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AN ANALYSIS OF VERY LARGE-SCALE TRACKING PV (VLS-PV) SYSTEMS IN THE GOBI DESERT

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ABSTRACT

The authors propose utilization of deserts for power plant by PV technology. 100 MW VLS-PV systems which are fixed flat plate system in the world deserts and sun-tracking system in the Gobi desert are assumed and evaluated in detail by using Life Cycle Assessment. It means that the VLS-PV systems are evaluated in terms of its input and output from cradle to grave.

As a result, 5.2 Cent/kWh cost, 1.6 years energy payback time, and 12 g-C/kWh CO_2 emission rate for Sun tracking system are obtained in the Gobi desert case. Of cause, fixed flat plate systems get the low cost and low energy requirement. The Very Large-Scale sun tracking Photovoltaic power generation system is very promising for the energy resource saving and environmental issue.

1. INTRODUCTION

1.1 Background

Fortunately, PV system needs are expanding. Unfortunately, its reasons in large part are world problems. Nowadays, world energy demand has been rapidly expanding due to the world economic growth and population increase, especially in developing countries. According to IEA's outlook, total CO_2 emissions and total primary energy supply in the world will be twice as 2000. Figure 1 shows it in detail. If world energy demands continue to increase, the primary energy will dry up in this century. In addition, too much energy consumption causes a variety of serious environmental problem such as global warming, acid rain and so on. But, renewable energies are expected to resolve both the energy problem and the environmental problem. Photovoltaic power generation system is one of promising renewables. Because it need no fuel, no maintenance and no emission when it's generating. On the other hand, the solar energy have a week point, which is its low density by nature. So, to generate large power such as nuclear power plant, a PV power plant must be very large scale system. It cause cost increase. Although, unutilized desert has a large potential, and resolve these problems.

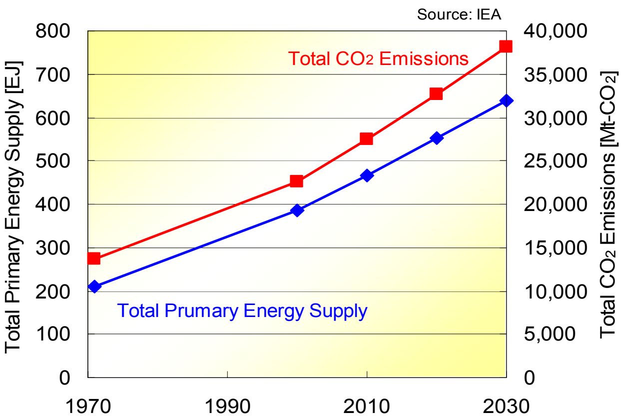

Fig. 1 World primary energy supply and CO_2 emissions [1]

1.2 Desert Potential

High irradiation and very large unutilized land areas are in world deserts. For example, even the Gobi desert that locates on high latitude has higher irradiation (4.7kWh/m^2/d) than Tokyo (3.5kWh/m^2/d). Furthermore, the Sahara desert has more irradiation as 7.4kWh/m^2/d. Theoretically, PV systems installed in the Gobi desert with 50% space factor, has potential to generate energy as much as the recent world energy supply (384 EJ in 2000).

Table 1 Global irradiation in the Gobi deserts [2]

Major deserts	Global irradiation [kWh/m^2/year]
Sahara (Mauritania)	7.36
Negev (Israel)	5.31
Thar (India)	5.96
Sonoran (Mexico)	5.47
Great Sandy (Australia)	8.92
Gobi (China)	4.67
Tokyo (Japan)	3.47

1.3 Kinds of Desert

When you image a desert, your picture may be sand desert. But a desert is not only sand desert, but also rock desert, gravel desert and so on. Sand desert is one fifth of total desert area. Even in the biggest Sahara desert, sand desert is one third of total area. Table 2 shows brief of deserts. Gravel desert is the best area to install Very large-scale PV systems, because lowest sand dune and sand storm cause minimum damage. Therefore the authors have been investigating very large-scale photovoltaic power generation (VLS-PV) systems in deserts.

Table 2 Kinds of deserts

Name	Characteristic
Rock desert	Low animals, low grass, a few pines grow in a little water area
Gravel desert	Consist of small rocks, a few plants exist
Dirt desert	A grain is very small, rainwater don't seep into the ground, be sometime dubbed yellow ocher
Sand desert	Sand dune change wind and become larger, and tuck plans
Salt desert	Too much irrigation cause salt injury.

2. OBJECTIVE

The purpose of this study is to evaluate the VLS-PV systems in world deserts, and to investigate feasibility of the system such as fixed flat plate system, tracking system and so on from economic and environmental view points. As indices taken up for the evaluation, cost, energy requirement, CO_2 emission of large-scale installing, toughness on hard desert condition, elucidated effect on climate and local, etc. are enumerated, and the possibility of solution to world energy and environmental problems is discussed.

This paper presents feasibilities of fixed flat plate and tracking PV systems from analysis of cost, CO_2 emissions and energy requirement.

3. METHODOLOGY OF EVALUATION

3.1 Life-Cycle Assessment

A methodology of "Life-Cycle Assessment (LCA)" is the best way to evaluate the potential of VLS-PV systems in detail, because, a purpose of this methodology is to evaluate its input and output from cradle to grave. In this study, generation cost, energy payback time (EPT) and CO_2 emission rate of the VLS-PV system are calculated with this method. They are defined by following equations.

$$\text{Generation cost (cent/kWh)} = \frac{\text{Annual expence of the PV system [cent/year]}}{\text{Annual power generation [kWh/year]}} \quad ----(1)$$

$$\text{EPT (Year)} = \frac{\text{Total primary energy requirement throughout its lifecycle [kWh]}}{\text{Annual power generation [kWh/year]}} \quad ----(2)$$

$$CO_2 \text{ emission rate (g-C/kWh)} = \frac{\text{Total } CO_2 \text{ emission on life-cycle (g-C)}}{\text{Annual power generation [kWh/year]} \times \text{Lifetime [year]}} \quad ----(3)$$

EPT means years to recover primary energy consumption throughout its life-cycle by its own energy production. CO_2 emission rate is a useful index to know how much the PV system is effective for the global warming.

3.2 Case Studies

This study is divided into detailed case studies and economic case studies. One is a fixed flat plate and a one axis tracking PV system simulations from economic and environmental view points by using three indices. Other is a fixed flat plate PV system simulation from economic view point by cost evaluation. Table 3 is a list of these case studies. Both case studies are assumed that VLS-PV system is installed in Gobi desert.

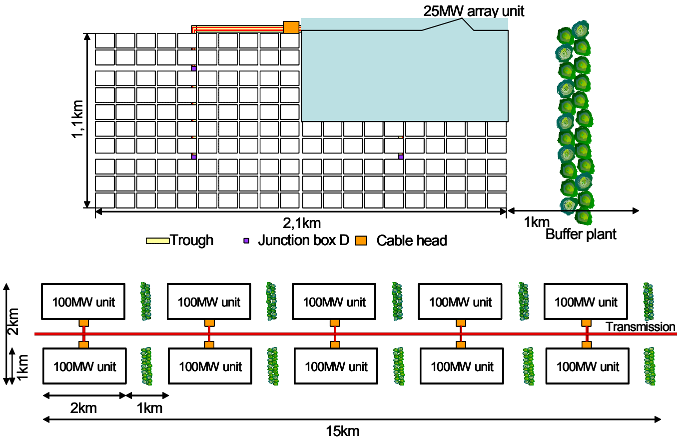

Fig. 2 Concept of 1GW PV array layout

Table 3 Case studies list

	Detailed study	Economic study
Array type	Fixed flat plate, one axis tracking	Fixed flat plate
Evaluation type	Economic, environment	Economic
Index	Cost, EPT, CO_2 emission rate	Cost
Desert area	Gobi (China)	Sahara, Negev, Thar, Sonoran, Gobi Great Sandy

4. SYSTEM PLANNING

All parts of a 100MW VLS-PV system are designed based on concept of LCA. The designing assumptions are explained as follows.

4.1 Installation Area

Gobi desert is elected for installing VLS-PV system. A desert area is suitable for PV system in view of irradiation and land area. Gravel desert is elected for installing the system. Because it consists of small rocks, and it is more flat and firm than sand or rock desert. Sand problems such as sand storm are seemed to be small.

Table 4 Geographic information for world deserts

Desert		*Gobi*
Location		Hoh hot (40°N 111°E)
Performance ratio (PR)		0.78
Ambient temperature [°C]		5.8
In-plane irradiation	Tilt angle=10°	1,854
	Tilt angle=20°	1,964
	Tilt angle=30°	2,026
	Tilt angle=40°	2,037
Irradiation on one axis tracker		2,579 [kWh/m^2/yr.]

Both irradiation and ambient temperature data referred from World Irradiation Data Book[2] used for system designs, as shown in Table 4. If the installation sites have no direct and diffuse irradiation data, which are estimated from grovel irradiation data by using Liu-Jordan model [3]. In-plain irradiation data is calculated by using r_b model, Hey model [4] and isotropic model [5]. Irradiation of tracking system is obtained to calculate a method which is referred to JSES [5], and is changed a part of above method.

4.2 System Assumptions

A target of this study is sustainable development with one GW VLS-PV system as shown in Fig 2. Both fixed flat plate and one axis tracking VLS-PV systems are designed based on the following assumptions.

1) Total capacity is about 100MW, which consists of four sets of 25MW unit field. A 25MW unit consists of 50 sets of 500kW unit system. A 500kW unit system has 4200 or 3888 PV modules. The total PV modules in 100MW system are 840,000 pieces for fixed flat plate system, and 777,600 pieces for tracking system. Layouts for tracking system are shown in Fig. 3.
2) South-faced fixed flat array structure, one axis E-W tracking array structure and foundation are designed. Wind pressure and earthquake are also taken into account.
3) Polycrystalline silicon PV module with 12.8% efficiency is employed. It is referred to Kyocera 120S.
4) System performance ratio is assumed considering operating temperature, degradation, load matching factor, efficiency factor, inverter officiating and so on, as shown in Table 4.
5) The system lifetime assumed to be 30 years.
6) Module and inverter price, and array tilt angle are given as valuable parameters. The four levels of module price are assumed as 1, 2, 3, 4 US$/W. Inverter unit price of 500kW is also set to 0.136, 0.159, 0.181, 0.204 million US$ for each module price. Interest rate is 3% (typical), 2% (supposing soft loan), and 6% (from ordinary financial institution). This paper show the results based on 3% interest rate.
7) Land preparation is considered.

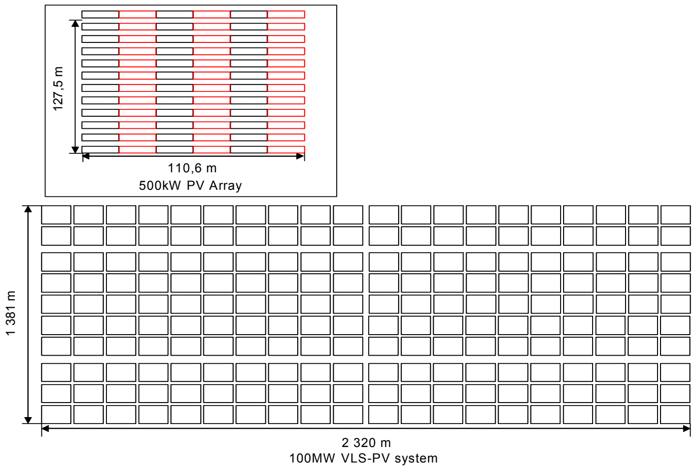

Fig. 3 Array layout for tracking system

4.3 Transport

Array support and foundation are produced in the country where the VLS-PV system is installed, and other system components such as modules, cables and inverters are manufactured in advanced country, Japan, USA or Australia. All the components are transported to the installation site by marine and land transport as shown in Fig. 4.

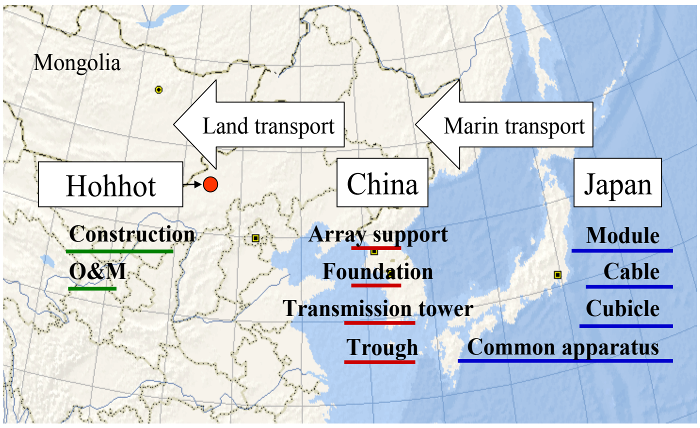

Fig. 4 Image of transportation

4.4 Operation and Maintenance

1) The method of operation and maintenance are calculated in view of experience of real PV system model, PV-USA project [6].
2) Three shifts of three operator team work in 100MW PV station. One team works in maintenance, and the other teams operate for alternation.
3) Concerning labor cost, different labor requirement for system construction was estimated by considering local conditions of each country, and unit labor cost was referred from ILO statistics [7] etc. Furthermore a supervisory charge is added to the cost for the installation of certain apparatus.
4) Decommission stage is not included in this study stage now.

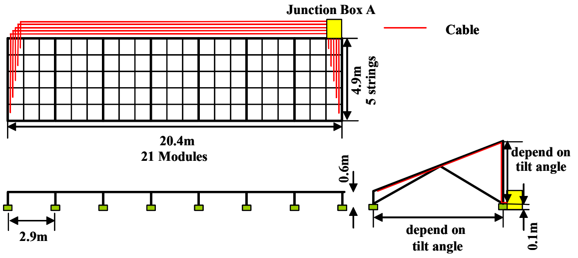

Fig. 5 Basic array structure of fixed flat plate PV system

5. DESIGNING VLS-PV SYSTEMS

The authors assumed and designed the VLS-PV systems which are fixed flat plate and sun-tracking system in the major deserts in detail. These case studies show characteristics of systems, and they show the best performance system configuration.

5.1 Fixed Flat Plate System

The very large scale fixed flat plate PV systems as shown in Fig. 5 are evaluated in previous papers [8][9]. They show that the VLS-PV system is very promising for economic and environmental view points. In this paper, the very large scale sun-tracking PV systems are assumed, evaluated and compare these systems.

5.2 One Axis Sun Tracking Design

The simplest one axis sun tracking PV systems consists of PV module mounted on horizontal axis that rotate from east to west in synchronization with the sun's position in the sky.

5.2.1 Array support structure and foundation

Fig. 6 shows the basic structure of array support. Foundation height over the ground is 0.1 m and lower height of array support is 0.2 m from the ground. It is assumed that array support is made of zinc-plated stainless steel (SS 400), and thickness of several types of steel material are chosen according to stress analysis assuming that the wind velocity is 42m/s (based upon the Design standard of structure steel [10] by the Japanese Society of Architecture).

A cubicle foundation made of concrete as in Fig. 7 was used. Its rectangular solid is 1.0 m each considering the design standard of support structure for power transmission by the Institute of Electrical Engineering in Japan. Material composition of the concrete is determined in order to obtain 240 kg/cm^2 of concrete strength;

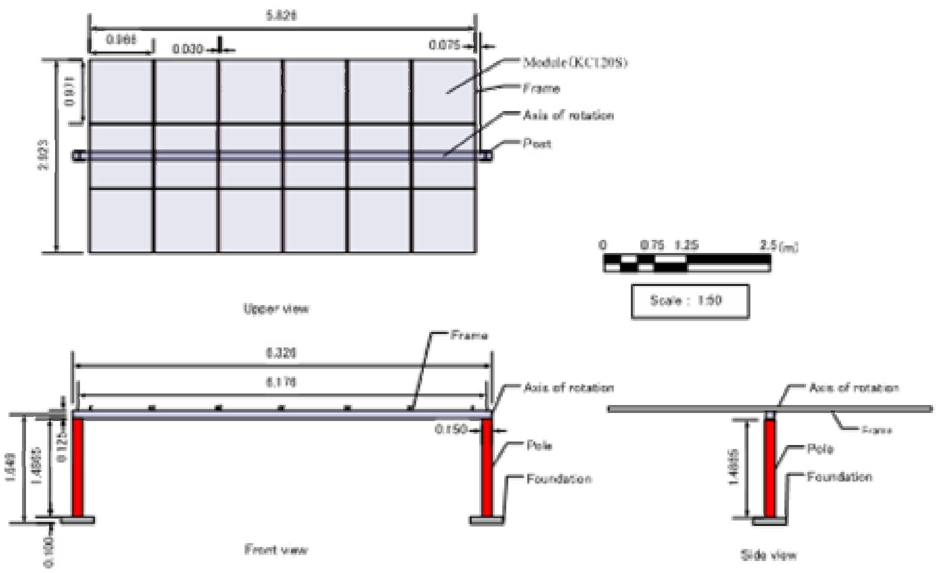

Fig. 6 Design drawing of one axis sun tracking PV system structure

347 kg/m^3, 603 kg/m^3 sand, 11,180 kg/m^3 gravel and 170 l/m^3 water.

5.2.2 Tracking system

Worm gear pair is assumed to furrow the sun as shown Fig. 8, because required energy to move it is lower than typical system which move axis of rotation directly. In addition, this structure with worm gear pair is stabilized.

5.2.2 Wiring

The shorter and simple wiring is designed in order to prevent miss wiring. The current capacity of cable is selected to make voltage drop less than 4 %. It is determined from Japan Industrial Standards-JIS.

5.2.3 Transmission

Electric transmission system is assumed 100 km, 2 channels and 110 kV. It consists of steel towers, foundations, cables and grand wires. They are considered wind velocity 42m/s. After calculations, cables and ground wires are decided TACSR 410 sq and AC 70 sq, 22.0 ton steel towers and 22.1 m^3 foundations are required 334 towers with foundations for 100 km transmission.

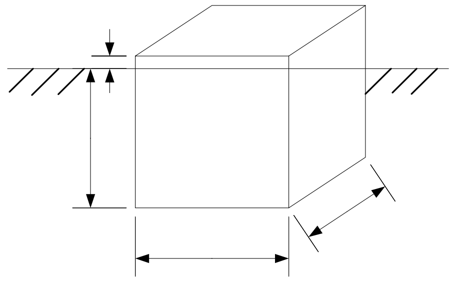

Fig. 7 Design drawing of foundation for tracking system

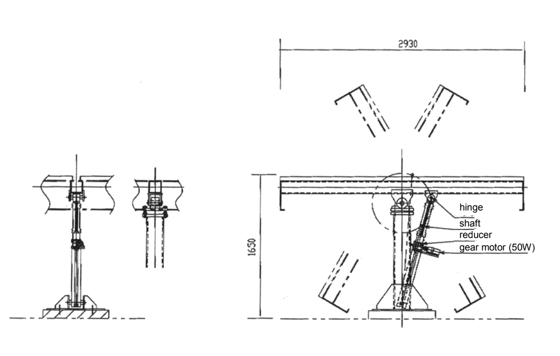

Fig. 8 Tracking design

6. EVALUATION RESULTS

By using the results of the system design and operation and maintenance, a life-cycle of the sun tracking 100MW VLS-PV systems in the world deserts are evaluated in terms of life-cycle cost, energy and CO_2 emission.

6.1 System Component

The 100MW sun tracking VLS-PV systems on the Gobi deserts are designed on the basis of the above assumptions. This system required 4.0 km^2 land area which is larger than fixed flat plate system. Array support requirement ranged 11 thousand ton steel, and foundation needed 105 thousand ton concrete. Land requirement is considered due to spacing between PV arrays.

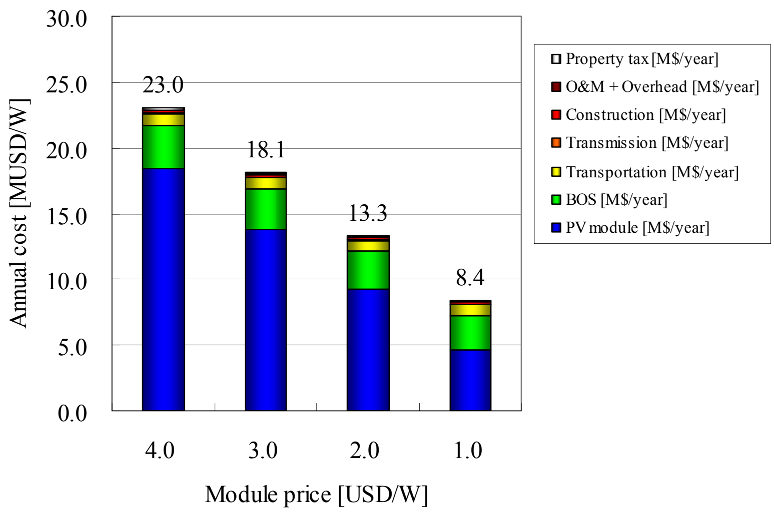

Fig. 9 Annual cost for a 100 MW tracking VLS-PV system

6.2 Cost Estimation

In this study, both investment cost and O&M cost of 100MW PV system for each installation site were estimated to obtain generation cost of the PV system. Total investment cost includes labor cost for system construction as well as system component cost. But worm gear price is not considered. Fig.9 represents example of the annual cost in Gobi desert for deferent PV module prices by each cost component. Even though 1.0 USD/W PV module is assumed, it is first majority of the total investment cost. A majority of construction cost is labor cost, which had big difference between countries. For example about one third of the total investment cost is construction even at 1.0 USD/W in Great Sandy. On the other hand, the least investment cost was estimated at both Sahara and Gobi mainly due to low labor cost. It was no more than 2% of the total at 1.0 USD/W.

The generation cost of fixed flat plate and sun tracking VLS-PV system for different tilt angles and different PV module prices are assumed 30 years lifetime and 3% of annual interest rate in the world deserts. Annual power generation and generation cost are given in Table 5. Optimal array tilt angle depended on both annual cost and annual power generation. The least generation cost of the Gobi case is obtained at 30º-tilt angle. In case of tracking system, annual power generation in Gobi desert is 20% lower than fixed flat plate case. In the Gobi desert tracking system case, though the generation cost with 4.0 USD/W module price corresponded to 15 cent/kWh, it was reduced to about 6 cent/kWh with 1.0 USD/W module price.

Table 5 Annual power generation and Generation cost for 100 MW fixed flat plate and sun tracking PV system

		Unit	Gobi (China)	Gobi (China)
			Fixed flat plate system	Tracking
Annual power generation	Tilt angle= 10º	GWh/yr.	147	190
	20º	GWh/yr.	156	
	30º	GWh/yr.	161	
	40º	GWh/yr.	162	
Generation cost (at optimum tilt angle)	Module price=1$/W	Cent/kWh	6.2	5.2
	2$/W	Cent/kWh	10.0	8.3
	3$/W	Cent/kWh	13.8	11.4
	4$/W	Cent/kWh	17.6	14.5

6.3 Energy and CO_2 Emission Analysis in Gobi desert

Table 6 represents the results of total primary energy requirements and Energy Payback Time (EPT). EPT is estimated assuming electricity from the PV system would replace utility power in China where recent conversion efficiency is around 33%.

Required energy for tracking systems with worm gear is included. Transportation also uses a certain amount of energy. Nevertheless, the EPT is still a low level. This suggests that the total energy requirement for introduction of a 100MW PV system to the Gobi desert in China can be recovered in less than two years.

Table 6 is also results of life-cycle CO_2 emissions and life-cycle CO_2 emission rate of the tracking 100MW PV system, assuming a 30-year operation period. Discussion of these results is the same as the total primary energy requirement and the EPT. Considering CO_2 emission rate of existing coal-fired power plants, about three hundred g-C/kWh, the life-cycle CO_2 emission rate of a 100MW tracking PV system is much lower.

Table 6 Energy requirement and CO_2 emissions for 100MW sun tracking PV system

	Energy requirement		CO_2 emission	
	Fixed (30°) [GJ]	Tracking [GJ]	Fixed (30°) [t-C]	Tracking [t-C]
Total	3300	3400	61600	64600
PV module	1700	1500	26100	24200
Array support (and tracking)	900	1000	22800	25276
Foundation and trough	160	160	4000	3900
Cable	30	40	500	600
Transportation	300	270	5200	5000
Transmission	200	180	2300	2300
Other	20	20	500	500
Value	1.8 [yr.]	1.6 [yr.]	12.8 [g-C/kWh]	11.7 [g-C/kWh]

7 CONCLUSION

A 100MW Very Large-Scale sun tracking power generation system and fixed flat plate system in the Gobi desert is designed, and its potential is evaluated from an economic and environmental viewpoint. Assuming 1.0 USD/W of PV module price and 3% of annual interest rate, generation cost of the VLS sun tracking PV system is estimated 5.2 ¢/kWh in Gobi desert. In addition, these large-scale projects make a lot of employments. One of case study needs 1500 labors in every year to construct it. This employment may look forward economic development in the country. Therefore VLS-PV systems in desert areas will be economically feasible in the near future.

The feasibility of very large-scale tracking system installed in the Gobi desert in China is evaluated in depth from a life-cycle viewpoint by using three indices, i.e., life-cycle cost; energy payback time (EPT) and life-cycle CO_2 emissions. This study suggests that the total energy requirement throughout the life-cycle of the PV system considering production and transportation of system components, system construction, operation and maintenance can be recovered in a short period much less than its lifetime. Therefore VLS-PV system is useful for energy resource saving. The much lower CO_2 emission rate of VLS-PV than that of existing coal-fired power plants means that it is a very effective energy technology for preventing global warming. The same conclusion must be given for the other desert areas.

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