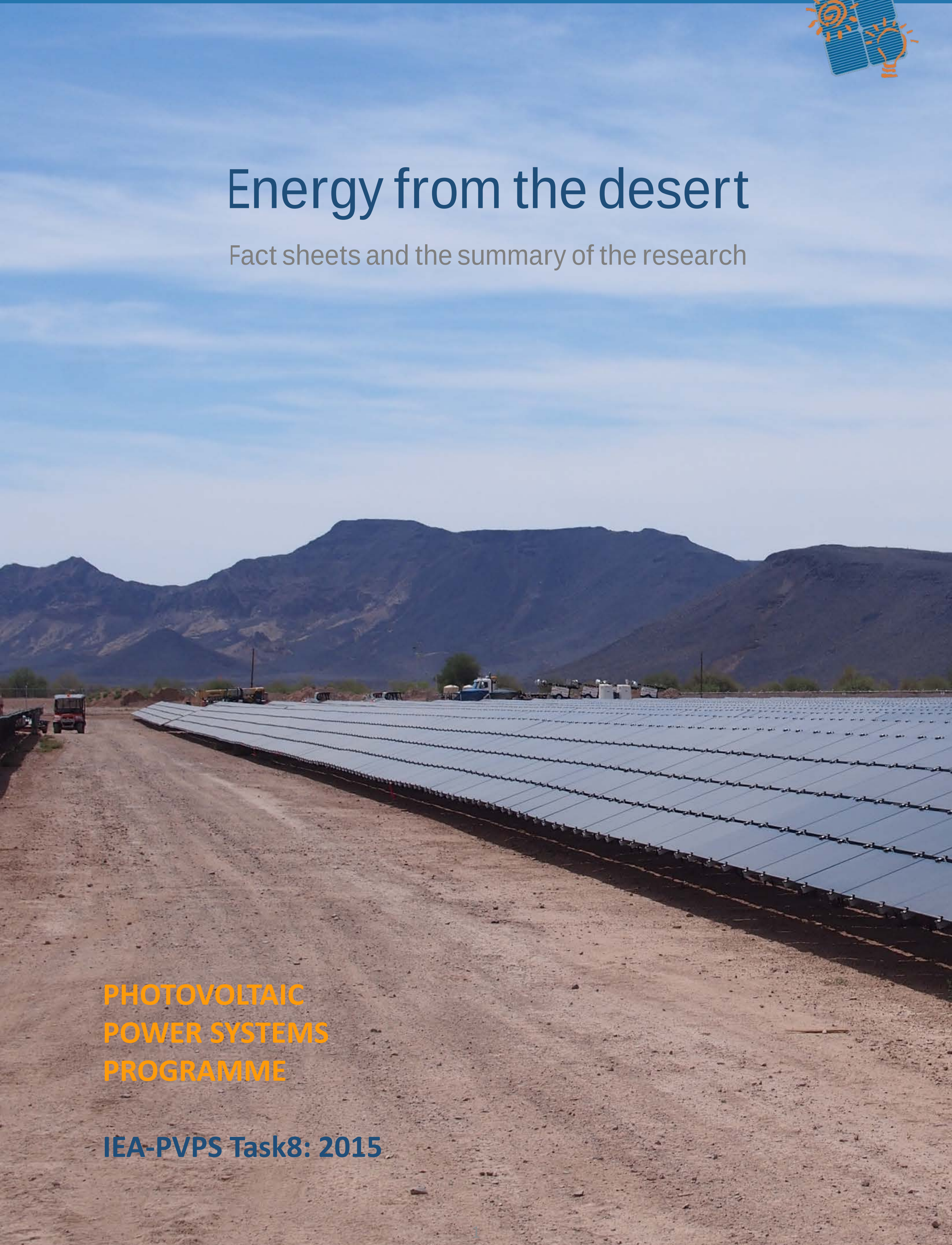
Energy from the desert

Fact sheets and the summary of the research



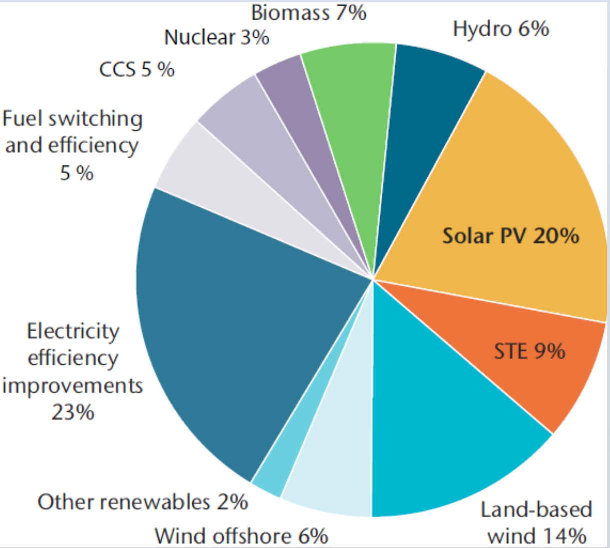
PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

IEA-PVPS Task8: 2015

Why VLS-PV in the desert?

PV as one of the sustainable energy sources for 21st century

Global energy consumption has been increasing since the Industrial Revolution, and is expected to increase for the next decades. In order to meet the environmental challenge in the 21st century, certainly, renewable energy must play an important role. Solar energy is one of the most promising renewable energy sources and a photovoltaic (PV) is the representative technology for utilising solar energy. It may no exaggeration to say that we're now coming to the stage of energy transition by PV power plants.



Cumulative technology contributions to power sector emission reductions in Energy Technology Perspectives 2014 hi-Ren Scenario relative to 6DS up to 2050

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PV potential in the desert

Although, PV is expected to be one of the major energy sources in the future, the solar energy is low density energy in nature and the irradiation is unevenly distributed among the regions. In order that the solar energy becomes one of the major power sources, vast land areas with high solar irradiation is essential. The desert area which covers one-third of the land surface is clearly one of the best site for the purpose.

1/3

of the global surface is covered by the desert

8%

of the total desert area is enough to provide global primary energy today

5 times

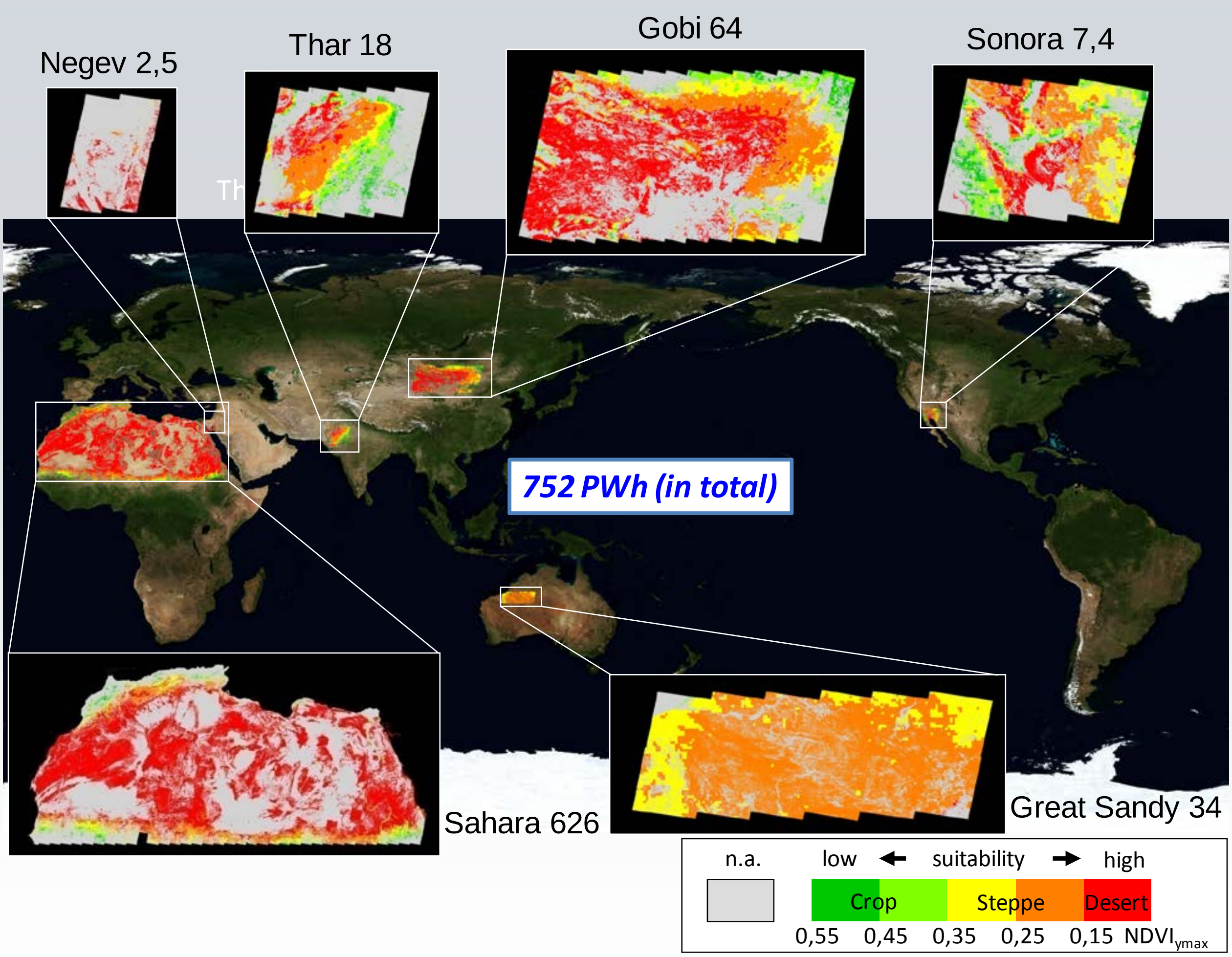
of global electricity demand can be generated from Gobi desert alone

The total electricity produced from the desert is simulated to be 2 239×10^3 TWh (=8 060EJ), which is 14 times of the world primary energy demand 560 EJ in 2012. In other words, only 8% of the surface area in the desert (without space factor, the value becomes 4%) is enough to provide global primary energy today. Another example is that, Gobi desert area located between China and Mongolia can generate 5 times more than the annual world power demand.

Why VLS-PV in the desert?

Suitable areas for PV power plant in the desert

The detail site evaluation is important since not all the desert area is suitable for PV power plant. For example, a sand dune area may not be suitable for the PV power plant in terms of construction and maintenance, while a flat gravel desert is much more feasible from engineering point of view.
Another important aspect for the assessment is social and environmental impact. Even if the land is classified as desert area, there are areas which have enough rainfall and can be utilized other purposes such as agriculture or cattle breeding. In our site evaluation study, those land area is regarded as “not suitable” even if there is no technical barriers for constructing the plant.
The figure below is the evaluation results of the suitable areas for PV power plants for selected six deserts in the world. The simulation uses remote sensing technology with satellite images. White areas correspond to unsuitable areas from technical, social and environmental perspectives, and coloured areas indicate suitable areas. The green coloured area is the land with vegetation, while the red coloured area is the arid land. The potential annual generation by PV power plants within the suitable desert area is calculated to be 752 × 10^3 TWh, which is approximately 5 times of the world energy demand and 33 times of world electricity generation in 2012.

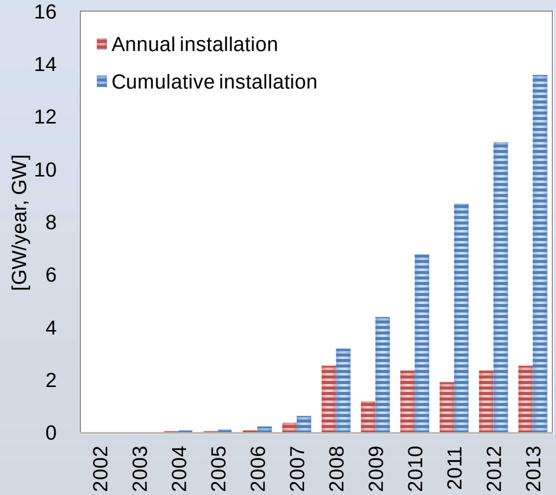


Expected annual electricity generation at the PV power plants in world 6 deserts

VLS-PV market expands drastically

VLS-PV market expands in a stable manner

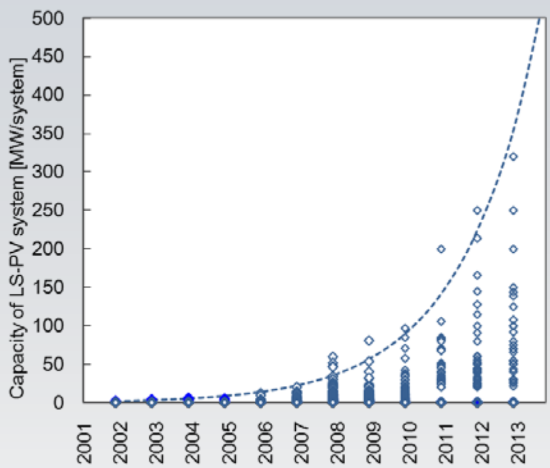
Large scale PV power plants came on the market first in the latter half of 2000s, and many large scale PV power plants over 20 MW were installed in Europe, under the Feed-in-Tariff scheme. After that, large scale PV power plant market expanded to other regions such as in USA and China. Today, PV power plants with several tens of MW capacities are also emerged in Chile as well as in South Africa. The right figure shows trends in large-scale PV installation until 2013, based on our survey. It is confirmed that there are at least 170 PV power plants over 20 MW in the world as of mid-2014 and cumulative capacity of those plants exceed 9 GW. By adding the PV power plants less than 10 MW and starting operation until 2010 on the 9 GW above, total capacity exceed 14 GW.



Annual & Cumulative Installation of large scale (over 20MW) PV systems

The largest PV power plants record in the world has been broken every year

The number of PV power plants over 100 MW in operational is more than 20. In 2011, 200 MW PV power plant is constructed and started operation. Its capacity was expanded to 300 MW in 2013, and further to 500 MW in late 2014. In 2012, 250 MW PV power plant started operation in Arizona, USA, and its capacity was expanded to 290 MW in 2013. In early 2013, 320 MW PV power plant emerged in China, and the plant was expanded to 520 MW in 2014. In November 2014 and December 2014, two 550 MW PV power plants started operation respectively in USA, e.g. Topaz Solar Farm in Arizona and Desert Sunlight in California.



Large scale PV system installation in each year

Topaz Solar Farm, CA, USA (550MW_{AC}, CdTe)

(©First Solar, Inc.)

Longyangxia, Qinghai, China (520$MW_{DC/AC}$, c-Si)

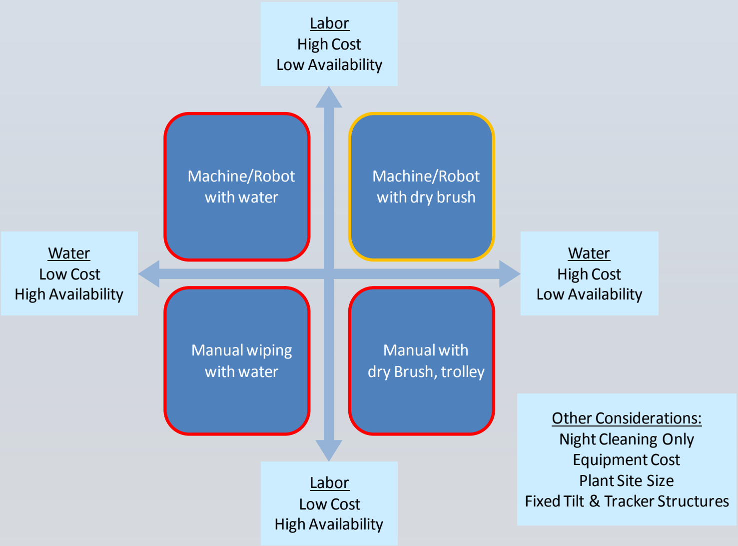
(©Yellow River Hydropower Company)

Technical solutions are available

Soiling issues

PV power plants in the desert areas have to endure severe environmental conditions. One of the most serious issues is a dust settlement (soiling). Dust accumulated on the surface of the PV panel can reduce the power output considerably. A degree of soiling and its impact is depending upon surrounding environments and meteorological conditions of the site. A solution to soiling is 'cleaning'. Cleaning option of the PV plants can be justified if the cost for cleaning is lower than the income generated by the solutions. In general, a cost for cleaning is heavily depending upon the local cost of labour and water.

Dust accumulation on the PV panel



Cleaning options

Pros and Cons of each cleaning options in China

Methods	Cleaning equipment	Water consumption (t/10MW/time)	Cleaning speed	Cleaning result	Cleaning cost
Wash + wipe	Water pipe installation or water transportation vehicles (water replenish)	100	Fast	Excellent	High
Spray + wipe	Water and spray pipe installation	50-60	Fast	Excellent	High
Special wash vehicle and machine	Cleaning equipment and water supply vehicles, water replenishment and equipment maintenance	30-40	Fast	Excellent	High
3-person + water	No need to pipes, vehicles and equipment	10	slow	Good	Low

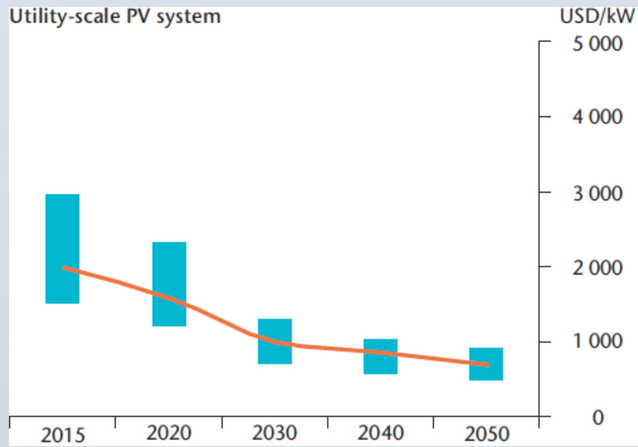
Other technical issues

Besides soiling, sand storm and particles, high temperature and large temperature difference between day and night, exposure to intense ultraviolet irradiation, etc. are the significant and special issues for PV power plants in the deserts environment. Recently, importance and necessity of evaluating capability and performance of PV modules under the desert condition is widely accepted. Evaluation method for those issues are not standardised internationally yet, and further discussions are needed.

VLS-PV in the desert is already competitive

Cost trends and perspectives

Initial cost for PV installation has been decreasing with a market expansion, performance improvement, technology innovation, etc. In some regions, LCOE of PV technology is already reached to the level of residential electricity tariff. Initial cost for PV installation per kW for the large scale PV power plants is generally lower than that of small scale PV systems. According to the IEA PV technology roadmap , initial cost for utility-scale PV system will be 1,5-3 MUSD/MW in 2015, and reached to approximately 1 MUSD/MW and 0,7 MUSD/MW in 2030 and 2050 respectively, as shown in the right figure. If the indicated costs are achieved, the LCOE of PV power plants will be able to compete with conventional power plants.



PV investments costs projections in the hi-Ren scenario of Energy Technology Perspective 2014

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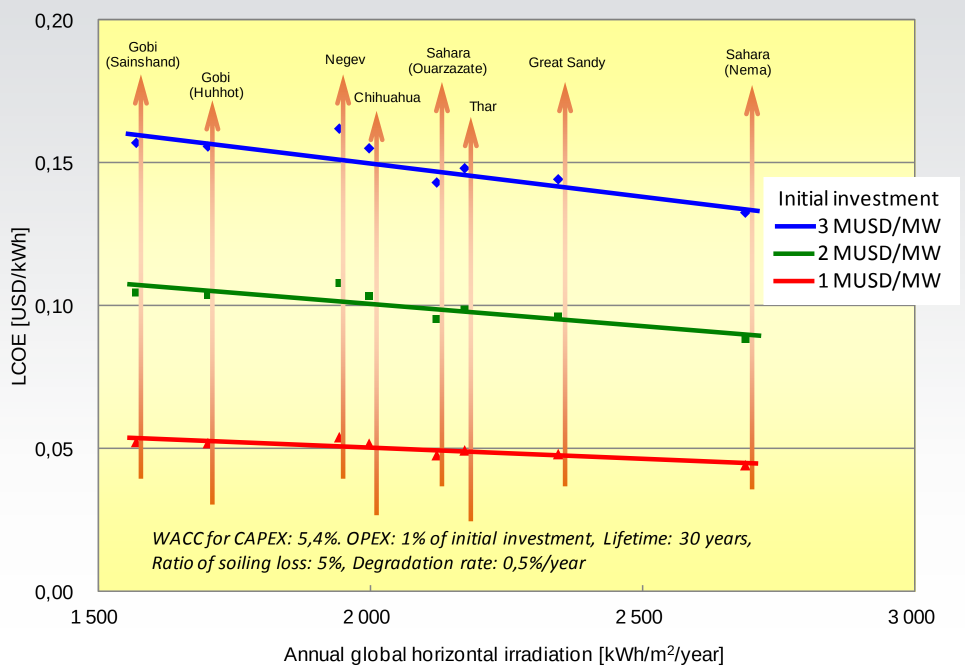
LCOE of VLS-PV in the desert

Clearly, the LCOE of PV power plants are heavily dependent on the solar irradiance on site. The higher the solar irradiance, the lower the LCOE. The figure below represents the expected LCOE of 1 GW PV power plants assuming some desert areas, as a function of global horizontal annual irradiation. Even the current level (2 MUSD/MW), PV power plant is economically competitive in some areas, and in the near future, PV power plants will become more competitive against conventional power plants



Expected LCOE of PV power plants

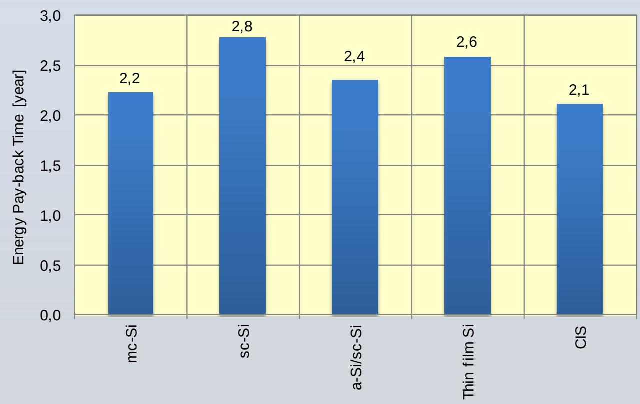
VLS-PV can contribute to sustainable world

Energy pay back time

< 3 years

The Energy Pay-Back time (EPBT) is years required to compensate the energy consumed throughout its lifecycle by the energy produced. That is, PV with shorter EPBT can create larger energy and provide bigger contribution as an alternative energy.

The EPBT of the VLS-PV plants are within the ranges of 1 to 3 years, depending on the type of PV module (efficiency mainly) and location of installation (irradiation and array manufacturing electricity mainly). In other words, PV can produce 10 to 30 times more energy than the total energy consumed throughout its 30 years life-cycle (EROI: Energy return on energy invested).



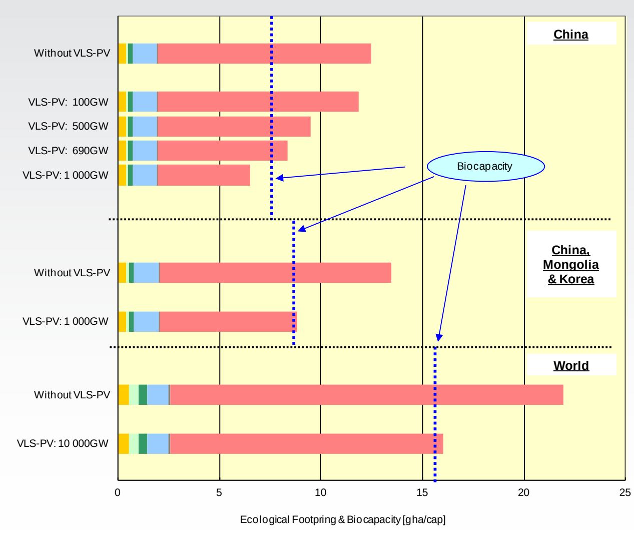
Energy pay back time of 1 GW PV power plant by PV technologies in the Gobi desert, China

Ecological Sustainability

1 000 GW

Ecological Footprint (EF) is one of the indicators to monitor the effects of CO_2 on the environment. The EF is expressed by the capability of ecosystem required to purify, absorb and mitigate the impact of human activities. Capability of ecosystem is called bio-capacity (BC). The earth is sustainable while the EF is smaller than the BC, but if the EF is higher than the BC, the earth is regarded as unsustainable.

The EF and BC in the Northeast Asian region can be balanced by installing the 1 000 GW VLS-PV plants in the Gobi desert covering China and Mongolia. The Area required for the VLS-PV plants is only 1 to 2 % of the Gobi desert. It should be noted that, this calculation considers the effects of CO_2 emissions reduction only. The environmental effect can be further exploited if the development is coupled with afforestation and agricultural development in the surrounding area.



Ecological impacts by VLS-PV project on the Gobi desert

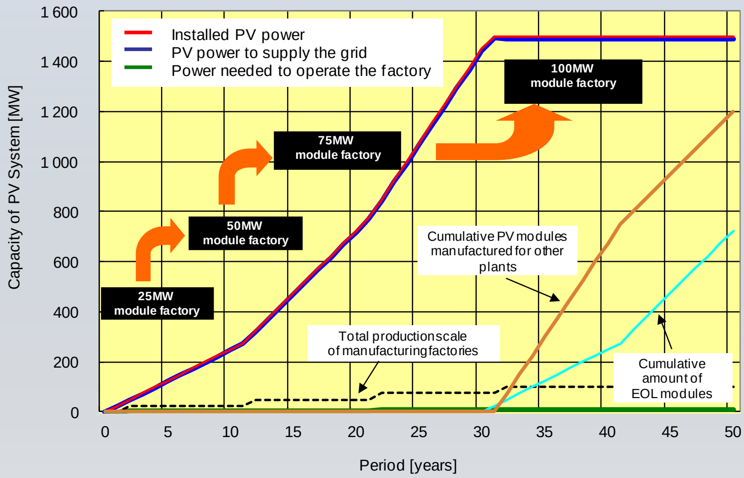
VLS-PV as a tool for social development

VLS-PV development scenario for local employment

A construction of GW-scale PV power plant will create substantial and stable demand for PV system components as well as employment for construction if the construction is managed in an appropriate manner. Below is one of our scenario proposed for GW-scale PV power plant with sustainable social development. At the initial stage, PV plant owner installed 25 MW of PV power plant and module manufacturer construct module factory nearby with 25 MW/year capacity. The modules are supplied for the plant construction purpose exclusively unless the production volume exceeds the demand of the construction site. The capacity of the factory is expanded 25 MW/year every 10 years and reached 100 MW after 30 years (See figure (top)).

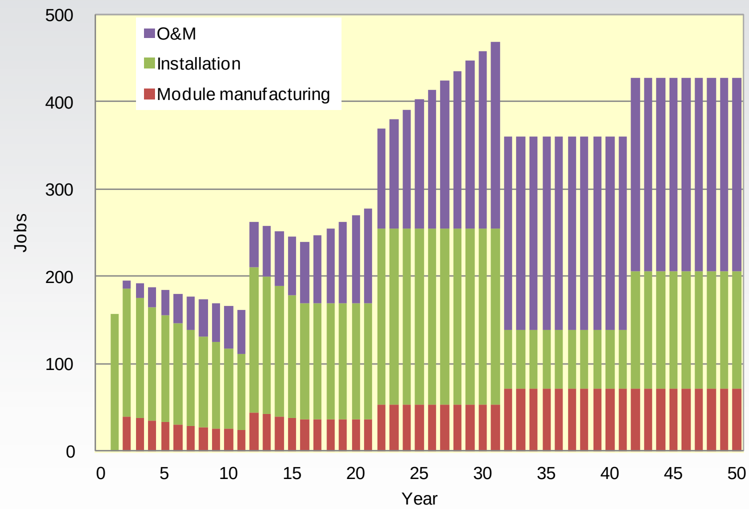
In this scenario, a capacity of PV power plant will achieve 1GW in 24 years and 1,5 GW in 31 years. Since then, PV modules installed in the initial stages reaches to the End-of-Life (EOL), and PV module manufacturing facility provide PV modules for the replacement as well as for another PV power plants.

The manufacturing facilities near the PV power plant will create local jobs for construction and operation of the plant. The right figure (bottom) is the estimated direct employment by a sustainable PV power plant development scheme. In the simulation, annual employment demand for PV module manufacturing, Plant construction, and operation & maintenance at the initial stage are assumed to be 2 person/MW, 7,5 person/MW, and 0.5 person/MW respectively. It also includes the impact of future labour productivity improvement. During constructing 1,5 GW PV power plant, approximately 9 thousand jobs are created during the projected period, and approximately 400 stable jobs are created annually. It should be noted that, the simulation only include direct employment.



Lifetime: PV system=30 yrs., factory=10yrs.

Sustainable scenario for VLS-PV development

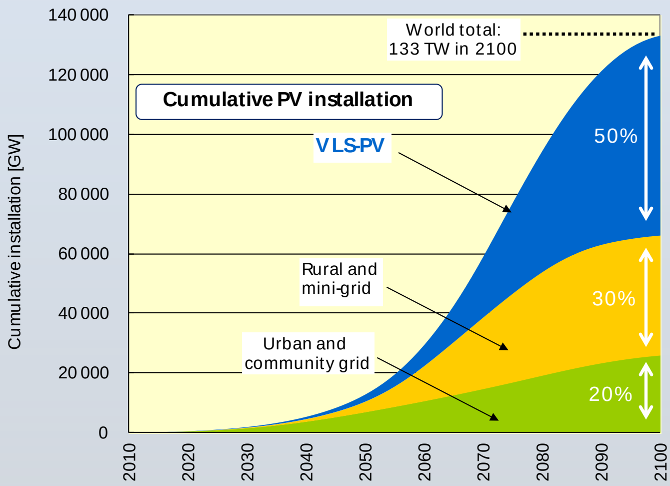


Direct employment by VLS-PV project, with productivity improvement

Vision and Challenges forward

VLS-PV vision

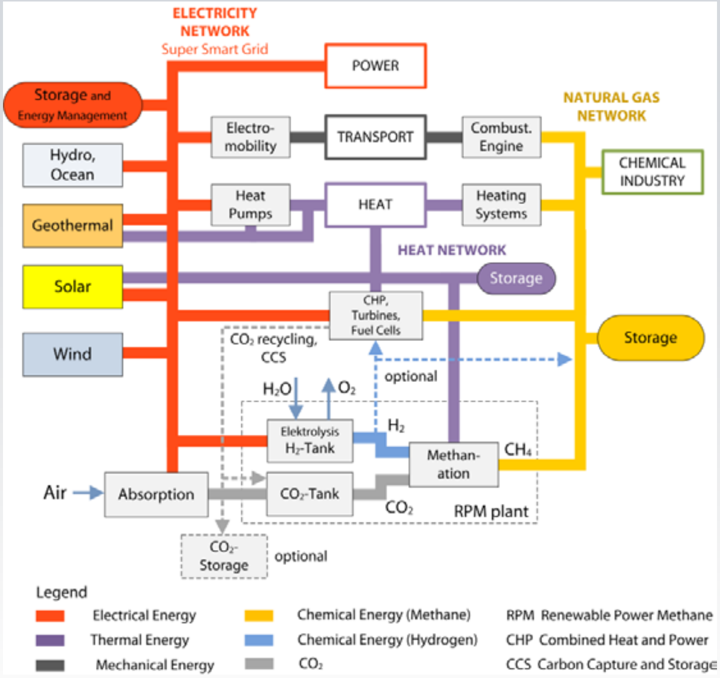
Task8 group has proposed a VLS-PV roadmap towards 2100, which is revealing a future expansion of PV power plants, as shown in the right figure.
The VLS-PV roadmap is based on assumption; PV electricity will provide one-third of primary energy supply in the world; PV application will be roughly classified rural and mini-grid, urban and community grid, and VLS-PV (PV power plants); VLS-PV will provide a half of PV electricity expected in 2100. The expected cumulative PV capacity in 2100 will be 133 TW and a half of the capacity will be PV power plants.



VLS-PV roadmap

Integrated energy system with other renewable energy sources

Global deployment of PV power plants will be accelerated by developing energy supplying system combined with other renewables and energy storage technologies. The integrated system will compensate their fluctuations each other and secure the electricity supply by the renewable energy technologies. The renewable energy can also be used to produce gaseous or liquid RE-based fuels when the power supply surpasses the demand. One of the advantages of this technology is that the energy can be stored in a stable manner and the RE fuels can be used for non-electricity energy demand such as heat or vehicle fuels. CO_2 captured and stored in the existing power plant or captured from ambient air is used to produce RE fuels; hence, it has a multiple environmental effects. Although there are technical and economic barriers to be solved for those RE-based fuel production system, low carbon energy system with 100% renewable energy is certainly possible with this integrated system.

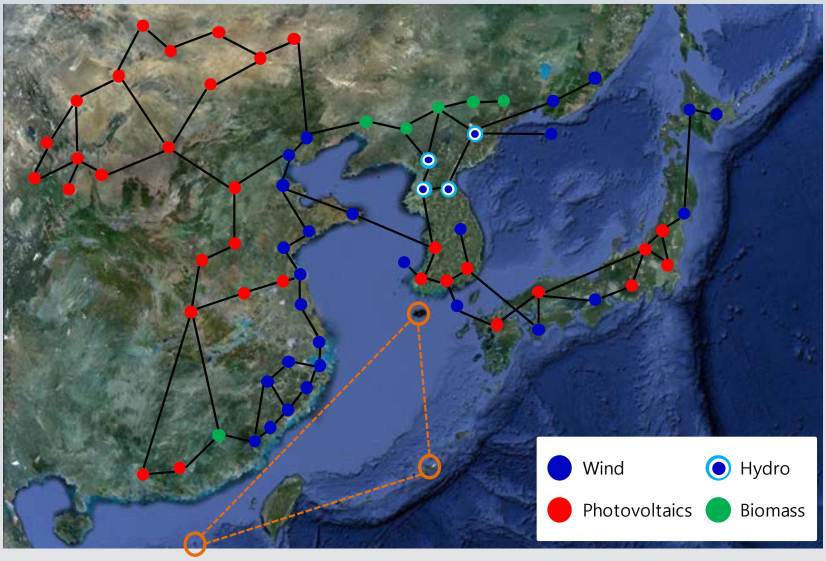


Hybrid PV-Wind-RPM plant as the integral centrepiece of a future sustainable energy supply system

Vision and Challenges forward

Regional and Global Supergrid Network

The variability of the power generation caused by the intermittent nature of the renewable energy sources such as solar and wind power systems are biggest challenge when contribution of renewables to transmission grid rises to very substantial level. One of the most efficient ways to overcome this challenge and to achieve the ambitious goals of increasing the share of renewable energy is to use high capacity transmission grids, called “Supergrid” designed to transfer large amounts of power over the long distances with lower losses. The High-Voltage Direct Current (HVDC) technology is most appropriate technology for the establishment of the regional and global electricity network connecting long distances. A number of global and regional network concepts have been proposed including ‘Desertec’ in the Mediterranean region to use solar energy of the Sahara desert and ‘Gobitec/Asian Super Grid initiative’ in Asia to use vast renewable energy potential of the Gobi desert to power Northeast Asia. IEA PVPS Task8 group also proposed a concept of VLS-PV supergrid in Northeast Asia as below in the figure:



Example of supergrid design in Northeast Asia

The Gobi desert covering China and Mongolia has an abundant solar energy potential and one of the best candidate sites for large scale PV power plants in the desert environment. PV electricity will be supplied to China and Mongolia mainly. In the long term future, the grid can be expanded to even Korea or Japan although there are a number of technical and institutional barriers to overcome.

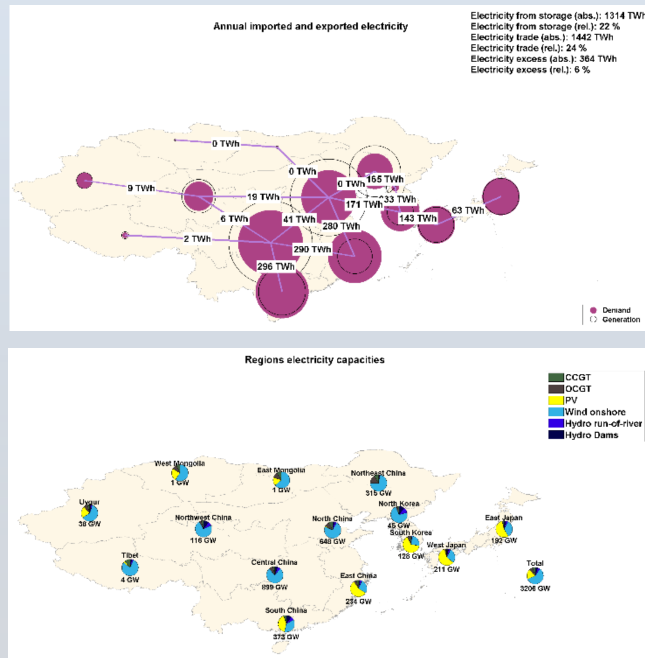
Global deployment of PV power plants will be accelerated by developing an energy supplying system combined with other renewables and energy storage technologies. Our precise study reveals that 100% Renewable Energy system in Northeast Asia is reachable. PV will play an important role although wind energy may dominate the region.

The successful implementation of the VLS-PV supergrid project in the Northeast Asia could significantly improve the increasing mismatch of energy supply and demand in Northeast Asia into an opportunity for substantive energy cooperation.

Vision and Challenges forward

Northeast Asian Supergrid: Renewable Energy Mix and Economics

For Northeast Asia it is proposed that the excellent solar and wind resources of the Gobi desert could be utilized for load centers in China, Korea and Japan as a contribution to the energy transformation ahead. The area is composed by regions, which can be interconnected by a high voltage direct current (HVDC) transmission grid. The results for total system levelized cost of electricity (LCOE), including generation, curtailment, storage and HVDC transmission grid, are 0,064 EUR/kWh and 0,081 EUR/kWh for centralized and decentralized approaches for 2030 assumptions. The importing regions are Japan, Korea, East China and South China, which receive their energy mainly from Northeast China, North China and Central China. The electricity generation shares of the cost optimized system design can reach up to 39 % for PV and 47 % for wind energy (decentralized, 2030) and additional hydro power utilization. The results for 100 % renewable resources-based energy systems are lower in LCOE by about 30-40 % than recent findings in Europe for the non-sustainable alternatives nuclear energy, natural gas and coal based carbon capture and storage technologies. These findings clearly indicate that a 100 % renewable resources-based energy system is THE real policy option.

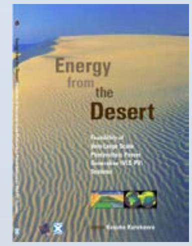


Annual generation and demand (top) and installed capacities (bottom) for area-wide open trade scenario for Northeast Asia and reference year 2030.

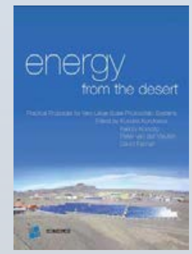
For further information

Our publication: Energy from the Desert

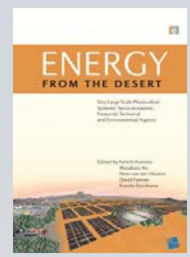
Kosuke Kurokawa, (eds.), 2003. Energy from the Desert - Feasibility of Very Large Scale Power Generation (VLS-PV) Systems, James & James, London (ISBN: 1 902916 41 7)



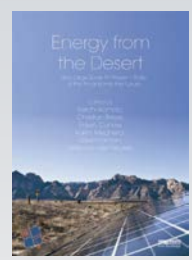
Kosuke Kurokawa, Keiichi Komoto, Peter van der Vleuten, David Faiman, (eds.), 2007. Energy from the Desert - Practical Proposals for Very Large Scale Photovoltaic Systems, Earthscan, London (ISBN: 978 1 84407 363 4)



Keiichi Komoto, Masakazu Ito, Peter van der Vleuten, David Faiman, Kosuke Kurokawa, (eds.), 2009. Energy from the Desert - Very Large Scale Photovoltaic Systems: Socio-economic, Financial, Technical and Environmental Aspects, Earthscan, London (ISBN: 978 1 84407 794 6)



Keiichi Komoto, Christian Breyer, Edwin Cunow, Karim Megherbi, David Faiman, Peter van der Vleuten, (eds.), 2013. Energy from the Desert - Very large scale PV power -state of the art and into the future, Earthscan from Routage, London (ISBN: 978 0 415 63982 8)



Summary documents of books above are available at the IEA PVPS website : http://www.iea-pvps.org

IEA PVPS Task8, External Final Report IEA-PVPS, February 2015. Energy from the Desert - Very Large Scale PV Power Plants for Shifting to Renewable Energy Future, Report IEA-PVPS T8-01: 2015 (ISBN: 978 3 906042 29 9)

(available at the IEA PVPS website: http://www.iea-pvps.org)

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The compilation of this brochure is supported by
New Energy and Industrial Technology Development Organization (NEDO), Japan