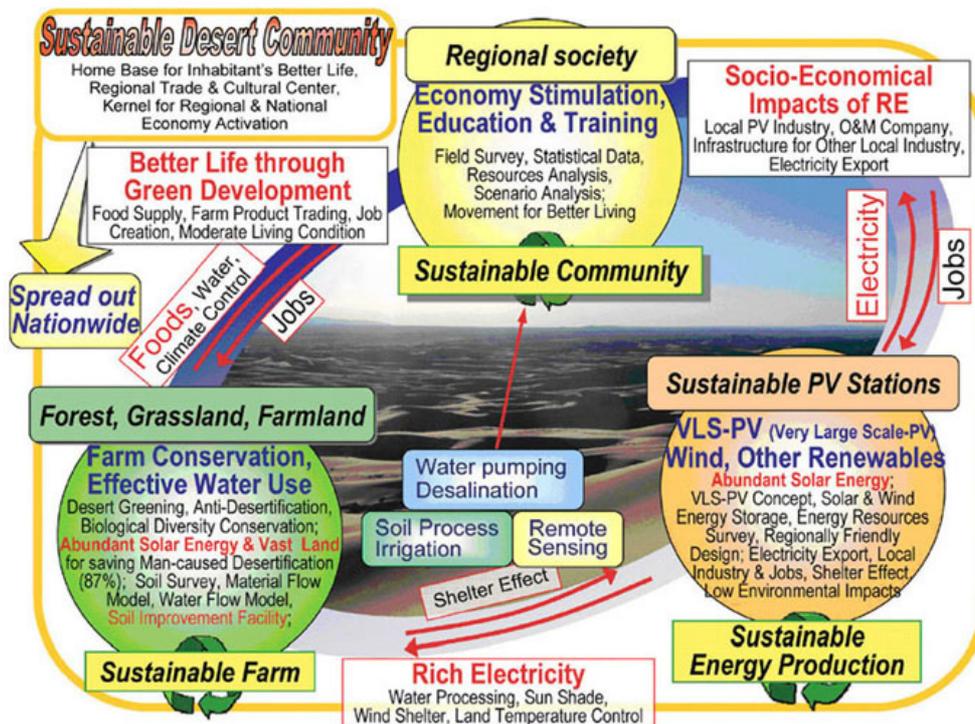

Figure 2 Framework of desert community development and research topic

has been discussed and a fundamental structure has been formulated in terms of a specific village in the Mongolian Gobi by considering the following items:

• *Sustainable energy production by sustainable PV stations.* Here, the VLS-PV system is the main feature. Other renewable energy source can also be utilised such as wind, biomass, etc.. Battery storage is essential for service during night.

• *Sustainable farming.* Utilising soil and water conservation technology, we will conserve and rehabilitate the environment of a desert area. This may be relatively easy to achieve with PV support.

• *Sustainable community.* Statistical and scenario analyses are used to develop an ideal community. In order to sustain regional society, education and training are also considered in addition to the facilities and technology needed.

• *Remote sensing.* It can be utilised find out suitable places where to implement VLS-PV and wind power systems. It can also bring data on soil and water required for sustainable agricultural production.

• *Desalination.* PV power can drive a desalination plant, which will supply enough amount of drinking and irrigation water.

• *Effect of PV station on local agriculture.* Proper operation of a water pump and desalination system can remove salt from the groundwater to provide good quality water. This can enhance crop yields and reduce the use of fuel wood. PV-driven greenhouse can produce agriculture product of high quality and yields.

• *Effect of PV station on the local community.* PV stations including a local module factory can create more employment. This would also increase local incomes through selling electricity.
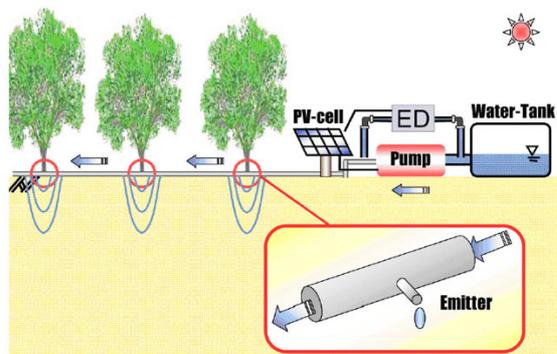

Figure 3 Desalinised drip irrigation system

• *Technology.* Implementing a subsurface drainage system may save groundwater quality, and desalination equipment protects soil from damage due to salinisation. Considerable amounts of low saline water will be available when PV system can drive a desalination system, such as reverse osmosis (RO) or electro-dialysis (ED). Figure 3 shows an example of a drip irrigation system with a desalination system.

8   CONCLUSIONS

It is strongly indicated that VLS-PV could directly compete with fossil fuel as the principal source of electricity and with existing technology 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. The proposals developed in this study may motivate expected stakeholders to realize VLS-PV project in the near future. Moreover, a series of these practical project proposals from different viewpoints and directions will enable us to provide essential knowledge or detailed practical instructions in order to realize the sustainable implementation of VLS-PV development in the 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.

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