IEA INTERNATIONAL ENERGY AGENCY

Energy from the Desert: Very Large Scale PV Power Plants for Shifting to Renewable Energy Future

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T8-01:2015

INTERNATIONAL ENERGY AGENCY
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Energy from the Desert: Very Large Scale PV Power Plants for Shifting to Renewable Energy Future

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<Photos of cover>
- *Top* : *Topaz Solar Farm, San Luis Obispo County, CA, USA (courtesy of First Solar, Inc.)*
- *Bottom* : *Longyangxia Hydropower PV station, Gonghe, Qinghai, China (courtesy of Yellow River Hydropower Company)*

Contents

Foreword

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 our work.

The work on very large scale photovoltaic power generation (VLS-PV) systems first began under the umbrella of the IEA PVPS Task6 in 1998. After that, the new Task8 – Study on Very Large Scale Photovoltaic power generation (VLS-PV) systems was established in 1999.

The scope of Task8 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 realising VLS-PV systems in the future. Issues covered reflect the many facets VLS-PV for target groups as to political and governmental organisations as well as for e.g. institutes world-wide to provide a better understanding of these issues.

Since Task8 has been established, we published our extensive reports as a series of 'Energy from the Desert', focusing on VLS-PV systems. The books show that the VLS-PV is not a simple dream but is becoming realistic and well-know all over the world.

During our works, large scale PV systems increasingly count as a realistic energy option and have started to appear around the world in the 2000s, and have been rising substantially year on year. Now 500 MW scale PV systems are becoming reality.

Here, we compile the final Task8 report, entitled 'Energy from the Desert' as well. This report presents comprehensively results coming from our 15-years activity, and also includes the brand-new topics on VLS-PV, e.g. PV power plants.

We have recognized that very large scale solar electricity generation provides economic, social and environmental benefits, security of electricity supply and fair access to affordable and sustainable energy solutions.

'It might be a dream, however ---'. It was a motivation when Task8 was established in 1999.

Now, we recognise that VLS-PV, e.g. PV power plant, has become one of the feasible options for large scale deployment of PV systems and renewable energy technologies.

河本 桂 一

Keiichi Komoto
Operating Agent, Task 8

Acknowledgement

This report and out activity, Task8, was accomplished with the kind support of various organizations and people around the world.

The Task8, started in 1999. Since then we published technical reports, as a series of ‘Energy from the Desert’. During the period, we organized some international symposiums, workshops and seminars in the world, e.g. Japan, China, Korea, Mongolia, Australia, Israel, France, Germany, Greece, Italy and the United Kingdom. Through these activities, we obtained various kinds of expert advices and new memberships. Based on these experiences, we started our 5th phase activity in 2012.

This report corresponds to the final Task8 report coming from our 15 years work since established, as well as a conclusion of our 5th phase activity during 2012-2014.

We thank Hiroyuki Yamada and Masamichi Yamamoto (NEDO, Japan), who provided us a great deal of support as the Operating Agent country member of the IEA PVPS Executive Committee.

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Last but not least the Task 8 members would like to thank all participants for their fruitful contributions and so many meetings ever in a constructive and pleasant atmosphere. Not to forget the always experienced kind hospitality.

Finally, the Task8 members express sincere thanks to Stefan Nowak (Chairman of the IEA PVPS) and Mary Jo Brunisholz (IEA PVPS ExCo secretary), for giving us valuable opportunities and strong supports for a long time.

Executive Summary: Very Large Scale PV Power Plants for Shifting to Renewable Energy Future

A. Expectations and potential for PV power plants: Why VLS-PV?

Global energy consumption has been increasing since the Industrial Revolution and is expected to increase for the coming 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.

A.1 World energy and environmental issues

World economic growth in the 20th century was strongly driven by technologies based on a mass-consumption of fossil energy. On the other hand, drastic increase in energy consumption has led to global environmental issues including climate change. Although historical energy consumptions and carbon emissions are mainly attributed to developed countries, the impacts of some emerging countries on those issues have been increasing in a drastic manner. The importance of transition to a low carbon society has been widely recognised internationally. The global actions are essential to achieve the goal of low carbon society with sustainable energy supply.

According to the World Energy Outlook by IEA[1)], energy consumption and CO_2 emission are projected to increase continuously, as shown in from Fig. A.1-1 to Fig. A.1-4. It is forecasted that energy and electricity demand in Non-OECD countries will also continue to increase and that as a result CO_2 emission will continue to increase in such countries.

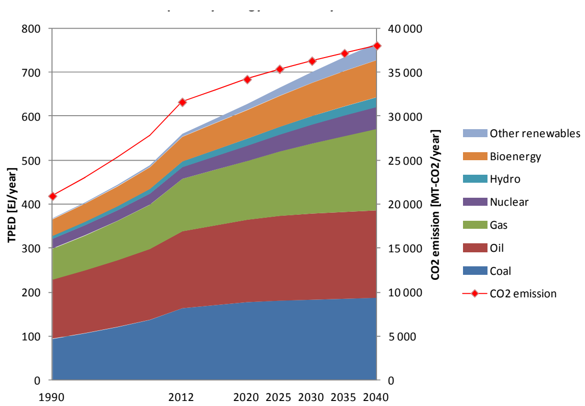

Fig. A.1-1 Primary energy demand and CO_2 emission in the world (New Policies Scenario)[1)]

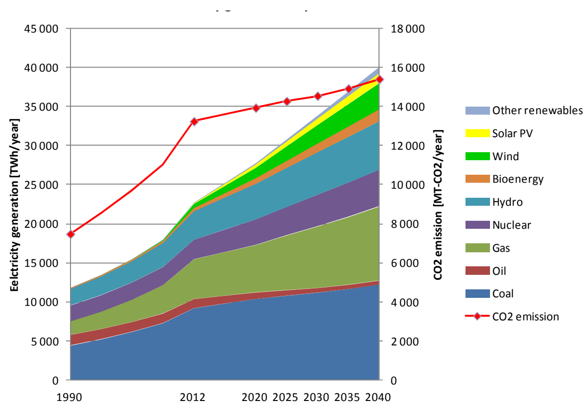

Fig. A.1-2 Electricity generation and CO_2 emission by electricity generation (New Policies Scenario)[1)]

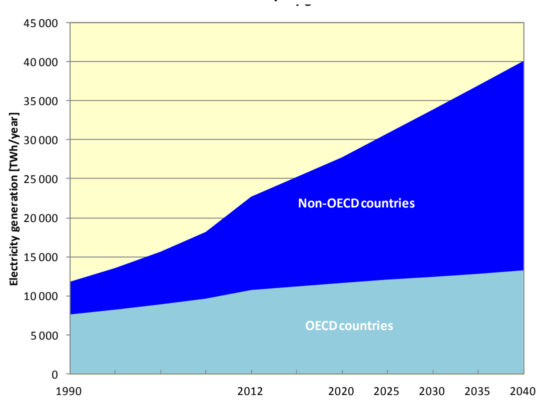

Fig. A.1-3 Electricity generation in OECD and Non-OECD countries (New Policies Scenario)[1)]

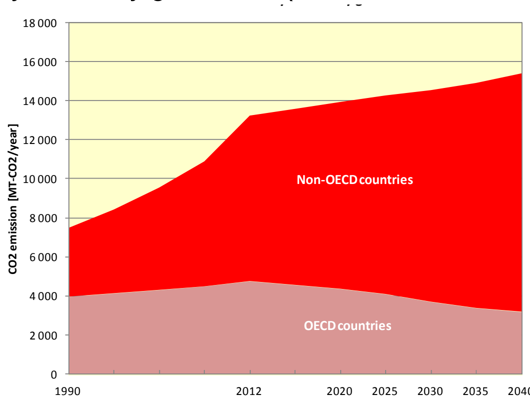

Fig. A.1-4 CO_2 emission by electricity generation in OECD and Non-OECD countries (New Policies Scenario)[1)]

The fifth assessment report from Intergovernmental Panel on Climate Change (IPCC)[2,3] concluded that climate change is mainly driven by human activity, saying that:

"Warming of the climate system is unequivocal; Globally, economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion; Direct CO_2 emissions from the energy supply sector are projected to almost double or even triple by 2050 compared to the level in 2010, unless energy intensity improvements can be significantly accelerated beyond the historical development."

On the other hand, the report also stated the possibility of renewable energy technologies including PV technology for overcoming the issues as follows:

"Decarbonising (i.e. reducing the carbon intensity of) electricity generation is a key component of cost effective mitigation strategies in achieving low-stabilization levels; Many RE technologies have demonstrated substantial performance improvements and cost reductions, and a growing number of RE technologies have achieved a level of maturity to enable deployment at significant scale."

Meanwhile, discussions and directions on nuclear power, which was positioned as low-carbon base-load power, have become polarised after Fukushima accident in March 2011. One is that nuclear power is necessary for suitable electricity supply and the other is that considerable extensive risks by nuclear power should be avoided. At the IPCC 5th assessment report[3], description on nuclear power is, for example, that *"nuclear energy could make an increasing contribution to low carbon energy supply, but a variety of barriers and risks exist"*.

Energy Technology Perspectives 2014 (ETP2014) from IEA[4], one of the representative projections in the world, developed and analysed several scenarios on future energy and electricity supply, as well as associated global temperature rise by 2100. Table A.1-1 shows major scenarios of ETP 2014.

Table A.1-1 Examples of scenarios under the ETP2014[4]

6DS	The 6DS is largely an extension of current trends. By 2050, energy use grows by more than two-thirds (compared with 2011) and total GHG emissions rise even more. In the absence of efforts to stabilise atmospheric concentrations of GHGs, average global temperature rise is projected to be at least 6 ^{o}C in the long term.
4DS	The 4DS takes into account recent pledges made by countries to limit emissions and step up efforts to improve energy efficiency, projecting a long-term temperature rise of 4 ^{o}C.
2DS	The 2DS is the main focus of ETP 2014. It describes an energy system consistent with an emissions trajectory that recent climate science research indicates would give at least a 50 % chance of limiting average global temperature increase to 2 ^{o}C. The 2DS also identifies changes that help ensure a secure and affordable energy system in the long run. It sets the target of cutting energy- and process-related CO_2 emissions by more than half in 2050 (compared with 2011) and ensuring that they continue to fall thereafter. Importantly, the 2DS acknowledges that transforming the energy sector is vital, but not the sole solution: the goal can be achieved only provided that CO_2 and GHG emissions in non-energy sectors are also reduced.
2DS hi-Ren	The 2DS-High Renewables (2DS hi-Ren) variant illustrates an expanded role of renewables in the power sector, based on a decreased or delayed deployment of nuclear technologies and CCS.

The 2DS is the main focus of ETP 2014 and offers a vision of a sustainable energy system with reduced greenhouse gas and CO_2 emissions[4]. It describes an energy system consistent with an emissions trajectory that recent climate science research indicates would give at least a 50 % chance of limiting average global temperature increase to 2 ^{o}C[4]. As shown in Fig. A.1-5, to meet 2DS targets, CO_2 emissions per unit of electricity must decrease by 90% by 2050. This reveals that a massive reversal of recent trends that have shown continued reliance on unabated fossil fuels for generation is required.

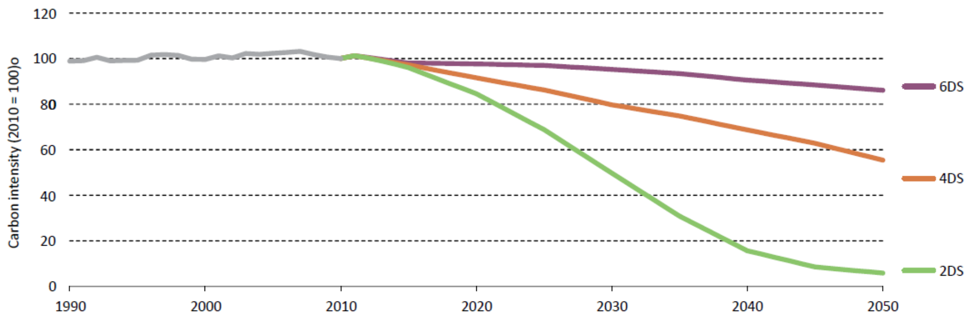

Fig. A.1-5 Electricity generation sector carbon intensity index by ETP2014[4)]
(©OECD/IEA 2014, Energy Technology Perspectives, fig. 3.3, p. 124, IEA Publishing.
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Fig. A.1-6 shows global electricity mix in various scenarios in 2050 described in ETP 2014. In the 2DS scenario, renewable energy comprises 65 % of the overall electricity demand, and the reminder 35 % is from nuclear and fossil fuel with CCS (carbon capture and storage). In 2DS-High Renewable (2DS hi-Ren) scenario, the share of the renewable energy in global power generation is even higher, and covers 79 % of the total demand[4)]. In the scenario, PV is the second largest energy sources (next to hydro) covering 16 % of the global electricity mix in 2050. The global cumulative capacity of the PV reaches to 4 626 GW.

Fig. A.1-7 shows cumulative CO_2 mitigation in the 2DS-hi Ren scenario from power sector in contrast to 6DS scenario by 2050.

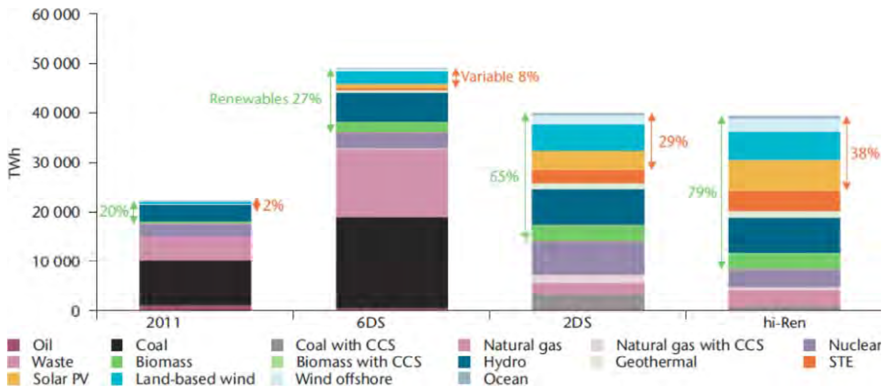

Fig. A.1-6 Global electricity mix in 2011 and in 2050 in three ETP 2014 scenarios[5)]
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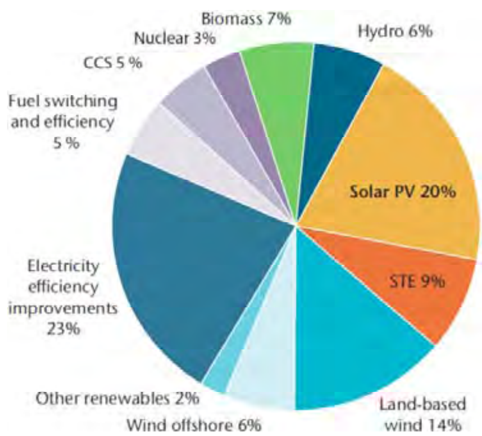

Fig. A.1-7 Cumulative technology contributions to power sector emission reductions in ETP 2014 hi-Ren Scenario relative to 6DS up to 2050[6)]
(©OECD/IEA 2014, Technology Roadmap: Solar Photovoltaic Energy, fig.6, p. 19, IEA Publishing.
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A.2 PV power in the deserts

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 are essential. The desert area which covers one-third of the land surface is clearly one of the best sites for the purpose.

Fig. A.2-1 and Table A.2-1 show world major deserts. Total area of deserts listed is approximately 1 900 million ha. It should be noted that the desert land areas have been expanding in the last few decades. Table A.2-1 also presents preliminary PV installation potential evaluation on the desert with 50 % space factor. The total electricity produced 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 of the annual world power demand (Fig. A.2-2).

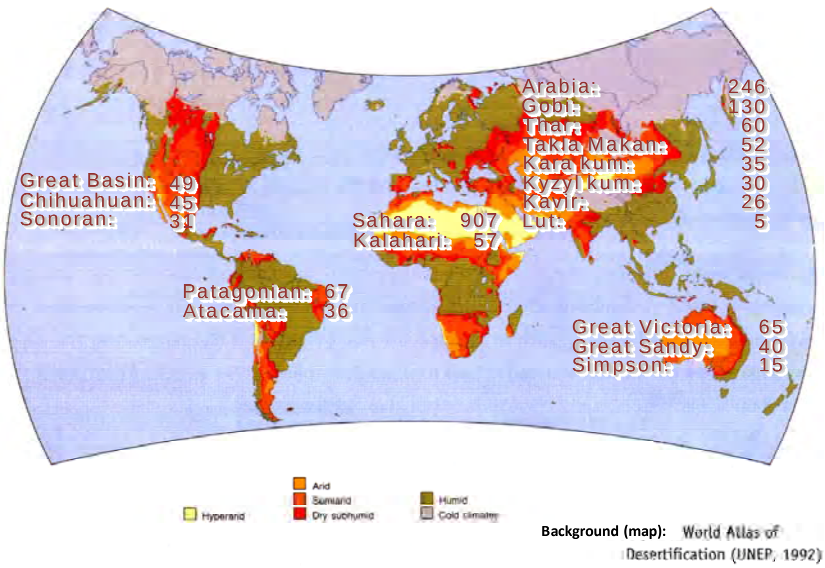

Fig. A.2-1 World desert (unit: 10^6 ha)[7)]

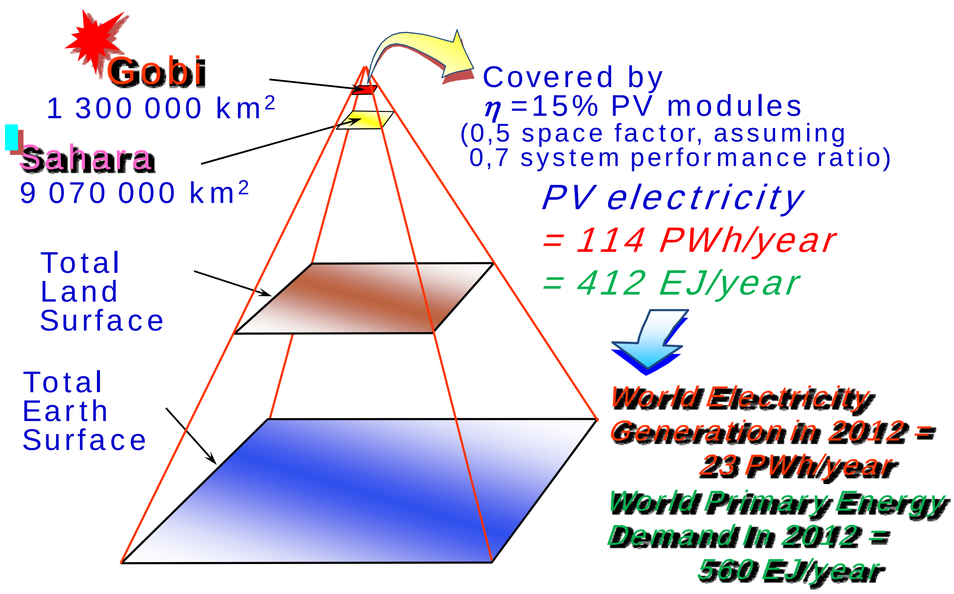

Fig. A.2-2 Solar Pyramid

Table A.2-1 World deserts and solar energy potential

Desert Name	(a) Area (10^6 ha)[7]	(b) Annual average Irradiation ($MJ \cdot m^{-2} \cdot d^{-1}$)[8]	(b) Annual reference Yield (h)	(d) Possible PV array Capacity (TW)	(e) Annual electricity Generation (10^3 TWh)
North America					
Great Basin	49	20,32	2 060	36,8	53,0
Chihuahuan	45	19,68	1 995	33,8	47,1
Sonoran	31	17,21	1 745	23,3	28,4
Subtotal	125			93,8	128,5
South America					
Patagonian	67	12,81	1 299	50,3	45,7
Atacama	36	22,08	2 239	27,0	42,3
Subtotal	103			77,3	88,0
Australia					
Great Victoria	65	21,57	2 187	48,8	74,6
Great Sandy	40	23,11	2 343	30,0	49,2
Simpson	15	21,57	2 187	11,3	17,2
Subtotal	120			90,0	141,1
Asia					
Arabia	246	22,24	2 255	184,5	291,2
Gobi	130	16,53	1 676	97,5	114,4
Thar	60	21,44	2 174	45,0	68,5
Takla Makan	52	16,19	1 641	39,0	44,8
Kara kum	35	16,34	1 657	26,3	30,4
Kyzyl kum	30	16,34	1 657	22,5	26,1
Kavir	26	18,33	1 858	19,5	25,4
Lut	5	21,09	2 138	3,8	5,6
Subtotal	584			438,0	606,4
Africa					
Sahara	907	23,52 26,46	2 534	680,3	1 206,5
Kalahari	57	22,54	2 285	42,8	68,4
Subtotal	964			723,0	1 274,9
Grand Total	1 896			1 422,0	2 238,9

(c) =(b) × 365d/($3{,}6 MJ \cdot m^{-2} \cdot h^{-1}$) : where $3{,}6 MJ \cdot m^{-2} \cdot h^{-1} = 1 kW \cdot m^{-2}$ is the reference irradiance.
(d) =0,14 × 1 kW/m^2 × (a) × 0,5 : where 0,15 is PV module efficiency, and 0,5 is space factor.
(e) =(d) × 0,7 × (c) : where 0,7 is system performance ratio.

The desert areas have abundant potential for PV power plants. However, not all the area is suitable for PV power plants and the site evaluation is very important. There are several unfavourable conditions for PV to be installed in the desert area. For example, a sand dune area may not be suitable for the PV power plants 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 utilised 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 plants.

Fig. A.2-3 is the evaluation results of the suitable areas for PV power plants for selected six deserts in the world using 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; hence, regarded as more suitable for PV. The potential annual generation by PV power plants within suitable desert area is calculated to be 752 PWh, which is approximately 5 times of the world energy demand and 33 times of world electricity generation in 2012.

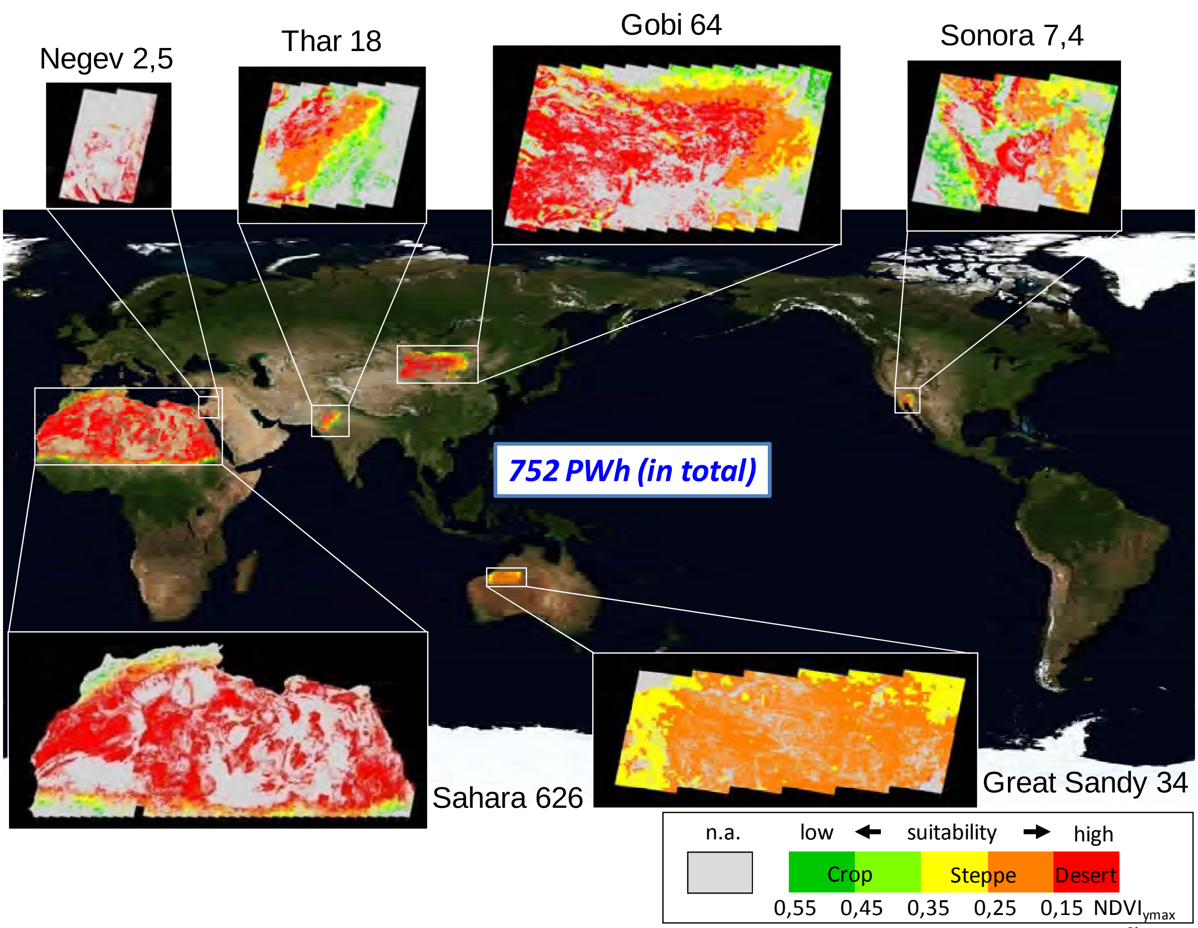

Fig. A.2-3 Expected annual electricity generation at the PV power plants in world 6 deserts[9)]

B. Technical feasibility of PV power plants: VLS-PV is already feasible!

B.1 Market trends in PV power plants

When Task8 established in 1999, cumulative capacity of PV installation in the world was less than 500 MW. Since then, PV market growth rapidly, especially in a latter half of 2000s. Cumulative PV installation in the world achieved 100 GW in 2012 and 140 GW at the end of 2013[10)]. In the last few years, annual PV installation has been around 30 GW or more (see Figs. B.1-1 and B.1-2).

In 2000s, major PV market was in European region. After 2011, the major PV market shifted to USA, China and other Asian region. Especially, expansion of Chinese market is remarkable as shown in Fig. B.1-3. At the end of 2013, cumulative PV installation in China was 19,7 GW, in which 16,3 GW is large scale PV power plant. Similarly, annual PV installation in China in 2013 was 13,0 GW, in which 12,1 GW is large scale PV power plant application.

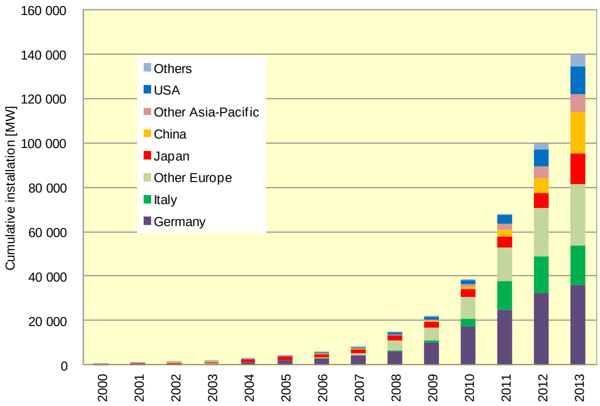

Fig. B.1-1 Cumulative PV installation in the world[10,11)]

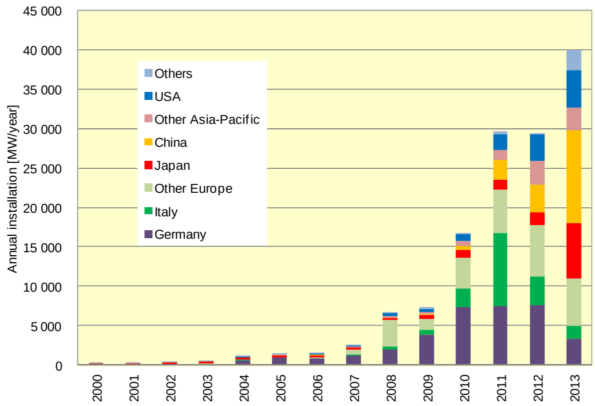

Fig. B.1-2 Annual PV installation in the world[10,11)]

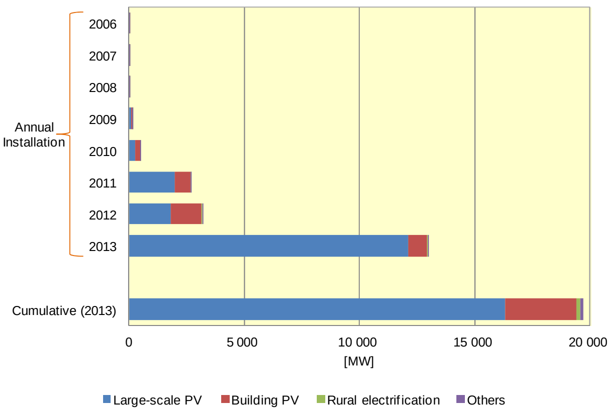

Fig. B.1-3 Trends in PV installation in China[12)]

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, especially in Spain, under the Feed-in-Tariff scheme. After that, large scale PV power plants market expanded to other regions such as in USA and China for utility scale. Today, PV power plants with several tens of MW capacities are also emerged in Chile, as well as South Africa.

Fig. B.1-4 shows trends in large-scale PV installation until 2013, based on our survey. Unfortunately, there is no reliable statistics to capture all the large scale PV power plants in the world. Therefore, we've counted large scale PV power plants as much as possible, and 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 exceeds 9 GW. By adding the PV power plants less than 10 MW and starting operation until 2010 on the 9 GW above, total capacity exceeds 14 GW. In addition, taking into account some external information resources regarding China (see Fig. B.1-3) and USA (7 GW in Nov. 2013)[13], the share of large scale PV power plants is at least 10-15 % of the total PV installation in the world.

Similarly, the largest PV power plants record in the world has been broken every year, as shown in Fig. B.1-5. The number of PV power plants over 100 MW in operational is more than 20 (see Fig. B.1-6). In 2011, 200 MW PV power plant was constructed and started its operation in China. The capacity of this plant was expanded to 300 MW in 2013 and 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. Also, in USA, Topaz Solar Farm in Arizona, and Desert Sunlight in California started operation in November 2014 and December 2014, respectively. Both plants have a capacity of 550 MW.

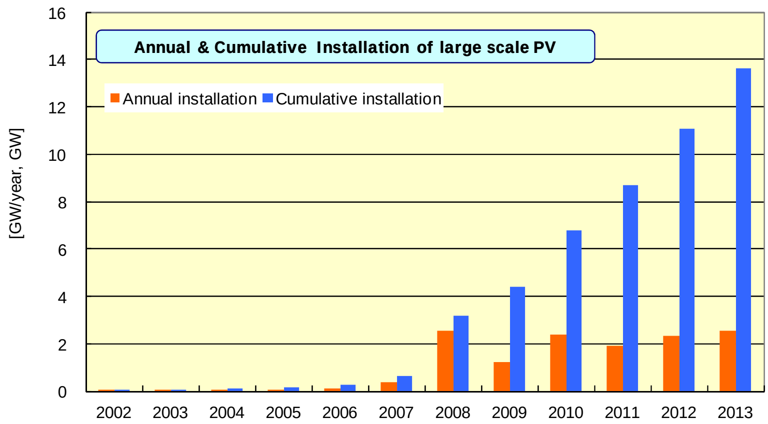

Fig. B.1-4 Trends in large-scale PV installation (based on confirmed projects)

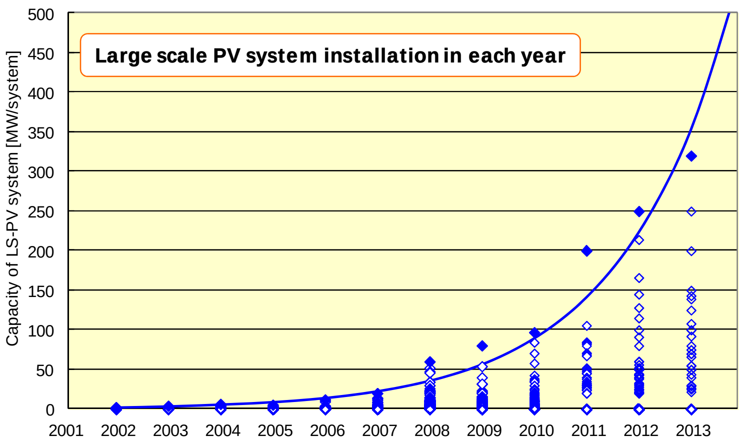

Fig. B.1-5 Expansion of capacity of large-scale PV system

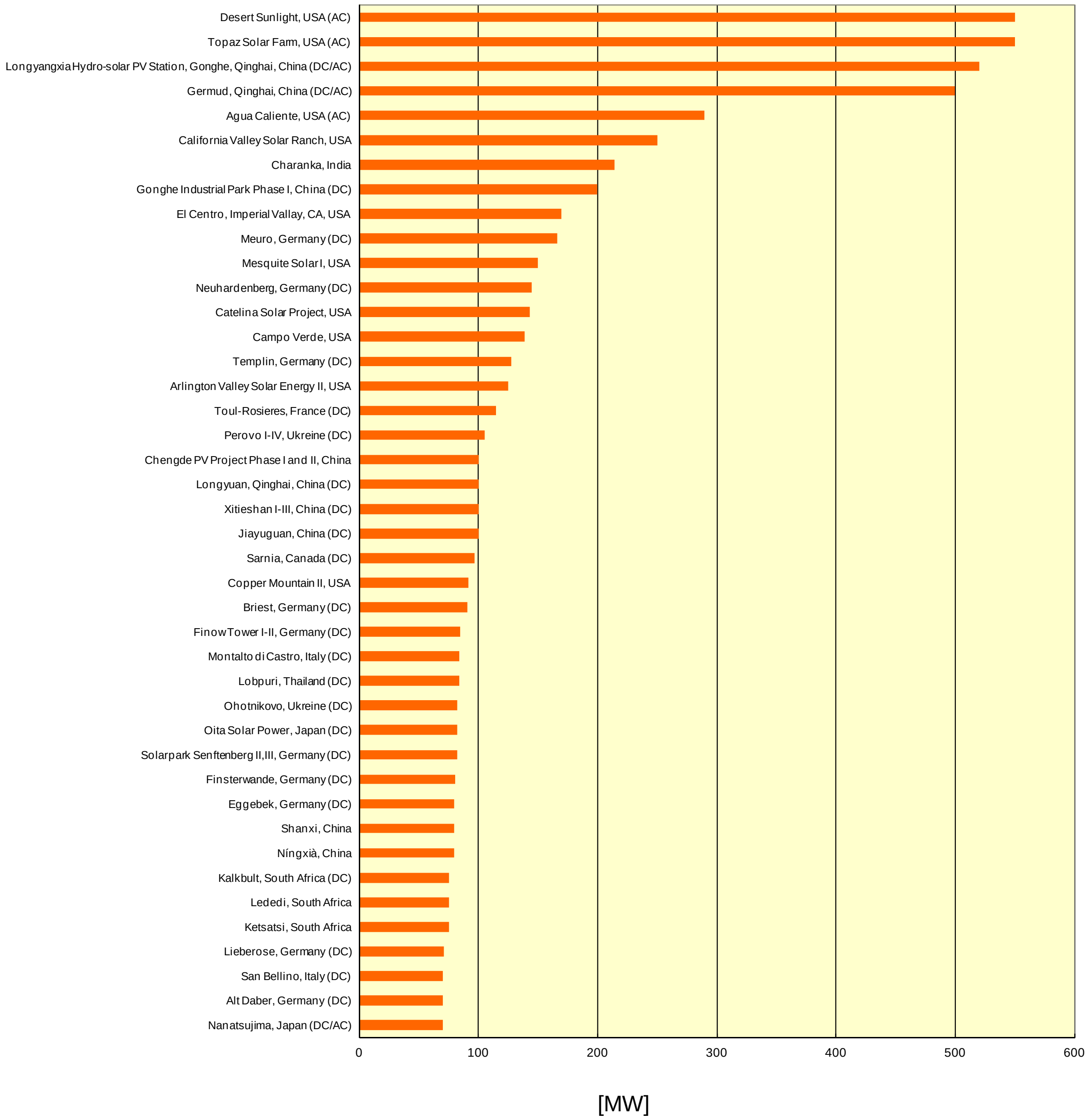

Fig. B.1-6 Examples of large-scale PV plants

As shown above, PV power plants with several hundred MW scale area already in the commercial stage and technically feasible. It may be reasonable to expect that GW-scale PV power plants will come on the market in the near future. Although it is not included in the statistics above, there are also several large scale concentrator photovoltaic (CPV) power plants which have a capacity of several tens of MW already under operation. Since high DNI (direct normal irradiance) is the prerequisite for the economic operation of the CPV technology, the desert areas are also an ideal place for CPV installations.

Fig. B.1-7 Longyangxia dam, Qinghai, China ($520MW_{DC/AC}$, c-Si) combined with 1,28 GW Hydro power

Fig. B.1-8 Germud, Qinghai, China (500 $MW_{DC/AC}$, c-Si)

Fig. B.1-9 Agua Caliente, AZ, USA (290 MW_{AC}, CdTe)

Fig. B.1-10 Osaka, Japan (12 MW, CIS) (courtesy of Solar Frontier K.K.)

Fig. B.1-11 Lobpuri, Thailand (84 MW_{DC}, TF-Si)

Fig. B.1-12 60MW HCPV in Qinghai, China

It should be noted that existing PV power plants over 100 MW may be constructed and operated under advantaged conditions, e.g. grid connection with and capacity of transmission line, O&M including output control, etc. In order that the PV power plants to be one of the major power sources in the future, technology development such as grid integration with energy storage and long-distance electricity transmission including HVDC will be essential. In addition, integrated energy network management with other renewable energy sources, such as wind and solar thermal generation will also become important.

B.2 PV in the desert environment

PV power plants in desert areas will 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 modules can reduce the power output considerably.

A degree of soiling and its impact is depending upon surrounding environments and meteorological conditions of the site, as shown in Fig. B.2-1. A solution to soiling is ‘cleaning’. Cleaning option for PV plants can be justified if the cost for cleaning is lower that the income generated by the solutions. In general, a cost for cleaning is heavily depending upon the local cost of labour and water. A cost effective cleaning method will be selected by considering local conditions, as shown in Fig. B.2-2.

In case of cleaning by water, amount of water consumption will be also influenced to the cleaning cost. Table B.2-1 summarises the pros and cons of each cleaning options in China, in terms of the volume of water required, speed, quality of cleaning, as well as cost required.

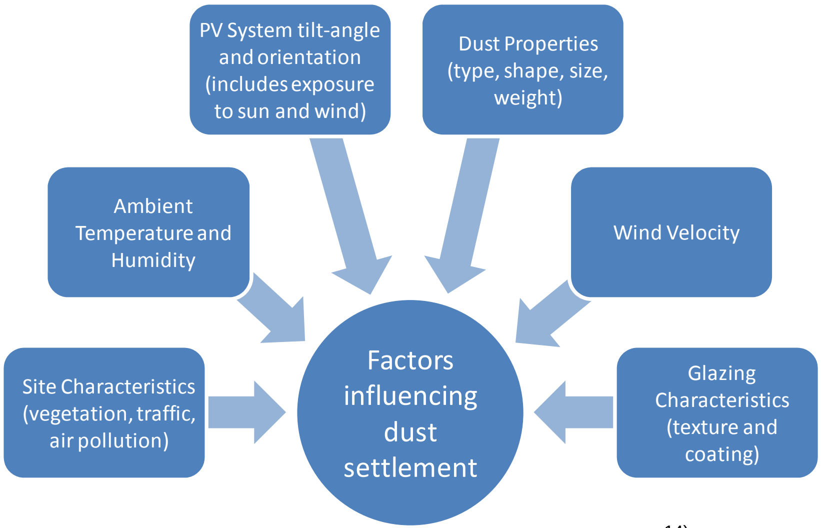

Fig. B.2-1 Factors influencing dust settlement[14)]

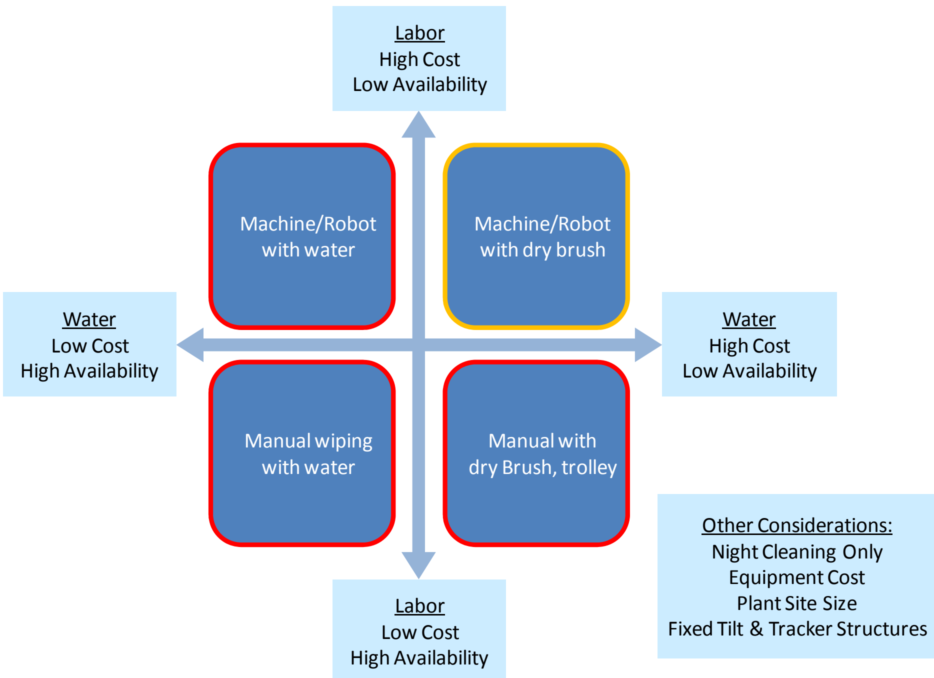

Fig. B.2-2 Classification of cleaning method[14)]

Table B.2-1 Comparing method of cleaning by water, examples in China[12)]

Methods	Cleaning equipment	Water consumption (ton/10MW/times)	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

Occurrence of soiling will be depending upon characteristics of sand particles, meteorological condition, etc. There are a number of academic researches on mechanisms of soiling. In the field of solar energy, e.g. not only PV and CPV, but also CSP, R&D on countermeasures against soiling are studied and proposed[15-17)]. Recent research trends shift from 'wet' to 'dry', from 'restoration' to 'prevention', as shown in Fig. B.2-3.

In addition, a simulation tool for evaluating influences of soiling to PV power plants has been also developed[18)]. The tool requires several parameters concerning surrounding environment. It estimates degree of soiling and influence on the electricity output, and allow plant owner to develop cleaning plan before starting operation. After starting operation, by updating environmental parameters and putting actual result of electricity generation, estimation is modified to improve the accuracy and the reliability.

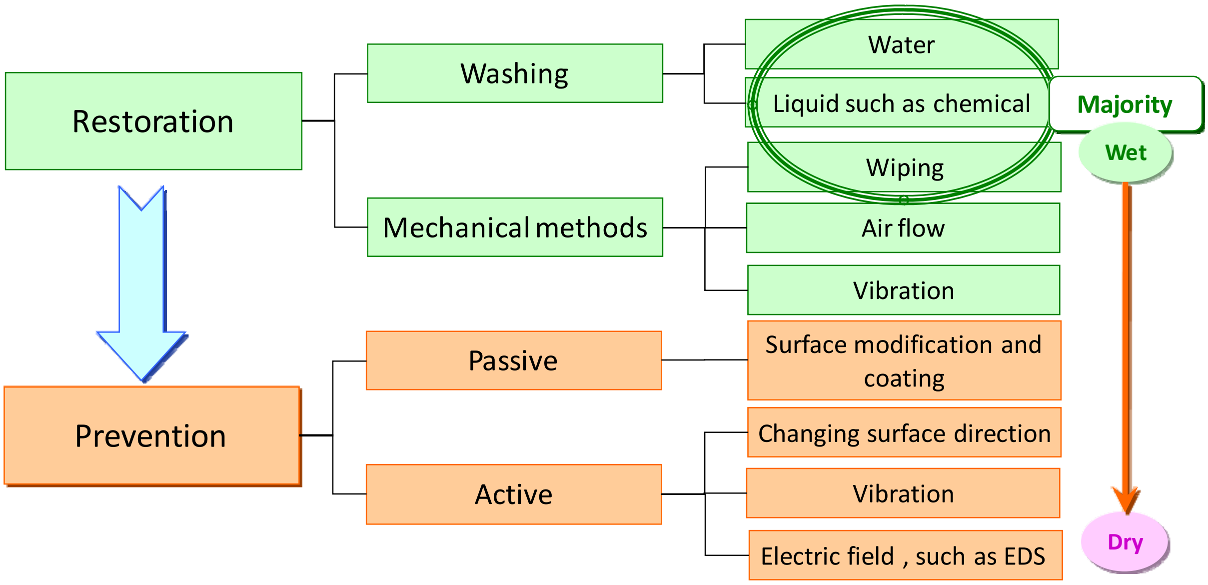

Fig. B.2-3 Examples of countermeasures for soiling

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.

C. Economic feasibility of PV power plants: VLS-PV can provide low-cost electricity!

C.1 Cost trends and perspectives

Prices of PV modules are falling down rapidly. The lowest prices in recent years may be below costs. However, the costs will decline further and the IEA PV technology roadmap[19)], as shown in Fig. C.1-1, is forecasting that module costs will be expected to fall to 0,3-0.4 USD/W by 2035.

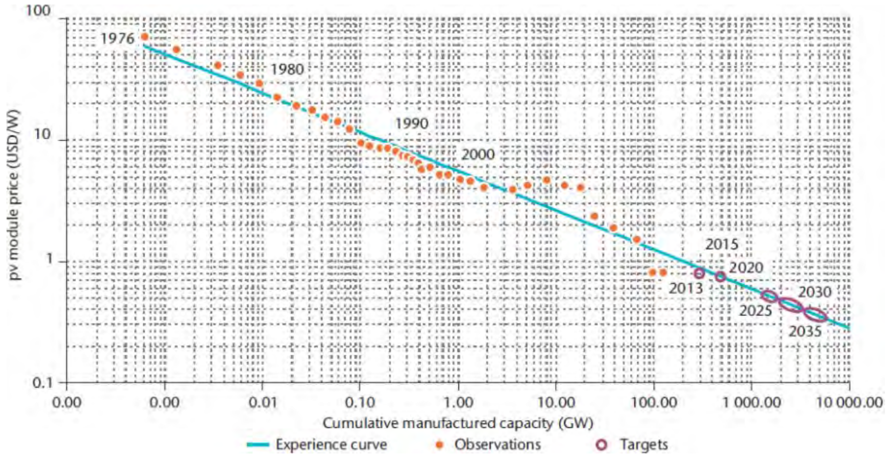

Fig. C.1-1 Past modules prices and projections to 2035 based on learning curve[19)]
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As well, initial cost for PV system installation has been decreasing with a market expansion, performance improvement, technology innovation, etc. In some regions, 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. However, further cost reduction will be required for PV power plants to compete with conventional power plants.

According to the IEA PV technology roadmap[20)], 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 Fig. C.1-2. If the indicated costs are achieved, the LCOE of PV power plants will be able to compete with conventional power plants.

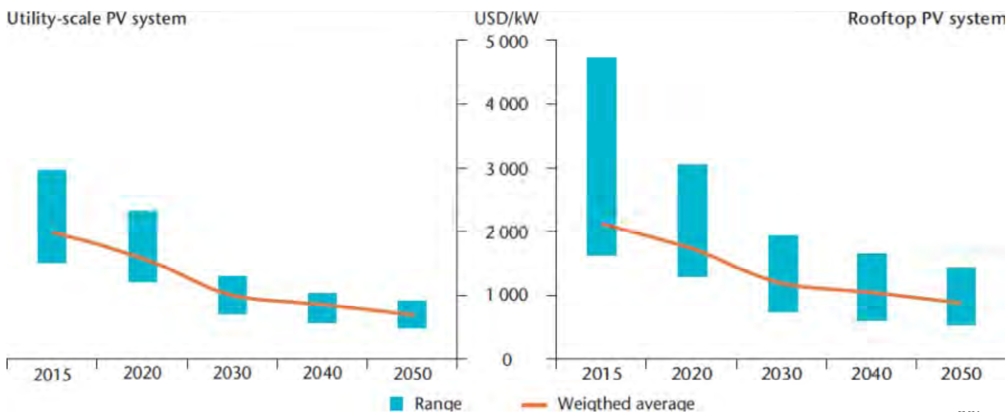

Fig. C.1-2 PV investments costs projections in the hi-Ren scenario of EPT2014[20)]
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C.2 LCOE of PV power plants

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. Fig. C.2-1 represents the expected LCOE of 1 GW PV power plants assuming some desert areas, as a function of global horizontal annual irradiation. The assumptions underlying the calculation are as follows:

- Initial cost including transportation and construction cost : 1-3 MUSD/MW
- WACC for CAPEX : 5,4 %
- Operational lifetime : 30 years
- OPEX : 1 % of initial cost
- Performance ratio excluding degradation rate : 0,73-0,83 (depending upon the area)
- Ratio of soiling loss : 5 % of overall output
- Degradation ratio : 0,5 %/year.

The LCOE in the higher initial cost case (3 MUSD/MW), middle case (2 MUSD/MW), which is the current average level) and lower case (1 MUSD/MW), which is corresponding to the level forecasted by the IEA PV technology roadmap[20) are approximately 0,15 USD/kWh, 0,10 USD/kW and 0,05 USD/kWh respectively, although there are some differences depending on regional conditions.

Even the current level, PV power plant is economically competitive in some area, and in the near future, PV power plants will become more competitive against conventional power plants.

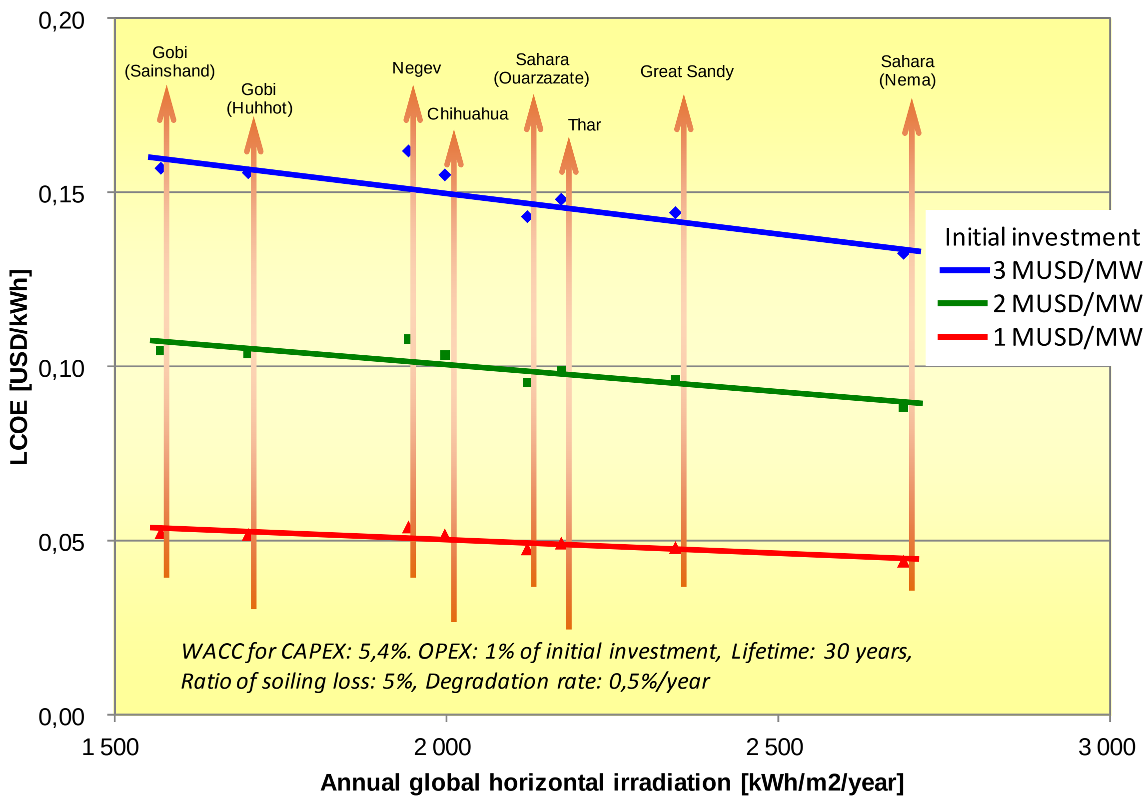

Fig. C.2-1 Expected LCOE of PV power plants

D. Environmental benefits of PV power plants: VLS-PV is a key for sustainable environment!

Technology level of the VLS-PV plants is already reached to the practical level. Economic status has been improved considerably and expected to compete with conventional power plants in the near future. Further development in technology and market will make PV technology more attractive as a major and reliable power sources. Considering its environmental value, PV is in a good position to replace the conventional power plants.

D.1 Low carbon and energy generation

The PV system is an alternative energy sources and one of the promising technologies for climate change mitigation. Life-Cycle Assessment (LCA) is a method to evaluate environmental effect quantitatively by using typical indices such as Energy Pay-back Time (EPBT) and CO_2 emission rate.

The EPBT is a year required to compensate the energy consumed throughout its lifecycle by the energy produced. After the period, the PV produces extra energy until its end-of-life. That is, PV with shorter EPBT can create larger energy and provide bigger contribution as an alternative energy.

CO_2 emission rate is CO_2 emissions of unit energy production (kWh), in other words, CO_2 emissions divided by its life-cycle energy production. The lower CO_2 emission rate is the more the technology can contribute on CO_2 emissions reduction.

The EPBT and CO_2 emission rate of the VLS-PV plants shown as Figs. D.1-1 and D.1-2 are within the ranges of 1 to 3 years and 30 to 70 g-CO_2/kWh respectively, depending on the type of PV module (efficiency mainly) and location of installation (irradiation and array manufacturing electricity mainly).

The EPBT of VLS-PV plants will be very short. Assuming 30 years life-time, the plants can produce 10 to 30 times more energy than the total energy consumed throughout the life-cycle. Similarly, the CO_2 emission rate will be very low. It is one-tenth or one-twentieth of average CO_2 emission rate in China or Africa. This means that 90 to 95 % CO_2 emissions for power generation can be reduced by substituting new fossil fired power plants with the VLS-PV plants.

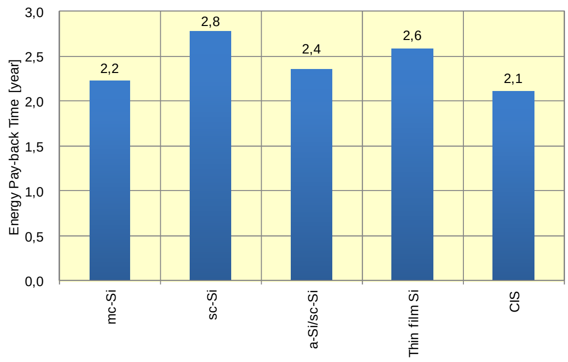

Fig. D.1-1 Energy Pay-back Time of PV power plant in the Gobi desert, China[21)]

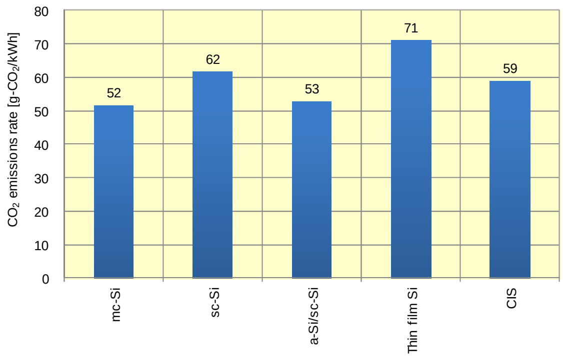

Fig. D.1-2 CO_2 emission rate of PV power plant in the Gobi desert, China[21)]

D.2 Ecological sustainability

The impacts of CO_2 emissions on global environment and the measure to mitigate the impacts are quantitatively evaluated by a number of institutions and scientists including IPCC. 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. The unit of EF is ‘gha’ which is weighted area in ha. For example, the impact of

CO_2 emissions are expressed by required forest area in ‘gha’ to absorb them. The impact of food production is expressed by the required agricultural land area in ‘gha’ to produce it. The construction of the new buildings or the reclamation of the farm land on the unused land area are expressed as reduction or increase in capability of ecosystem compared to the original ecosystem. Capability of ecosystem is called bio-capacity (BC), and also expressed in ‘gha’. 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.

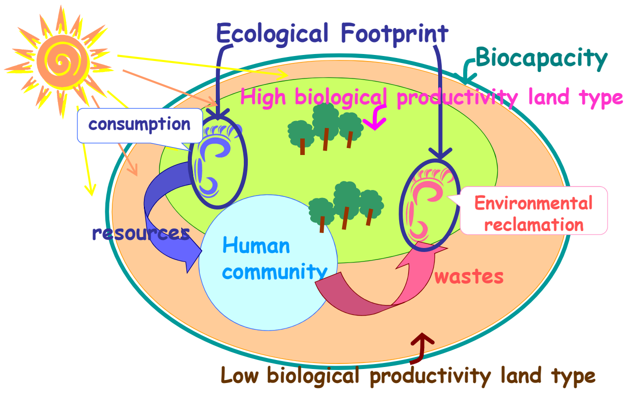

Fig. D.2-1 Conceptual image of ecological sustainability[9)]

According to the Global Footprint Network[22)], the EF of the world overshot and the world is not sustainable since 1970s. Amount of overshooting, e.g. the EF minus the BC, increases every year. This is mainly caused by the increase in CO_2 emissions from fossil fuel consumption. Therefore, CO_2 emission mitigation by the VLS-PV plants can contribute to the reduction of the EF. Although the installation of the VLS-PV plants may reduce the BC of the land, the impact will be limited if it is constructed in lower BC land such as desert. The reduction of BC will be easily compensated by the reduction in fossil fuel consumption. In addition, BC can be increased if VLS-PV plants are developed with surrounding area with afforestation or agricultural development.

For example, the EF and BC in the Northeast Asian region can be balanced by installing the 1 TW 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.

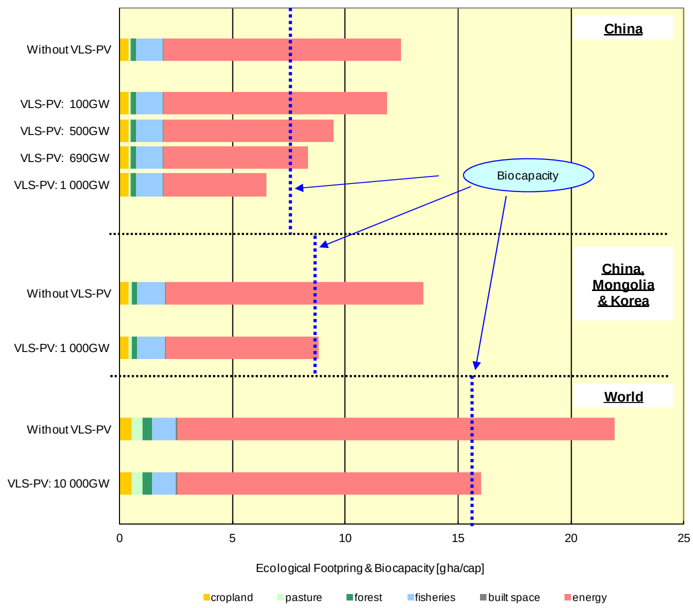

Fig. D.2-2 Ecological impacts by VLS-PV project on the Gobi desert[9)]

D.3 Saving ground water resource

Our economic and industrial activity is based on water use at various stages such as manufacturing products, producing and supplying energy, etc. On the other hand, water resources including ground water are indispensable for drinking, agriculture, etc. In some regions of the world, the ground water is used in the unsustainable manner and the situation is expected to be more serious in the future.

'Water Footprint' is an indicator which monitors the water consumption for the industrial products throughout its life cycle. Water is required for most of the power generation technologies as well.

Figs. D.3-1 and D.3-2 show example of study on life-cycle water use for electricity generation. As is shown in the figures, conventional power plants such as fossil power and nuclear power consume much water for cooling. The plants locating inland are generally using ground water. On the other hand, PV technologies consume water at the production stage to some extent, but little during their operation. Clearly, PV power plants will contribute to saving ground water use by substituting conventional power plants inland.

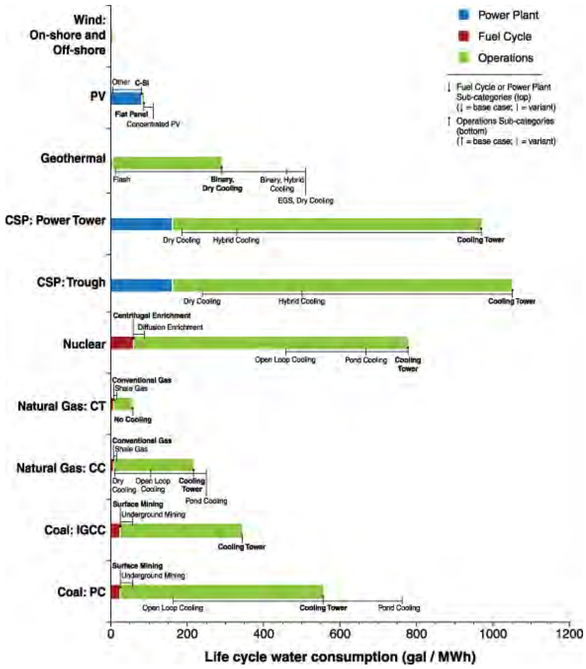

Fig. D.3-1 Life cycle water consumption[23)]

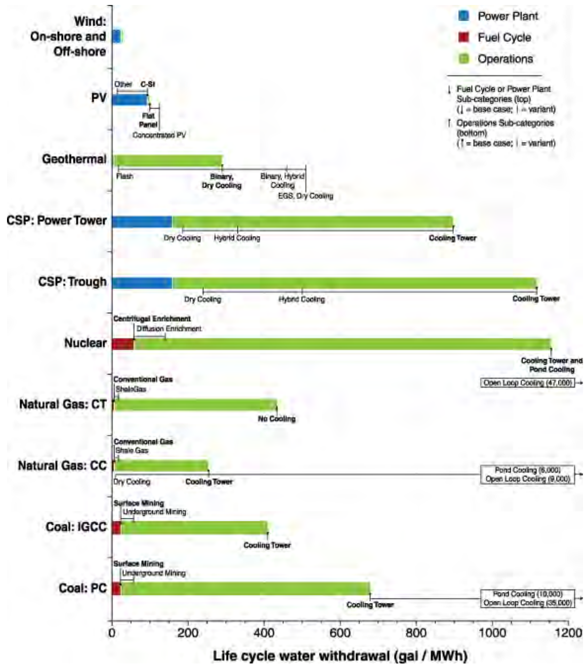

Fig. D.3-2 Life cycle water withdrawal[23)]

E. Socio-economic benefits of PV power plants: VLS-PV can contribute to sustainable social development!

E.1 Sustainable scenario for VLS-PV development

A construction of GW-scale PV power plant will create substantial and suitable 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 scenarios proposed for GW-scale PV plant with sustainable social development.

At the initial stage, PV plant owner installs 25 MW of PV power plant and module manufacturer constructs 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 every 25 MW/year every 10 years and reached 100 MW/year after 30 years.

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

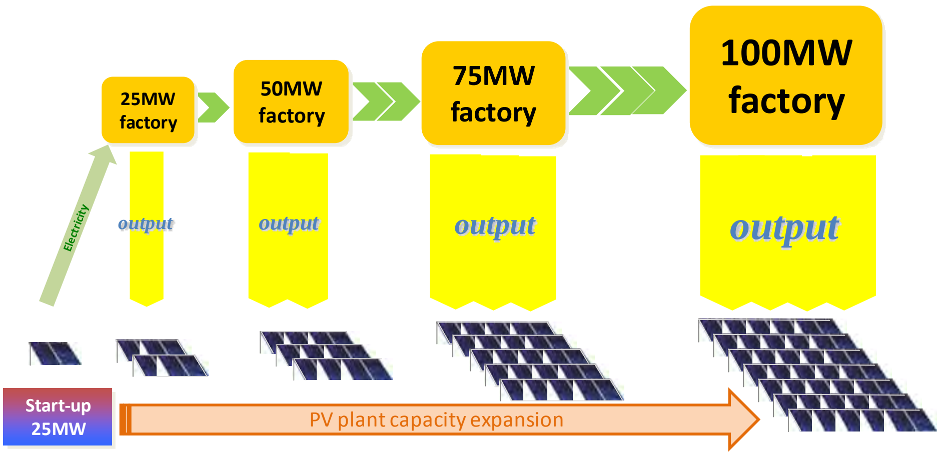

Fig. E.1-1 Conceptual view of a sustainable scheme

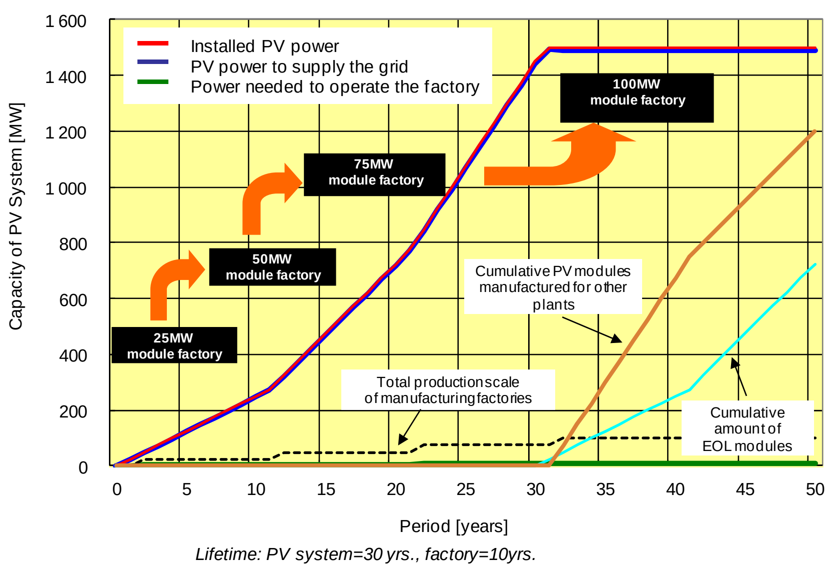

Fig. E.1-2 Sustainable scheme for VLS-PV development

The manufacturing factories near the PV power plant will create local jobs for construction and operation of the plant. Fig. E.1-3 is the estimated direct employment by a sustainable PV power plant development scheme shown in Fig. E.1-2. 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[24)]. 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 includes direct employment. If it is coupled with indirect employment, the impact of VLS-PV on sustainable job creation can be doubled.

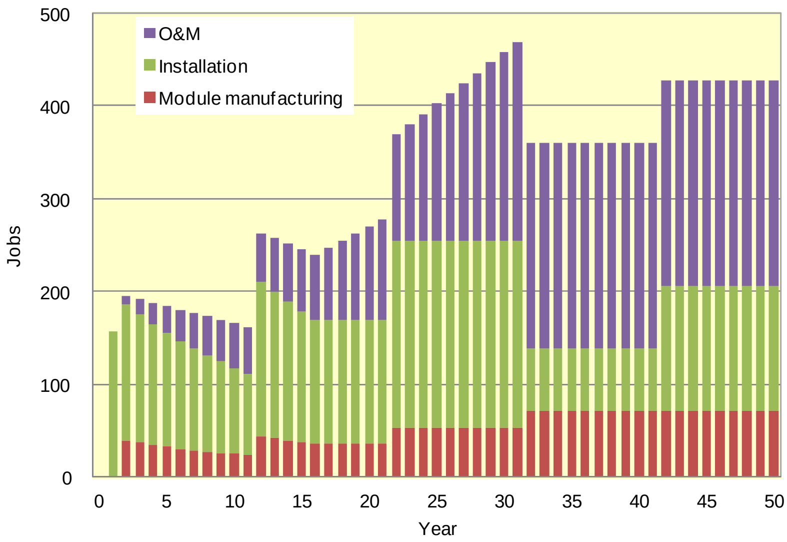

Fig. E.1-3 Expected direct employment by VLS-PV project with productivity improvement

E.2 Technical transfer

The technology transfer is the key for success of the scenario presented above. The PV module manufacturing factory near the PV power plant will be operated by experts from overseas in its initial stage. However, it is ideal to transfer the technology as much as possible to the local labours are employed to operate by themselves at certain stage. This will contribute to an intrinsic regional development with PV industry.

Difficulty level of technology transfer for PV module manufacturing is depending upon PV cell technology. In case of crystalline Si, PV module manufacturing (assembling) is relatively easy. On the other hand, PV cells manufacturing requires high technology and secured infrastructure; therefore there are many barriers to overcome for local manufacturing. In case of thin-film PV modules, the technology transfer is not straight forward since sub-module and PV module are produced through continual process.

However, considering improvement and rationalisation of manufacturing technology, technology transfer for PV cells manufacturing and thin-film PV modules production may become feasible options in near future. By localising the cell manufacturing process, the positive effects on the local economy increase considerably.

Concentrator PV modules, e.g. CPV, is another technology suitable for desert and arid areas. Although local production of super high efficiency PV cell technologies for CPV may not be a realistic option so far, local assembly of CPV modules can be attractive options. The volume of the CPV system per unit of weight is higher than that of the conventional flat plate PV modules; therefore, it can reduce transportation cost and contribute to reduction in total initial investment.

Further, if the other components of PV power plant are manufactured locally or if recycling factories of end-of-life components are introduced nearby, sustainable 'Scrap and Build' concept of the PV power plant presented in Fig. E.2-1 can be realised.

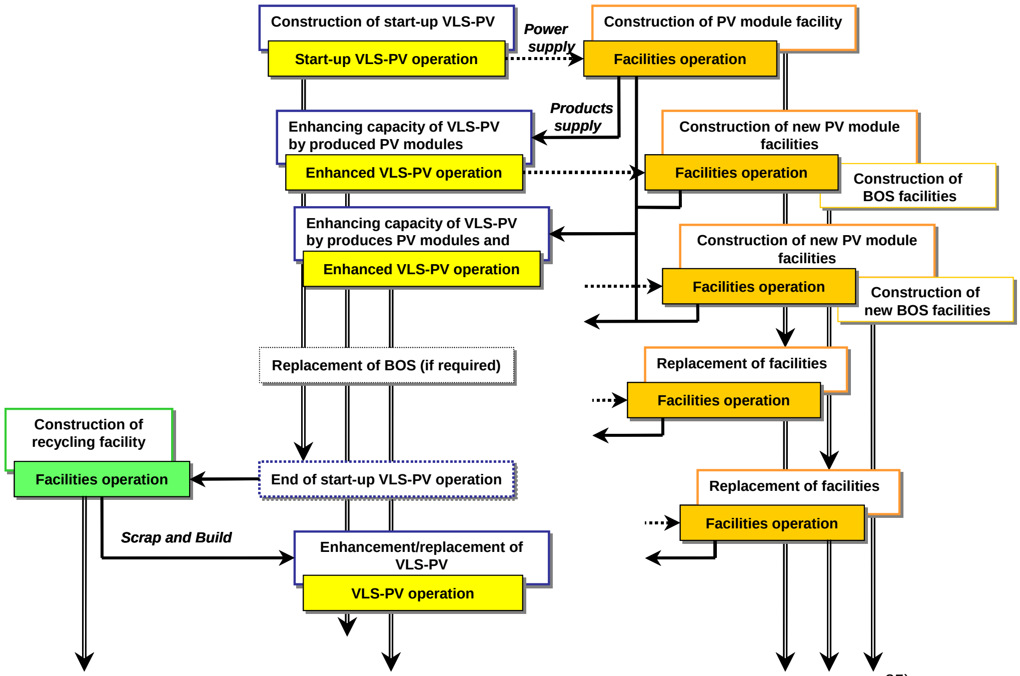

Fig. E.2-1 Example of a concept for sustainable growth of VLS-PV[25)]

E.3 Sustainable desert community development

PV power plants constructed in desert areas will provide electricity to neighbouring community or power-consuming industries through existing or newly developed transmission line. The PV power plants can be a centre of the sustainable desert community development.

Fig. E.3-1 shows our proposal on a framework of desert community development. In addition to creating PV industry based on technology transfer discussed above, various values can be created through the sustainable desert community development concept.

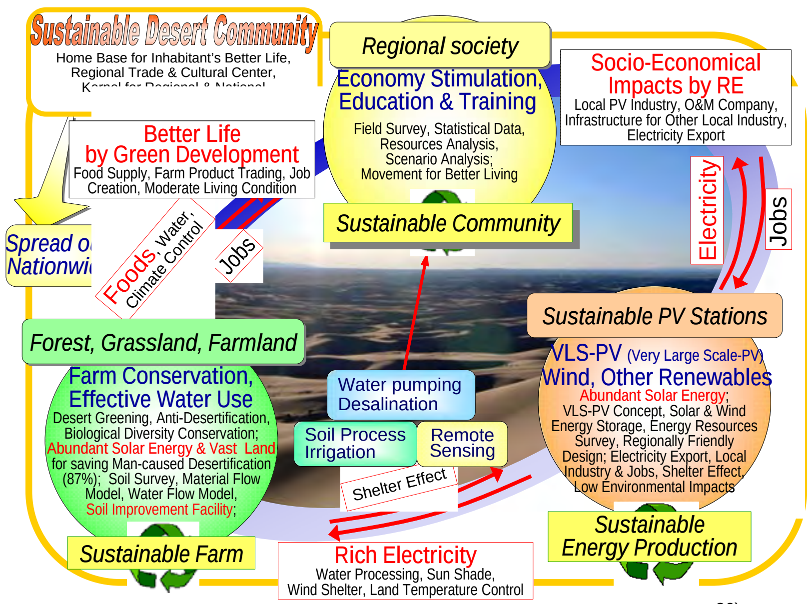

Fig. E.3-1 Framework of desert community development[26)]

The most serious problem in desert areas will be a land degradation including desertification. The degradation leads to expand in low-productivity land area: and hence, results in less income of the inhabitants. That forces residents to migrate to other regions, and accelerate land degradation even further. Examples of the possible solutions for the land degradation are afforestation and agricultural land development. The sustainability of the large scale PV development project in the desert region can be substantially improved by integrating those solutions into the whole concept.

Electricity generated from PV power plant can be used for water supply in the regions through ground water pump, desalination technologies, or irrigation systems. Comprehensive design and management of the whole regions is required for the sustainable water consumption in the regions, and the power supply from PV can contribute to those solutions. Adequate quantity of the power and water supply can be used for recovering vegetation as well as agricultural productions in the regions.

In some areas including the Middle-East, North Africa, and the South Asia, the water consumptions already exceed the renewable water resources within regions. The large-scale desalination plant is expected to be a countermeasure to secure sustainable water supply. Fortunately, in general terms, those areas have abundant solar energy and have desert or dry land close to coastal regions. A combination of PV power plant and desalination plant can provide attractive options to the regions in questions.

F. VLS-PV visions: How VLS-PV can contribute as a major power source?

The technical and economical feasibility of the large scale PV power plants are already proven, and the environmental and socio-economic benefits can make the project more attractive.

To deploy large scale PV power plants as a major power source and to realise expected benefits, in this chapter, a potential for global energy system is discussed, as well as a supply capability of PV power plants.

F.1 VLS-PV roadmap

Various scenarios, visions and forecasts projected that PV electricity plays an important role for electricity generation in the middle of 21st century. In order to set an expected target and potential of PV power plants, Task8 group has proposed a VLS-PV roadmap towards 2100, as shown in Fig. F.1-1.

The VLS-PV roadmap is based on the following assumptions; PV electricity will provide the one-third of the primary energy supply in the world; PV application will be roughly classified rural and mini-grid, urban and community grid, and the VLS-PV (PV power plants); The expected cumulative PV capacity in 2100 will be 133 TW and a half of the capacity will be PV power plants.

The roadmap was originally developed in 2009[9], and modified in 2014 by referring recent installation trends and discussion, but the target for 2100 is unchanged.

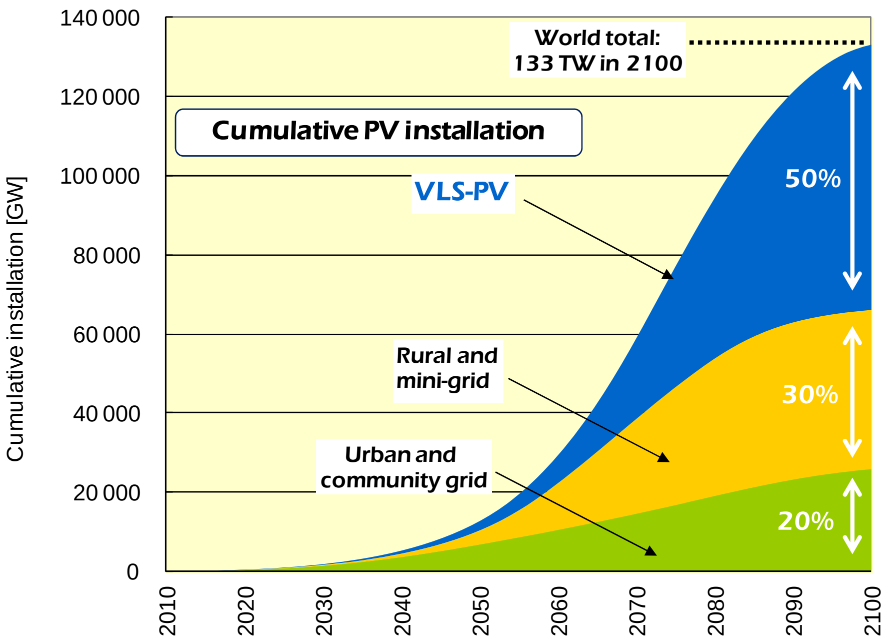

Fig. F.1-1 VLS-PV roadmap (updated)

F.2 Considerable option for 100% renewable energy supplying system

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 renewable energy-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 renewable energy fuels can be used for non-electricity energy demand such as heat or vehicle fuels. Fig. F.2-1 shows one of those systems. As shown in the figure, CO_2 captured and stored in the existing power plant or captured from ambient air is used to produce renewable energy fuels; hence, it has a multiple environmental effects.

Although there are technical and economic barriers to be solved for the renewable energy-based fuel production system, low carbon energy system with 100 % renewable energy is certainly possible with this integrated system.

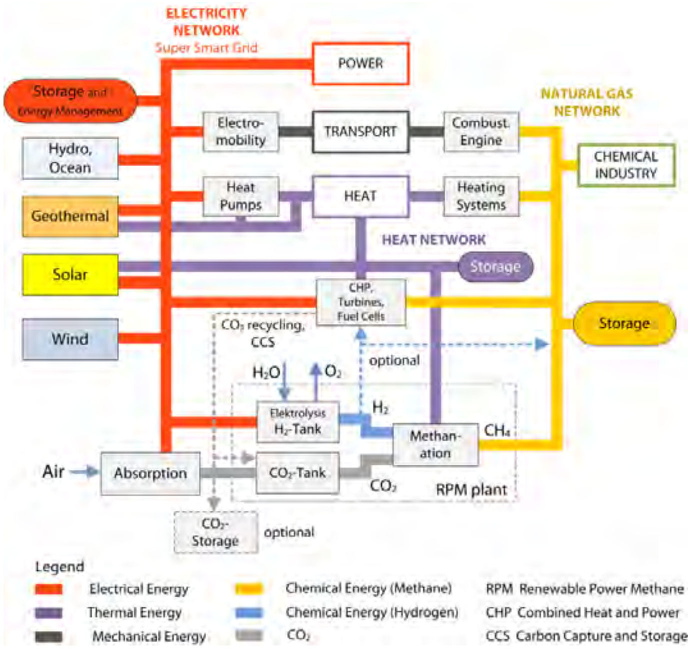

Fig. F.2-1 Hybrid PV-Wind-RPM plant as the integral centrepiece of a future sustainable energy supply system[21)]

F.3 VLS-PV supergrid in the Northeast Asia

The cross-border supply networks for electricity are the prerequisite for the mass deployment of PV power plants. There are global or regional network concepts proposed including 'Desertec' in the Mediterranean region with solar energy in the Sahara desert[27)] and 'GOBITEC/Asian Super Grid' in the Asian region with renewable energy in the Gobi desert[24)]. Task8 group also proposed a concept of a VLS-PV supergrid in the Northeast Asia[28)].

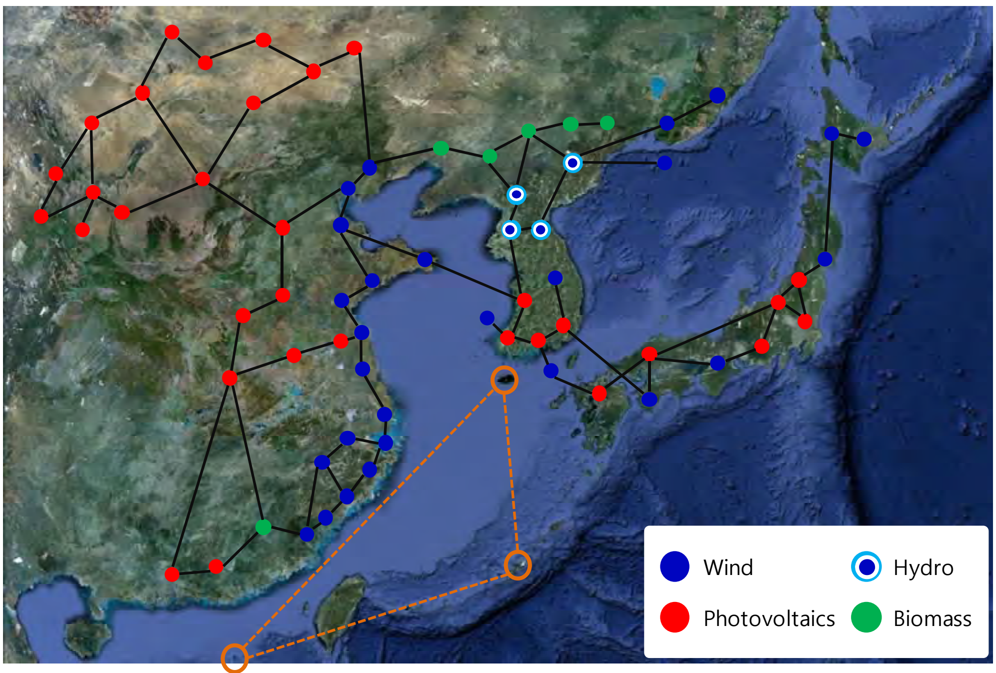

Fig. F.3-1 Example of supergrid design in the Northeast Asia[29)]

For Northeast Asia, it is proposed that the excellent solar and wind resources of the Gobi desert could be utilized for the 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. Our precise analysis has shown that expected total system levelized cost of electricity (LCOE), including generation, curtailment, storage and HVDC transmission grid, will be 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.

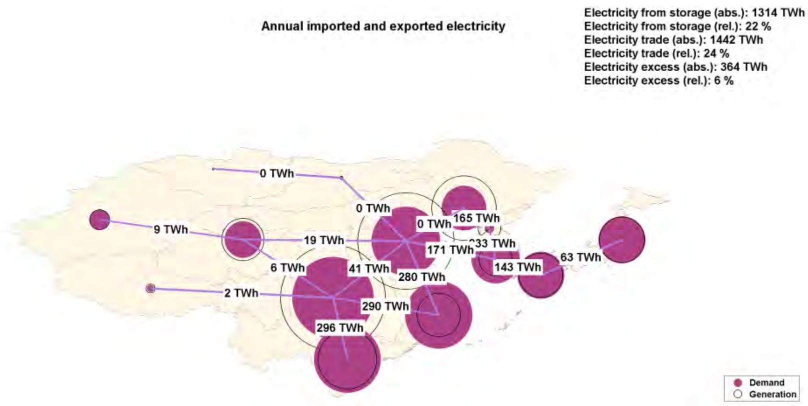

Fig. F.3-2 Annual generation and demand for area-wide open trade scenario for Northeast Asia and reference year 2030[30)]

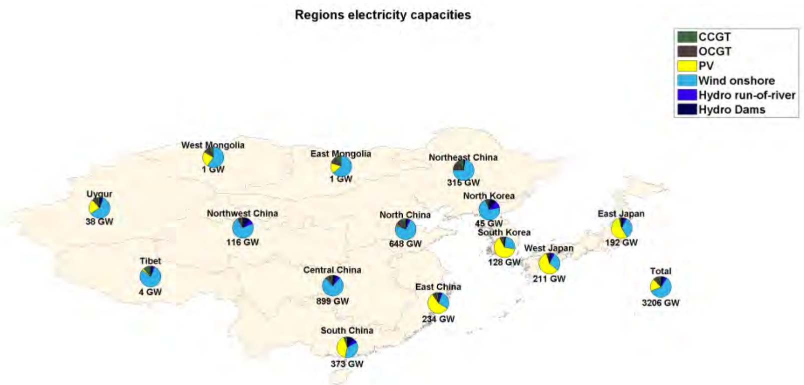

Fig. F.3-3 Installed capacities for area-wide open trade scenario for Northeast Asia and reference year 2030[30)]

Supposing to supply the incremental electricity demand in the Northeast Asia by the PV electricity, annual installed capacity required to fulfil the demand will be a few hundred GW per year. On the other hand, PV power plants installed in the Gobi desert with 1 000 GW (=1 TW) generation capacity have a potential to improve the ecological balance, from unsustainable to sustainable.

It will be difficult, of course, to immediately start a super grid project, including construction of hundreds of GW of PV power plants. However, socio-economic benefits as well as environmental value of a concept of a VLS-PV supergrid in Northeast Asia should be seriously taken into account from a long-term viewpoint. In order to achieve the goal, technical and institutional issues for international grid connection should be addressed and discussed in a more intensive manner.

G. Conclusions and recommendations: Directions for VLS-PV

< Why VLS-PV? >

- PV is one of the promising renewable energy technologeis to solve the energy and environmental issues in the world. In one of the scenarios (2DS hi-Ren) presented in the recent report by IEA, PV become the second largest energy source in 2050 and its contribution to the CO_2 reductions is the largest among all the power generation technologies.
- As solar energy is a low-density energy in nature, vast land areas with high solar irradiation are necessary to extensively utilise the solar energy as the major power source. From that viewpoint, large scale PV power plants should play an important role as well as distributed PV systems.
- One-third of land surface of the earth is covered by dry deserts, and the irradiation levels in those areas are generally high. Estimate shows that only 8 % of the desert area is enough to generate annual energy demand today.
- The detail study on site suitability assessment using remote sensing technology with satellite images show that PV power generation potential of world six deserts, namely Sahara, Gobi, Great Sandy, Thar, Sonora and Negev, is approximately 5 times of the world energy demand and 33 times of world electricity generation in 2012.
- It is obvious that the desert areas have abundant potential and promising areas for PV power plants.

< VLS-PV is already available! >

- PV market is rapidly growing, especially in a latter half of 2000s. Cumulative PV installation in the world achieved 100 GW in 2012 and 140 GW at the end of 2013. Major PV market shifted from Europe to USA, China, Japan and other regions. Especially, expansion of Chinese market is remarkable.
- Currently, the large scale PV power plants account for at least 10-15 % of cumulative PV installation in the world.
- The largest PV power plants record in the world has been broken every year. In 2011, 200 MW PV power plant started operation in China, and the capacity of this plant was expanded to 300 MW in 2013 and to 500 MW in late 2014. In 2012, 250MW PV power plant started operation in USA, and its capacity was expanded to 290 MW in 2013. In early 2013, 320 MW PV power plant started operation in China, and its capacity was expanded to 520 MW in 2014. Further, in USA, two 550 MW PV plants started operation in late 2014.
- As shown above, PV power plants with several hundred MW scales are already in the commercial stage and technically feasible. It may be reasonable to expect that GW-scale PV power plants will come on the market in near future.
- CPV is another promising technology option suitable in the desert environment.
- In order that PV power plants to be one of the major power sources in the future, technology development such as grid integration with energy storage and long-distance electricity transmission including HVDC (High Voltage Direct Current) will be essential.
- PV power plants in the desert have to endure the severe environmental conditions, such as soiling, temperature cycle. As one of countermeasures for soiling, 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.
- There are a number of countermeasures available as well as simulation tools for soiling issue.
- Besides soiling, sand storm and particles, high temperature and large temperature difference between day and night, exposure to intense ultraviolet irradiation, etc. are significant and special issues for PV power plants in the deserts environment. Evaluation methods for those issues are not standardised internationally yet, and further discussions are needed.

< VLS-PV can provide low-cost electricity! >

- Initial cost for PV installation has been decreasing. In some regions, LCOE of PV technology is already reached to the level of residential electricity tariff.
- When it comes to the PV power plant in the desert environment, the LCOE is already low even with the current module price level (0,10 USD/kWh). In the near future, PV power plants will become more competitive against conventional power plants.

< VLS-PV is a key for sustainable environment! >

- The PV system is an alternative energy technology and one of the promising technologies for climate change mitigation.
- The EPBT (Energy Pay-Back Time) of large scale PV power plants are within ranges of 1 to 3 years. Assuming 30 years lifetime, PV can produce 10 to 30 times more energy than the total energy consumed throughout its life-cycle.
- CO_2 emission rates of large scale PV power plants are between 30 to 70 g-CO_2/kWh. The rate is very small and it is one-tenth or one-twentieth of average CO_2 emission rate in China or Africa, coal-based country.
- The Ecological Footprint (EF) is expressed by the capability of ecosystem required to purify, absorb and mitigate the impact of human activities. The EF is compared with the Biocapacity (BC) which means a capability of ecosystem. The EF and BC in the Northeast Asian region can be balanced by installing the 1 TW VLS-PV plants in the Gobi desert covering China and Mongolia. The environmental effect can be further exploited if the development is coupled with afforestation and agricultural development in the surrounding area.
- PV technologies consume water at the production stage to some extent, but little during their operation. Clearly, PV power plants will contribute to saving ground water use by substituting conventional power plants inland.

< VLS-PV can contribute to sustainable social development! >

- GW-scale PV power plant will create substantial and stable demand for PV system components as well as employment for construction, operation and maintenance if such works are managed in an appropriate manner. In our study, GW-scale PV power plant with sustainable social development scenario is proposed.
- At the initial stage, 25 MW of PV power plant, and PV module factory with 25 MW/year capacity are constructed nearby. The modules produced are supplied for the plant construction purpose exclusively. The capacity of the factory is expanded every 25 MW/year every 10 years and reached 100 MW/year after 30 years. Then, a capacity of PV power plant will achieve 1 GW in 24 years and 1,5 GW in 31 years.
- Under the scenario, approximately 9 thousand jobs are created during the projected period, and approximately 400 stable jobs are created annually. If it is coupled with indirect employments, the impacts of VLS-PV on sustainable job creation can be doubled.
- It is ideal to transfer technology as much as possible to the local labours employed to operate by themselves at certain stage. This will contribute to an intrinsic regional development with PV industry.
- If the components of the PV power plant other than PV modules, such as inverters, cables, support structures, foundation, etc. are manufactured locally or if recycling factories of end-of-life components introduced nearby, sustainable ‘Scrap and Build’ concept of PV power plant can be realised.
- In addition to creating PV industry in local based on technology transfer as discussed above, various values can be created through the sustainable desert community development concept. Electricity generated from PV power plant can be used for water supply in the regions through ground water pump, desalination technologies, or irrigation system, and will contribute to mitigating land degradation in the area of question. Adequate quantity of the power and water supply can also be used for recovering vegetation as well as agricultural productions in the regions.

- In some areas including the Middle-East, North Africa, and the South Asia, the water consumptions have exceeded the renewable water resources within regions, and the large-scale desalination plants are expected to secure sustainable water supply. In general terms, those areas have abundant solar energy and have desert or dry land close to coastal regions. A combination of PV power plant and desalination plant can provide attractive options to the regions in questions.

< How VLS-PV can contribute as a major power source? >

- To deploy large scale PV power plants as a major power source, integration with other energy sources must be discussed from global energy supply point of view.
- Task8 group has proposed a VLS-PV roadmap towards 2100. The roadmap aims to provide one-third of the primary energy by PV in the world, and the expected cumulative PV capacity in 2100 will be 133 TW, in which VLS-PV is account for 50 % of the total electricity from PV.
- The cross-border supply networks for electricity are the prerequisite for the mass deployment of PV power plants. Global deployment of PV power plants will be accelerated by developing energy supplying system combined with other renewables and energy storage technologies.
- 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. Task8 group also proposed a concept of a VLS-PV supergrid in the Northeast Asia.
- Our precise study shows that the expected LCOE, including generation, curtailment, storage and HVDC transmission grid, will be 0,064 EUR/kWh and 0,081 EUR/kWh for 2030 assumptions. This reveals that 100% renewable energy system in Northeast Asia will be reachable, although there are technical and institutional barriers to be solved.
- The renewable energy can also be used to produce gaseous or liquid fuel 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 renewable energy fuels can be used for non-electricity energy demand such as heat or vehicle fuels. The low carbon energy system with 100 % renewable energy is certainly possible in the future.

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Chapter 1 Technical Requirements for PV Power Plants

1.1 State-of-the-art of PV power plants in China

1.1.1 Development of PV power plants in China

The first 100kW PV power plant was built in 2005 and it was China-Korea cooperation project. The capital investment is subsidized by Ministry of Science and Technology and the PV modules were provided by Korea government free of charge. So, the PV plant has no special FIT and the PV electricity is purchased by Grid Company with the whole sale price of coal-fire power plants. The PV plant was built for demonstration purpose with not only fixed PV arrays, but also various types of sun trackers.

Fig. 1.1-1 100kW PV Power Plant at Yangbajing, Tibet

In 2013, total domestic PV installation is 13 GW, which is 4 times higher than last year. Such big jump is due to the hot installation of LS-PV in western China. All developers want to catch the FIT of 1,0 CNY/kWh, which will expiry on Jan. 1st, 2014. The installed LS-PV power plants are 12,12 GW, distributed PV is about 800 MW and off grid PV is 80 MW. The PV installation in China is listed in Table 1.1-1. As well, PV market development from 2000 to 2013 is shown as Fig. 1.1-2.

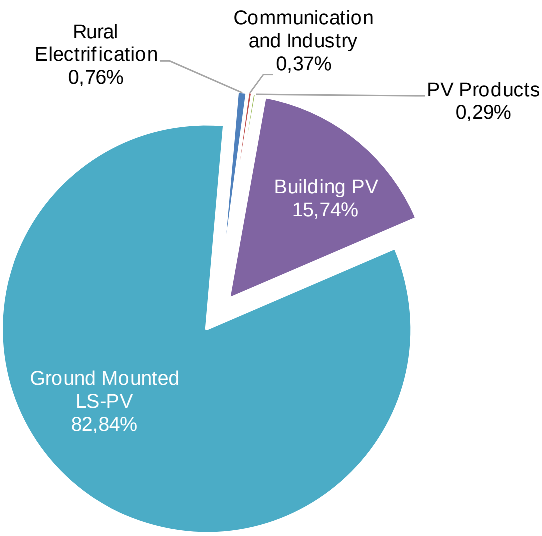

Fig. 1.1-2 PV Market Development in China since 2000

Table 1.1-1 PV Installation in China in 2013 by Sector

Market Sector	Annu.Ins. (MWp)	Share (%)	Cumm. Ins. (MWp)	Share (%)
Rural Electrification	50	0,38	150	0,76
Communication & Industry	15	0,12	72	0,37
PV Products	15	0,12	58	0,29
Building PV	800	6,15	3 100	15,74
Ground Mounted Large Scale-PV	12 120	93,23	16 320	82,84
Total	13 000	100,00	19 700	100,00

In 2013, National Energy Administration (NEA) adjusted the market targets of PV and want to promote distributed PV in priority. The updated cumulative PV target is 35 GW by the end of 2015, but according to the real installation of 2013 and the cap set by NEA of 2014, the real cumulative PV installation by the year of 2015 will definitely reach to at least 40GW. The target for 2020 is set to 100 GW as shown in Table 1.1-2. The market share of cumulated LS-PV is estimated about 50 %. Even in the long-term forecast, the LS-PV will share at least 50 % of the total market of PV in China. Further, a long-term target until 2050 is shown in Table 1.1-3.

Table 1.1-2 Near-Term target for cumulative installation of PV in 2015 and 2020 in China (GW)

Market Sectors	2013	2015	2020
Large Scale PV (LS-PV)	16,32	26,0	50,0
PV Buildings	3,10	13,0	46,0
Rural Electrification and Others	0,28	1,0	4,0
Total	19,70	40,0	100,0
Share of LS-PV	82,84	65,0	50,0

Table 1.1-3 Long-Term target until 2050 for cumulative installation of PV in China (MW)

Market Sectors	2013	2015	2020	2030	2050	Location
Rural Electrification and Micro-grid	150	200	700	2 000	4 000	Western China and Islands
Communication and Industry	72	82	180	1 000	2 000	All over China
PV Consumer Goods	58	68	120	1 000	2 000	Mainly at East Cities
PV Buildings	3 100	14 000	49 000	196 000	492 000	All over China
Ground Mounted LS-PV	16 320	25 650	50 000	200 000	500 000	Western China and Seashore Mudflat
Total	19 700	40 000	100 000	400 000	1 000 000	
Share of LS-PV (%)	82,84	64,13	50,00	50,00	50,00	

The largest PV power plant is 520 MW, in Gonghe, Qinghai province, built by Yellow River Hydropower Company, which is combined with the Longyangxia Hydropower plant (see Fig. 1.1-3). The plant was starting operation as 320 MW capacity in early 2013, and expanded to 520 MW in 2014. Another largest PV power plant is 500 MW, which is located in Germud, Qinghai and also built by Yellow River Hydropower Company (see Fig. 1.1-4). The plant was expanded from 300 MW to 500 MW in late 2014.

For LS-PV, different types of solar tracker have been widely used and CPV power plants have been demonstrated as well, as shown in from Fig. 1.1-5 to Fig. 1.1-7.

Fig. 1.1-3 The largest PV power plant in Gonghe, Qinghai, 520 MW (courtesy of Yellow River Hydropower Company)

Fig. 1.1-4 The second largest PV power plant in Germud, Qinghai, 500 MW

Fig. 1.1-5 Different Solar Trackers

Fig. 1.1-6 10 MW 500x CPV and 60 MW 1000x CPV Power Plan in Qinghai

Fig. 1.1-7 1 MW 4x L-CPV Power Plant in Gansu Province

1.1.2 Lessons learnt from existing PV power plants

(1) Incentive policies

The Feed-in Tariff for PV was firstly issued in China is in 2007 and 4 CNY/kWh for the projects of 1 MW rooftop project in Shanghai and 205 kW LCPV project in Inner-Mongolia. At the end of 2008, NDRC was started the first concession bidding for a 10 MW PV plant in Dunhuang, Gansu province and the FIT set by the bidding is 1,09 CNY/kWh. The second concession bidding was in 2010 for the 13 LS-PV plants in western 7 provinces and the FIT is between 0,7288-0,9907 CNY/kWh. In 2011, the standard FIT for whole China was issued by NDRC: 1,15 CNY/kWh. This standard FIT was reduced to 1,0 CNY/kWh in 2012 and valid to the end of 2013.

On Aug. 26, 2013, NDRC released the “Notice on Matters Regarding Adjustment to Electricity Price Surcharge Standard for Renewable Energy and Environmental Protection Electricity Price” (No. 1638 [2013] of NDRC), raising the RE price surcharge from 0,008 CNY/kWh to 0,015 CNY/kWh and hence generating a 40 billion CNY subsidy fund per year for supporting RE power generation, which may fully satisfy the need of covering RE power generation subsidies by 2015 (with an installed wind capacity of 100 GW, solar PV capacity of 35 GW, biomass capacity of 13 GW and solar thermal power capacity of 1 GW).

On Aug. 27, 2013, NDRC issued the “Notice on Giving Play to the Role of Price Leverage in Promoting Healthy Development of the Solar PV Industry” (No. 1651 [2013] of NDRC), the document specifying the long-expected FIT policy for LS-PV plants based on solar resources and the subsidy standard for distributed PV. The detail of such policy is listed in Table 1.1-4.

Table 1.1-4 New FIT for PV Power Plants and the Subsidy Level for Distributed PV

Solar Irradiation Zone	PV Power Plant	Distributed PV Benefits	
	FIT (CNY/kWh)	Subsidy for Self-Consumed PV Electricity (CNY/kWh)	Subsidy for Surplus PV Electricity Feed-back to grid (CNY/kWh)
I:	0,90	Retail price of grid-electricity + 0,42	Whole-sell Tariff of coal-fire power + 0,42
II	0,95		
III	1,00		

Main points of the new FIT and subsidy policies are as follows:

- Three level benchmark PV feed-in tariffs: 0,90, 0,95, 1,0 CNY/kWh;
- A 0,42 CNY/kWh subsidy is available for both self-consumed distributed PV electricity and the surplus PV electricity feed-back to grid;
- Surplus electricity generated by distributed PV will be purchased by Grid Company with local standard whole-sell rates of coal-fire power (approx. 0,35-0,45 CNY/kWh) ;
- In principle, the period of execution will be 20 years

During 2012 to 2013, Chinese Government, NEA, NDRC, Grid-Company, China Development Bank, Ministry of Finance, and so on, issued a series of incentive policies. The newly released policies include: government plans, Feed-in tariffs & subsidy standard, funding sources, rules of subsidy issuance, grid connection, financing, taxation, demonstration projects and project application & management rules. By such complete series of supporting policies, Chinese PV market will be expanded according to the plan and the targets will be definitely reached.

(2) Cost

a) Price and capital investment

As shown in Table 1.1-5 and Fig.1.1-8, during 2007-2012, the cost of PV has been reduced sharply and in 2013, the PV price was kept stable and only a little bit lower than last year.

The capital investment for LS-PV is about 8 000 CNY/kW, the price breakdown is listed in Table 1.1-6.

Table 1.1-5 Price reduction of PV during last 7 Years

Year	2007	2008	2009	2010	2011	2012	2013	2014
Cumulative Installation (GWp)	0,10	0,14	0,30	0,80	3,20	6,70	19,70	30,00
Module Price (CNY/Wp)	36,0	30,0	19,0	13,0	9,0	4,5	4,2	3,8
System Price (CNY/Wp)	60,0	50,0	35,0	25,0	17,5	10,0	9,0	8,0
FIT of PV (CNY/kWh)	4,0	Set through Bidding			1,15	1,00	0,9-1,0	0,9-1,0

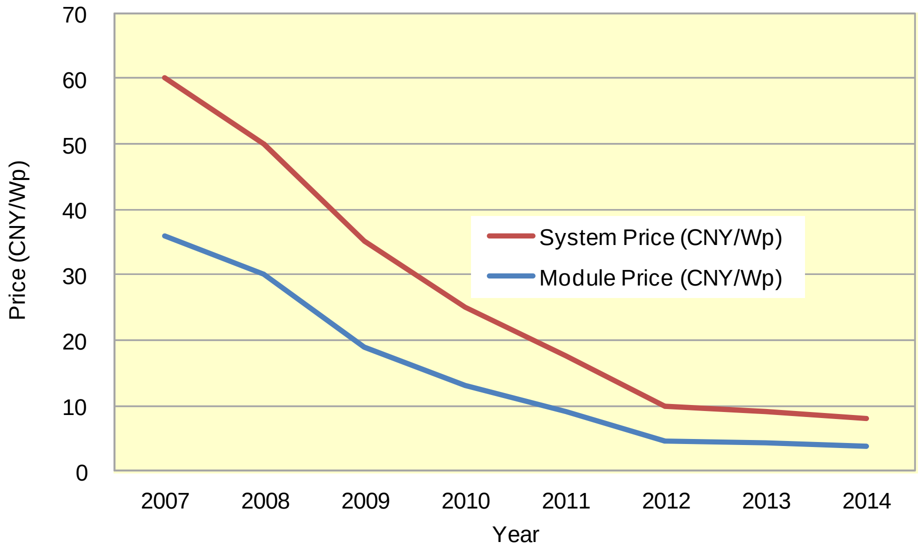

Fig. 1.1-8 Price decreasing of PV modules and systems (2007-2014)

Table 1.1-6 Examples of capital investment of 10MW PV power plants

No.	Items	Equipment (10^3 CNY)	Installation (10^3 CNY)	Others (10^3 CNY)	Sum (10^3 CNY)	Share (%)	Unit Price (CNY/Wp)
1	Equipment & Installation	54 000	3 000		57 000	71,25	5,70
	PV Modules	40 000	1 000		41 000	51,25	4,10
	Supporting Structure	6 000	1 000		7 000	8,75	0,70
	Inverters	4 000	400		4 400	5,50	0,44
	Monitoring & Communications	2 000	300		2 300	2,875	0,23
	Other Equipment	2 000	300		2 300	2,875	0,23
2	Civil Works		17 000		17 000	21,25	1,70
	Foundation & Grounding		5 000		5 000	6,25	0,50
	Cables and Installation		6 000		6 000	7,50	0,60
	Control Rooms		2 000		2 000	2,50	0,20
	Grid-Connection		2 000		2 000	2,50	0,20
	Shipment & Warehouse		1 000		1 000	1,25	0,10
	Others		1 000		1 000	1,25	0,10
3	Other Cost			5000	5 000	6,25	0,50
	Land Fee			1000	1 000	1,25	0,10
	Field Survay & Design			2000	2 000	2,50	0,20
	Management			2000	2 000	2,50	0,20
	Sum of Item 1-3	54 000	20 000	5000	79 000	98,75	7,90
	Miscellaneous				1 000	1,25	0,10
	Static Total Investment	(10^3 CNY/MW)			80 000	100.00	8,00

b) LCOE (Levelized Cost of Electricity)

The LCOE can be calculated as below;

LCOE = Total investment during Lifetime / Total output during Lifetime

Various factors will effect LCOE, such as: capital cost, O&M cost, solar resources, operational mode (fixed, sun-tracking, etc.), system efficiency, performance ratio, curtailment issue, troubles, etc.

The FIT for PV Power Plants is set according to local solar resources; the relationship between solar resources and FIT is described as shown in Table 1.1-7.

There are many places in Qinghai, Inner-Mongolia and Gansu the EUH is much higher than 1 500 hours per year, so the IRR will be very high (15 – 25 %) at such places.

Table 1.1-7 New FIT Policy Based on Annual Equivalent Utilization Hours (EUH)

Resource Zone	Annual Ground-Surface Global Irradiation		Irradiation on Inclined PV Surfaces	Annual EUH	EUH for IRR calculation	Feed-In Tariff
	(MJ/m^2)	(kWh/m^2)	(kWh/m^2)	(hours/year)	(hours/year)	(CNY/kWh)
I	5 400 -7 500	1 500 -2 000	1 725 -2 300	1 380 -1 840	1 500	0,90
II	4 500 -5 400	1 240 -1 500	1 389 -1 680	1 100 -1 345	1 200	0,95
III	< 4 500	< 1 240	1 320	1 056	1 000	1,00

Besides the solar resources, the sun-tracking can be another effective way to lower LCOE. According to the 30 year's (1961-1990) test data of Phoenix Weather Station, Sun-Tracker can increase the irradiation on PV arrays significantly, as shown in Table 1.1-8.

- Fixed Latitude Angle v.s. Fixed Horizontal : 13,4 % more output;
- E-W Horizontal Tracking v.s. Fixed Horizontal : 41,0 % more output;
- 2-Axis Tracking v.s. Fixed Horizontal : 56,0 % more output;
- E-W Horizontal Tracking v.s. Fixed Latitude Angle : 24,4 % more output;
- 2-Axis Tracking v.s. Fixed Latitude Angle : 37,6 % more output.

Table 1.1-8 Comparison of Various Type of Operation Modes

Type	Output Comparison between Various Operational Modes (kWh/m^2/day)												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
Horizontal Fixed	3,2	4,3	5,5	7,1	8,0	8,4	7,6	7,1	6,1	4,9	3,6	3,0	68,8
Tilted Latitude Angle Fixed	5,1	6,0	6,7	7,4	7,5	7,3	6,9	7,1	7,0	6,5	5,6	4,9	78,0
Horizontal E-W Tracking	4,7	6,2	7,8	9,9	11,0	11,4	10,0	9,6	8,6	7,1	6,3	4,4	97,0
2-Axis Tracking	6,6	7,7	8,7	10,4	11,2	11,6	10,1	9,8	9,3	8,5	7,1	6,3	107,3

WBAN No.：23183, Arizona, the sun-tracking system can significantly increase the irradiation received by PV arrays. Latitude：33,43 ºN, Longitude：112,02 ºW, Elevation：339 m, Air Pressure：974 mb.

Definitely, the sun-tracker can increase the output significantly, but the reliability is the main barrier in distribution. To solve the problem of reliability, Zhenfa Co. developed a self-driven passive sun-tracker without electronic control circuit. The tracker uses two small PV panels to sense the sun and drive the tracker, as shown in Fig.1.1-9.

The sun-trackers still have a week point, the turning bearing. To avoid using the turning bearing, Suncore has developed a bearing-free turning system using high polymer material which is self-lubrication. This technology has been used many years before by APS Testing Field, USA, as shown in Fig. 1.1-10 and Fig. 1.1-11. Also, Fig. 1.1-12 shows sun-trackers by Suncore, China.

Fig.1.1-9 Passive Drive Sun-Tracker

Fig 1.1-10 Horizontal E-W Sun-Tracking Systems with Bearing –Free Turning Axis at APS Test Field

Fig. 1.1-11 Details of the Bearing-Free Turning Axis at APS Test Field

Fig. 1.1-12 Simplest Bearing-Free Turning System by SunCore, Qinghai, China

c) Maintenance cost and soil cleaning

In western China, water resource is very rare, so the cleaning of PV arrays is a headache issue and is the most expansive issue. The average cost is 0,7 CNY/m^2 for cleaning PV arrays (include labour cost and water cost) and 60 000 CNY is needed to clean once for 10 MW PV plant. Different ways of soil cleaning were adopted in Gobi-Desert in western China.

Slashing water, water pipe, washing vehicle or washing tools and manual washing (three women), the comparison is shown in Table 1.1-9 as well as from Fig. 1.1-13 to Fig. 1.2-17.

Table 1.1-9 Comparison of the methods for PV cleaning

Methods	Cleaning equipment	Water required for 10 MW per once	Cleaning speed for 10MW per once	Cleaning result	Cleaning cost
Flashing Water	Water Holding Vehicles are required (water replenish)	≥ 100 ton	One vehicle, 15 Days	Excellent	High
Spray Pipes + wipe	Water sources inside and spray pipe installation is required	50-60 ton	10 people, 15 Days	Excellent	High
Special washing vehicles or Tools	Requiring special washing vehicles or special tools and water replenishing vehicles.	30-40 ton	One Washing Vehicle, 10 Days	Excellent	High
3-person Solution	No need of any pipes, vehicles and special tools	＜ 10 ton	3 Women, 150 Days	Good	Low

Fig. 1.1-13 Cleaning by flashing water

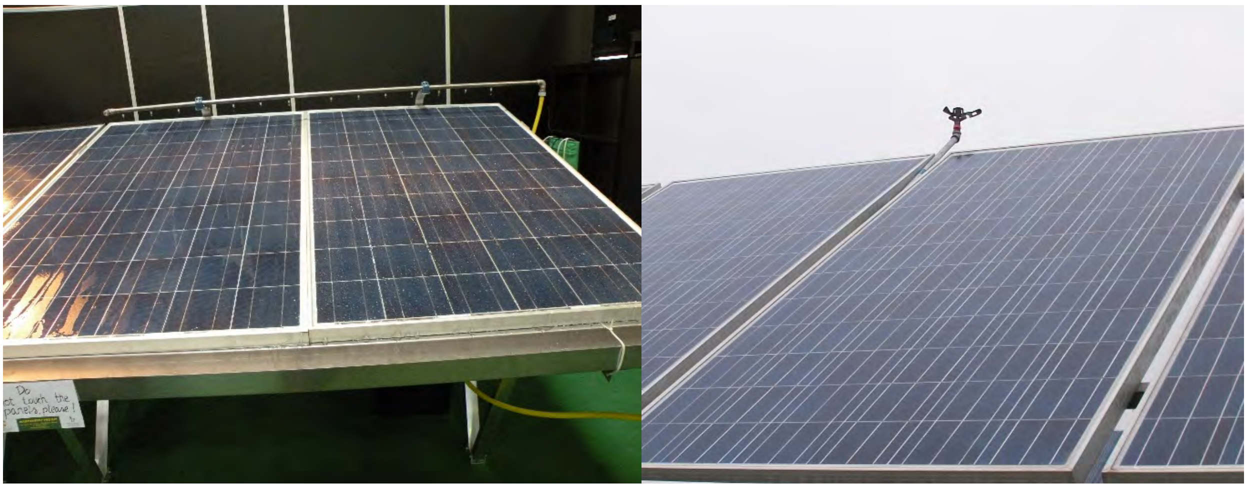

Fig. 1.1-14 Cleaning by water pipes

Fig. 1.1-15 Cleaning by specific water vehicles

Fig. 1.1-16 Cleaning by special pressured water brush

Fig. 1.1-17 Cleaning by three-women solution

1.1.3 Environmental friendly piling

The environmental issues need urgently considered, especially for the construction of PV power plants in western China, where the land surface too weak to be damaged. Since 2009, LS-PV plants are installed in western provinces very fast and are mainly built on Gobi-Desert. At beginning, the foundation of PV arrays was built in the way of opening land surface and building concrete blocks. In this way, the land surface is totally damaged and cannot be recovered forever (see Fig. 1.1-18).

<Before PV Installation> <Three-years Later after PV Installation>

Fig. 1.1-18 Example of changing land surface by PV installation

Today, people realized the problem and start using Pole-type foundation. There are 3-type of pole foundation: screw drilling poles, static-pressure poles and concrete poles, as shown in from Fig. 1.1-19 to Fig. 1.1-21.

The concrete poles are created by Chinese PV developers and making the foundation of PV friendly with environment, easy in construction and with very low cost. The concrete poles can be easily built by digging a hole and putting a bone in it and making concrete blocks in the field. For digging a hole, you don't need special machines, you just hire a local farmer who can help you to do the job with revised tractor and charge you only 40 CNY per hole. In this way, the cost of concrete poles becomes very low. For screw-drilling poles and static-pressure poles, the cost is about 1,5 CNY/Wp and for concrete poles, the cost is only 0,2 CNY/Wp.

Fig. 1.1-19 Screw-drilling poles

Fig. 1.1-20 Static-Pressure Poles

Fig. 1.1-21 Concrete poles by digging a hole and putting a bone

1.1.4 Innovation design and configuration

(1) Over-sized Design of PV Capacity

In past years in China, the capacity ratio between PV and inverter is always 1,0:1,0. In recent years, over-sized of PV capacity is popular in EU and US to get better benefits. So the capacity design today in China, developers are also trying to make the capacity ration between PV and inverter 1,2:1,0. In this case, the inverter should have the function of full power limitation, means when the output power of the inverter reach to the rated level, it must be capable to keep at the level to avoid over-capacity running. By such innovative design, the developer can easily get 20 % more output with only half investment.

Fig. 1.1-22 shows the 1,0:1,0 capacity ratio of PV to inverter. In this case, the output power is never reach to the rated level (500 kW) due to the system efficiency. On the other hands, Fig. 1.1-23 shows the 1,25:1,0 capacity ratio of PV to inverter. In the case, the output power of the inverter reach to the rated level (500 kW) at around 10:30am, then the inverter comes to power limitation status till to 14:30 to keep the output at the rated power level.

For the capacity ratio 1,0:1,0, the annual output is 720 MWh for the 500 kW unit and for the capacity ratio of 1,25:1,0, the annual output is 864 MWh for the same unit. The added 25 % PV needs 450 000

CNY, the more income is 129 600 CNY (144 MWh x 0,9 CNY/kWh) and the payback time only 3,5 years and the IRR is as high as 29 %.

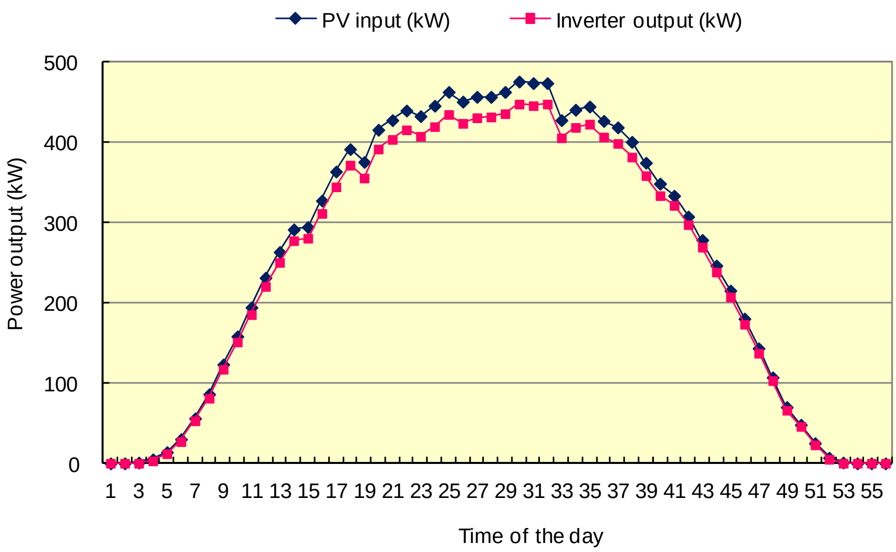

Fig. 1.1-22 Inverter output never reach to the rated level (500 kW) (Capacity Ratio: 1:1)

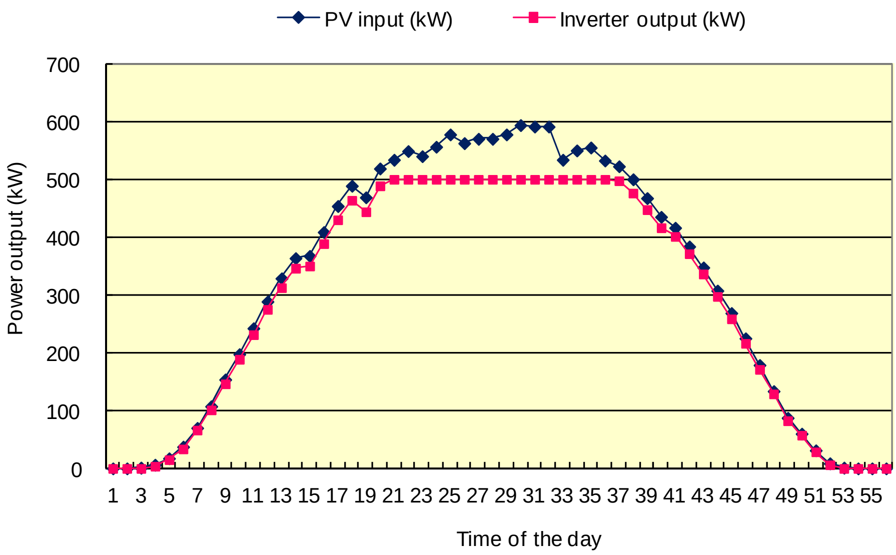

Fig. 1.2-23 Inverter output never reach to the rated level (500 kW): During 10:30 to 14:30 (Capacity Ratio: 1.25:1)

(2) String Inverter used for PV power plants

For LS-PV power plants, the central inverters are used normally. Huawei Co., the famous communication company now is also inverter manufacturer, raised a concept to use string inverters for LS-PV.

In this case, there are several advantages:

- No DC cables;
- No combiner boxes;
- No DC distributions;
- No central inverters;
- No inverter rooms;

- No DC cable losses;
- No DC mismatches losses;
- Higher MPPT efficiency;
- Easy in construction and installation;
- Easy to deal with inverter troubles.

By this way, the performance ratio (PR) can be increased at least 5 % and make the trouble shooting much easier. Once the string inverters have trouble, the operators can easily and quickly replace the inverter with backup unit. But for the troubles of central inverter, the operators must telephone to the manufacturer and waiting for the engineer to deal with the troubles, waste time and waste money.

Fig. 1.1-24 PV power plant with string inverters
(Total capacity of the plant is 500 MW, of which 200 MW with string inverters)

1.1.5 Quality and Performance Ratio (PR)

From April 18 to April 24, a team by PV committee of China RE Society go to Qinghai for the quality assessment upon LS-PV power plants.

To evaluate the quality of the PV plants, the team carry out the following works:

Quality Inspects (17 items): real capacity, monitoring system, PV modules, supporting structure, foundation type, design of PV string and arrays, installation, DC cables, cable installation, combiner-boxes, Clearances and creepage distances, capacity ration of PV and inverter, inverter room and capacity density, transformer, lightning protections, fence, equipment nameplates.

Quality Testing (19 items): dust losses, module degradation, mismatch losses, MPPT shifting, temperature losses, hot-spots IR test, hidden cracks test, shading losses, DC wiring losses, weighted efficiency of inverters, MPPT efficiency, transformer efficiency, AC wiring losses, power quality, power factor, PV system insulation, continuity of protective earthing test, anti-islanding test, LVRT test.

Performance Ratio (PR): The efficiency chain covers more than 10 factors: (see Fig. 1.1-25)

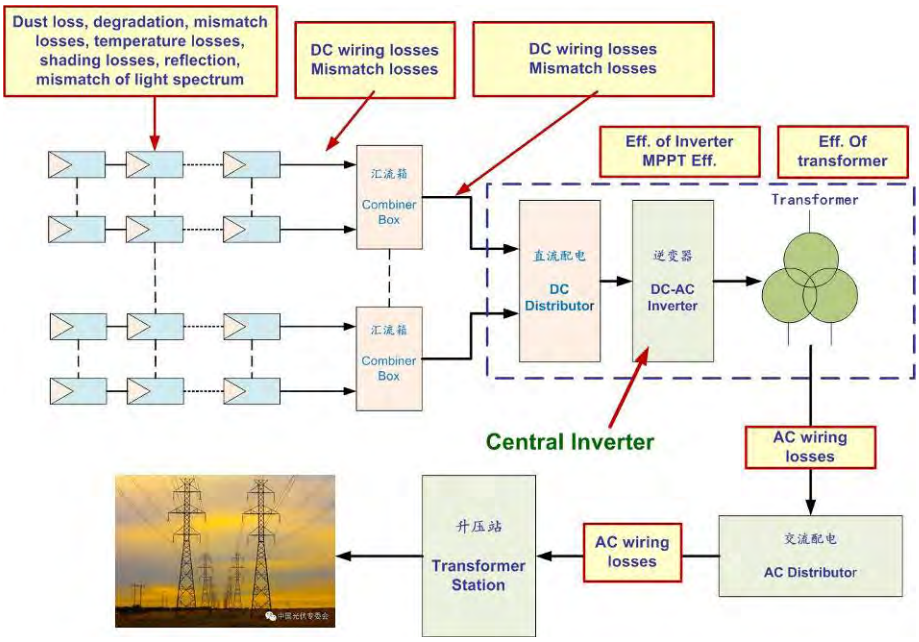

Fig. 1.1-25 Efficiency chain of PV power plants with central inverters

Fig. 1.1-26 Testing team for PV power plants

The tested PV power plants are shown in Table 1.1-10, and main testing results are listed as Table 1.1-11.

Based on running data, the PRs are measured as shown in Table 1.1-12.

Table 1.1-10 PV power plants tested by the team

PV Plants	Rated Power(MW)	Complete Date	Inverter Type
1	30	Sep. 15, 2012	Central
2	20	End of May, 2011	Central
3	20	Nov. 21, 2011	Central
4	10	Nov. 10, 2010	Central

Table 1.1-11 Main testing results

No.	Test Items	Descriptions	Test Results	Remarks
1	Dust Losses	Once a month cleaning	4 – 5 %	
2	Degradation	C- Si	3,8 - 7,2 %	2 years
		Thin Film	More than 20 %	3 years
3	Mismatch Losses	String to CB & CB to Inverter	About 5 %	
4	Temperature Losses	10-15 ºC Env. Temperature	4 - 5 %	
5	DC Wiring Losses	CB to Inverter	around 2,6 %	
	Hot-Spots IR Test	Find HotSpot Module	30 % power losses	
6	Shading Losses	GB/T50797-2012	≤ 3,0 %	
7	AC Wring Losses	Inverter to Transformer	≤ 1,5 %	
		Transformer to Grid-connection Point	≤ 1,5 %	
8	Weighted Efficiency of Inverter		about 96 %	
9	Weighted Efficiency of Transformer		NA	
10	Power Quality	Voltage Deviation	≤ 20 kV： ± 7 % ≥ 35 kV： ± 10 %	
		Frequency Deviation	± 0,5 Hz	
		Total Harmonic Current Distortion	＜ 5 % at Rated Power	
		Phases Un-Balancing	≤2 % at connection point and ≤ 4% in short time	
		DC Leakage	≤ 0,5 %	
11	Power Factor	Normal Working Condition	≥ 0,95	
12	PV array Insulation resistance test	Positive to Ground	≥ 1 MΩ	
		Negative to Ground	≥ 1 MΩ	
		Active Poles shorted to Ground	≥ 1 MΩ	
13	Continuity of protective earthing test	Between Arrays	≤ 100 mΩ	
		Array to Combiner Box		
		Array to Inverter Room		
		Grounding Resistance	＜ 4 Ω	
14	Accuracy Test of Inverter MPPT		NA	Optional
15	Islanding Protection	For Distributed Grid	NA	Optional
16	LVRT Test	For Transmission Grid	NA	Optional

Table 1.1-12 The Measured PRs for the 4 LS-PV Power Plants in Qinghai

PV Plants	Accurate Power (kW)	PR Period	Solar Irradiation (kWh/m^2)	Theoretical AC Output (MWh)	Actual AC Output (MWh)	PR (%)
1	30 492,21	365 days	2 321,03	70 773,33	54 262,68	76,671
2	19 922,78	365 days	2 371,26	47 237,42	37 356,6	79,083
3	20 022	365 days	2 096,28	41 971,72	30 774,98	73,323
4	10 027	169 days	1 359	13 626,69	10 138,83	74404
					Average	75,87

1.2 Lessons learnt and operational status of PV plants

The purpose of this review is to consider general issues for operating PV plants through lessons learned from deployment of several large-scale (10-550 MWac) PV plants around the world.

1.2.1 Example of PV power plants in the world

Large-scale PV power plants can serve a variety of purposes from providing bulk power to powering water treatment and desalination facilities to providing beneficial reuse of degraded lands (see Table 1.2-1). Some operational details of one of the largest of these plants, the Topaz Solar Farm, are provided in Table 1.2-2.

Table 1.2-1 Examples of large-scale PV plants (10-550 MWac) around the world[1)]

Project Name (Owner)	Year	Size (MWac)	Location	Notes	Photo (courtesy of First Solar Inc.)
Topaz Solar Farm (MidAmerican Solar)	2014	550	San Luis Obispo County, CA, USA	Historically largest investment grade renewable bond	
Agua Caliente (NRG Energy and MidAmerican Solar)	2014	290	Yuma County, AZ, USA	Advanced plant controls and forecasting	
Templin (Commerz Real)	2013	128	Brandenburg, Germany	Example of brownfield re-development	
Phalodi (Kiran Energy Solar Power)	2013	50	Rajasthan, India	Contributing to energy security in India	
Copper Mountain 1 (Sempra Generation)	2010	48	Boulder City, NV, USA	Co-located with existing gas combined cycle power plant	
Greenough River (Verve Energy and GE Energy Financial Services)	2012	10	Geraldton, Australia	Displacing the energy requirements of a desalination plant	
DEWA Solar Plant (Dubai Electricity and Water Authority)	2013	10	Seih Al Dahal, UAE	1st phase of 1GW Solar Park in the UAE	

Table 1.2-2 Operational details of the 550 MWac Topaz Solar Farm[2,3)]

Plant name		Topaz Solar Farm
Location	Country	USA
	State, province, city, etc.	San Luis Obispo County, California
PV power		550 MWac
Projected energy yield		~1 100 000 MWh/year
Organization / Institution		MidAmerican Solar
Developer		First Solar Inc.
Mounted type		Ground Mounted PV
Array type (Fixed / tracking)		Fixed
Installed or operated year		2015
Period of construction		2011 - 2014
Daily solar irradiation		Approx. 5,7 kWh/m^2/day (horizontal)
Total area of PV plant		~4 000 acres
Size of subfields		1,3 MWac
No. of PV modules		~8,4 million
Type of PV cells		First Solar CdTe thin film
Manufacturer of PV modules		First Solar Inc.
Capacity of inverters		650 kVA ea.
Nominal grid voltage		230 kV
No. of fixed arrays		All
Structure materials		Steel
Type of foundation		Steel posts
Expected (minimum) lifetime	(years)	25 year+

1.2.2 Lessons learnt from the operational experiences

While standard reference conditions used to characterize solar photovoltaic (PV) performance include ASTM G173 spectrum, air mass of 1,5, incident irradiance of 1 000 W/m^2, and operating temperature of 25 °C, real-world conditions often differ from these reference conditions in important ways (Table 1.2-3). Current understandings of the role of field variables are discussed below.

Table 1.2-3 Field variables affecting PV performance

Temperature	Change in the instantaneous power generation of a module due to deviations in module temperature from the reference 25 °C. Module temperature is primarily affected by ambient air temperature and irradiance.
Humidity	Change in the spectral content of solar radiation due to greater absorption or scattering of select wavelengths
Aerosols	A reduction in the power of the solar radiation due to absorption, scattering and reflection in the atmosphere
Clouds	
Soiling	A reduction in the effective solar radiation due to absorption, scattering and reflection from contaminants on the module surface

(1) Temperature

Module temperature is a function of the ambient temperature and the amount of irradiance incident on the module surface. In a typical region of high solar irradiance such as the U.S. Southwest, the majority of solar energy production occurs when the module operating temperature is much greater than 25 °C, with the temperature coefficient expressing the instantaneous rate of change of power output as a function of module operating temperature. Temperature coefficients for PV modules can range from approximately –0,29 % per ˚C to –0,5 % per ˚C for thin film and crystalline silicon (c-Si) PV modules, respectively[4,5)].

(2) Humidity and Aerosols

The effects of atmospheric precipitable water content on PV performance have been evaluated using the spectral shift factor (M), a metric indicative of how much the performance of a PV system will vary from nameplate due to deviations from the ASTM G173 spectrum. A strong dependence of M on precipitable water content arises from water vapor’s absorptivity being highly wavelength dependent (Fig. 1.2-1). When evaluated for the case of thin film CdTe PV power plants, on average the magnitude of the annual shift in the spectrum is less than 1 % except in relatively high humidity environments, where these power plants can perform several percent better than predicted without a spectral correction[6]. Like humidity, atmospheric aerosols also affect the spectral distribution of sunlight. For example, Maywerk and Ramanathan investigated the effects of continental aerosols on the global, direct, and diffuse portion of spectral irradiance[7]. Continental aerosols were found to shift the peak in the direct solar radiation from 470 nm for pristine conditions to 580 nm for the polluted region.

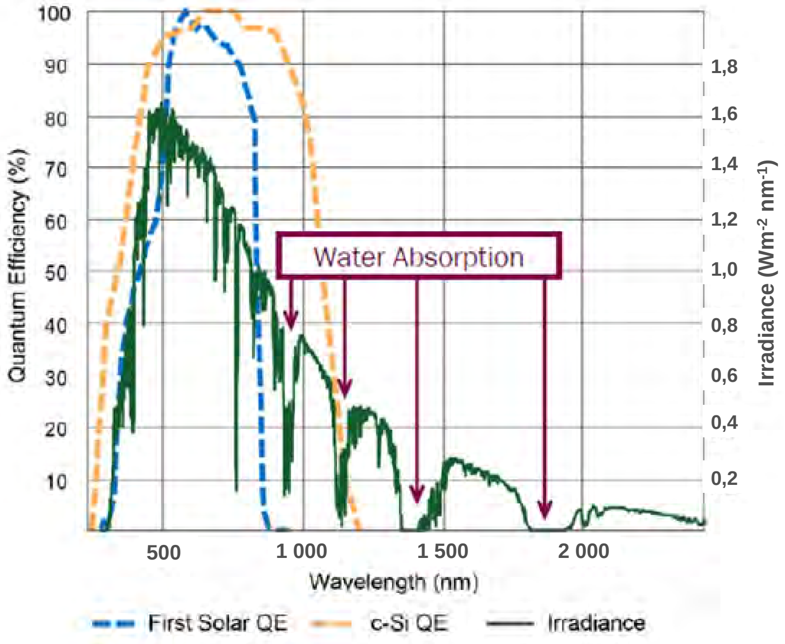

Fig. 1.2-1 Spectral irradiance and quantum efficiency for c-Si PV (orange dash) and CdTe PV (blue dash)[8]

(3) Clouds

Depending on the type of cloud cover, incident power can be strongly reduced. High, thin cirrus clouds act in a way similar to clear air because they are highly transparent to shortwave radiation. In contrast, low stratified clouds such as stratocumulus clouds are much thicker than high cirrus clouds, and therefore do not allow as much solar energy to reach the Earth's surface. Deep convective clouds, such as cumulonimbus clouds, can be many kilometers thick and also strongly reduce shortwave radiation reaching the Earth's surface. Numerical weather prediction models are used to forecast cloud cover and associated impacts on solar irradiation for several days in advance. Recent efforts have been undertaken to improve the accuracy and resolution of these forecasts using high resolution satellite data and the community mesoscale model WRF to develop short term nowcasts[9].

To help improve grid integration of variable power sources, some utility-scale PV power plants now have power plant controller architecture to regulate real and reactive power output from the PV plant, such that it behaves like a single large generator. For example, plant-level control functions at the 290 MWac Agua Caliente solar project, Yuma County, Arizona include dynamic voltage and/or power factor regulation, power output curtailment, ramp-rate and frequency controls, and start-up and shut-down control[10]. When the plant is curtailed to a specified limit and the plant has additional available generating capacity, the plant-level control functions can minimize the impact of cloud passage on a portion of the plant by increasing the output of other inverters that are not impacted. This will result in increased energy yield (Fig. 1.2-2).

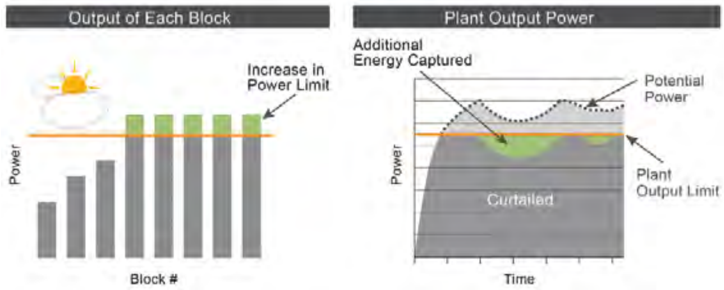

Fig. 1.2-2 Impact of Cloud Passage on a PV power plant with controller architecture[10)]

(4) Soiling

Soiling from dust and dirt directly impacts the performance of PV modules, and the effects of soiling are dependent on a variety factors (Fig. 1.2-3). In most climates, cleaning is not necessary as soiling losses are minimal and dust is periodically removed by wind and rainfall. An exception is for humid, dust-prone climates, which can transform dry dust into clustered and sticky dust. When cleaning is necessary, a variety of robotic or manual, water-using or water-free cleaning methods can be selected depending on the cost and availability of labor and water. For example, in the Middle East region where labor is available but water is limited, dry brush cleaning methods have been implemented (Fig. 1.2-4), limiting soiling losses to less than a few percent per year without the use of water[11)].

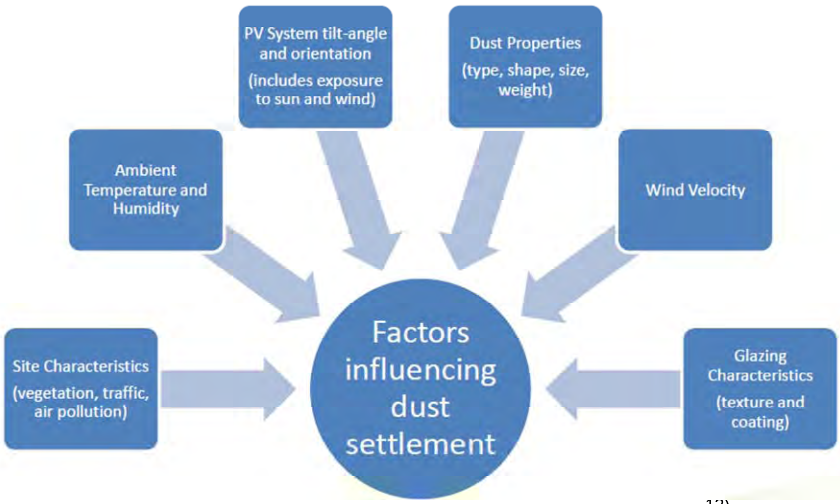

Fig. 1.2-3 Factors influencing soiling of PV modules[12)]

Fig. 1.2-4 Manual dry brush trolley cleaning method deployed in the Middle East[12)]

(5) Other variables

Severe winds, hail, and heavy snowfall can potentially damage PV system components. As a result, PV modules are subjected to hail impact testing and static and dynamic load testing to simulate wind, snow and ice loads at varying temperatures and load rates (e.g., IEC 61215, IEC 61646). In the case of tracking systems, on-site weather stations allow for automated stowing in the case of strong winds. Corrosion from ambient moisture ingress and sandblasting from wind-blown particulates can also potentially damage PV system components. IEC 61701 salt mist corrosion testing and IEC 60068-2-68 dust and sand environmental testing can characterize PV modules for such conditions. In addition, long-term parallel testing protocols such as the Thresher Test and Long Term Sequential Test have recently been developed to further extend test durations to better differentiate PV modules in long-term field performance[5)].

1.2.3 Summary

Better understanding of operational aspects of PV power plants has been gained in recent years through the deployment of large scale plants (10-550 MWac). Real-world conditions differ from reference conditions due to field variables such as temperature, humidity, aerosols, clouds, and soiling. Accounting for these conditions can help improve the performance of PV power plants and reduce the uncertainty in solar PV energy predictions, thereby improving the bankability of the technology. For example, a recent review of predicted energy ratio (PER; actual to predicted specific yield in kWh/kWp) of large scale PV power plants showed stable and predictable performance over time (Fig.1.2-5).

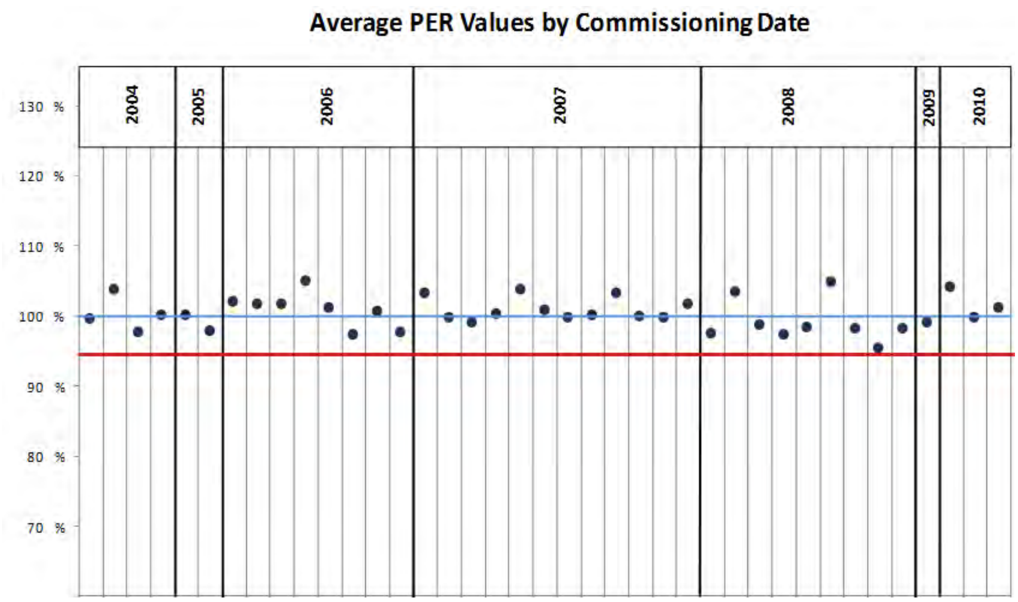

Fig. 1.2-5 Predicted energy ratio (PER) of over 250 MWac of PV solar plants in hot and temperate climates[4)]

1.3 Importance of operation and maintenance

1.3.1 Plant operation in general

After complete erection and testing period of a PV plant it is handed over to the customer / owner[13)]. Now a long-term operation period starts. During the testing period usually owner's operators are trained by the EPC how to effectively work with the monitoring system. A system operator furthermore needs a comprehensive overview of the current plant situation. On one hand he needs a clear picture of the plant status which indicates an orderly operation. On the other hand – in case of a not orderly operation – he will get warnings and/or signalling from the system which case by case may require him to actions.

Organisation of plant operation could be differently arranged:

- Complete plant operation by plant owner
- Plant operation by plant owner, servicing by an external service provider
- Plant operation and servicing of the plant completely by an external service provider

Criteria of which kind of operation would be the optimal solution for the employer may differ. It may depend on the employer himself as well as on the country and the individual plant. According to that contracts have to be formed for maintaining an orderly and professional operation (service contracts). Referring operators shall in any case have a very good knowledge of the system itself and of the applied monitoring / SCADA[a] system. Another precondition is a clear structured schedule of maintenance works, repair organisation and conditions of reporting to the management.

Beside operation monitoring VLS-PV plants additionally have a video surveillance system installed as theft protection measure. The operator is also in charge for operating this system.

In principle nearly each large PV power plant could be remotely monitored and operated, by means of the original SCADA system and the video system. The decision whether an unmanned or manned-on-site operation is again depending on each individual case. It should be weighed which kind of operation could be the better suitable solution. In many cases the highest availability has the highest priority which rectifies a manned-on-site operation.

1.3.2 Monitoring and controlling PV power plants

Only appliances of suitable software and monitoring platform in the long run allow optimal energy yields preventing incalculable costs.

The quality of the applied Monitoring / SCADA system and of the operators has a great influence on the quality of plant operation. Professional systems monitor online all relevant plant-internal measured data of the different PV sub-arrays, inverters, meteorological stations, switching devices, transformers as well as of the entire plant. The challenge for operators is the identification, analysis and characterisation of loss mechanisms so that energy losses can be reduced to the minimum level possible.

Fig. 1.3-1 Remote plant monitoring / supervision platform, daily routine

[a] SCADA System Control and Data Acquisition

Furthermore the SCADA system informs about data of the medium / high voltage grid in which the plant feeds in its power.

In the meantime VLS-PV plants are not more only feeders, they increasingly fulfil functions such as grid-improvements and grid-stabilisation. In more and more countries MV/HV grid owners force by referring regulations the plant owners to provide the plants with a so-called Power Plant Controller PPC. PPCs take over control signals sent via ripple-control system of the grid operator. According to those signals inverters have to vary e.g. the feed-in power, the frequency and the power factor to support the quality of the current MV/MV grid situation.

The extent of these external interventions may differ from country to country or even from grid owner to grid owner. Cross-border standards with fix control parameters do not exist.

Most of the inverter suppliers have already prepared hard- and control-software in their machines. Special companies offer PPC devices. The SCADA system also monitors remote control actions of that kind.

The SCADA system provides also automatically performance data for the management like

- PR values
- Irradiation
- Yield values
- and a high-resolution data basis of historical data (e.g. 1-minute resolution) over the entire plant life time for e.g. evaluation of a trend of module performance

These indications allow an assessment of performance of the plant and a comparison between initially calculated and really achieved ones. Should an underperformance be identified a critical review of historical plant data is required and an evaluation of reasons. Should underperforming of PV modules be a reason guarantee conditions have to be examined. Sample testing of PV modules by a certified institute may clarify whether the module supplier should be contacted and power output guarantee be stressed.

1.1.3 Maintenance and spare part strategy

A well structured maintenance strategy is assuring a high functionality and availability of the plant. It encloses a conception of which and how many spare parts shall be kept in a short-term available and in a mid-term stock. Driving cost factor of the stock are usually PV modules. A well balanced risk assessment of the local situation and of how many replacements of modules for e.g. 10 years should be calculated may come to an economical optimum. Keeping track of the stock situation over the entire operation period is very important.

A risk analysis together with an economic calculation may discover that even an inverter and/or a transformer as spare part may be justifiable. Taking the lost energy into account caused by a breakdown of e.g. an inverter or transformer, it could need unjustifiable time for ordering, transport installation and commissioning etc. until the sub-plant is operating again.

Maintenance strategy has to be incorporated different actions for reduction of downtimes also:

- actions for preventive maintenance, regular maintenance and the case of trouble-shooting and repair services

The strategy is more or less written down in a Maintenance Manual. In the manual are listed in detail all the measures to be carried out by the maintenance personnel.

(1) Maintenance of pyranometers and reference cells

Two types of measuring devices are usually needed and processed by the SCADA system as basis for calculation of operational performance of the plant and last but not least for the Performance Ratio PR[b] factor.

Pyranometers are used for measuring horizontal global irradiation and one in plane of the PV generators. Yearly measured values serve as comparison to initial in a simulation programme generated irradiation values. At module level tilted reference cells provide data of theoretical achievable yield per square meter.

Both types of sensors have to be maintained. They underlay certain degradation which shall be eliminated by recalibration by an authorised institute every two years. Otherwise e.g. the PR factor is not more up to the truth and delivers not more reliable values on the efficiency of the plant.

Some types or downtimes of the plants cannot be avoided by plant maintenance, since they are out of influence of the operator– although a good maintenance strategy and service are in place:

- downtimes attributed by vandalism
- interruptions by the network of the grid owner
- force majeure, e.g. extreme weather conditions

(2) Maintenance contracts

Some maintenance contracts have to be taken into account to keep the plant at a high functionality and availability:

- service contract for site care
- service contract for preventive, regular maintenance and repair
- service contract for inverters , suppliers should have a service crew in the referring country or a co-operation partner allowing short-term service on site if required
- service contract cleaning PV modules (if required)
- service contract with supplier of the video surveillance system (theft protection)

Beside maintenance for above mentioned items national electrical and safety regulations require regular maintenance for MV components too, like e.g. MV/HV switchgears and transformers. Such inspections and testing may be required every three or four years and could be ordered separately.

An example of maintenance procedure initiated by the operator is shown in Fig. 1.3-2.

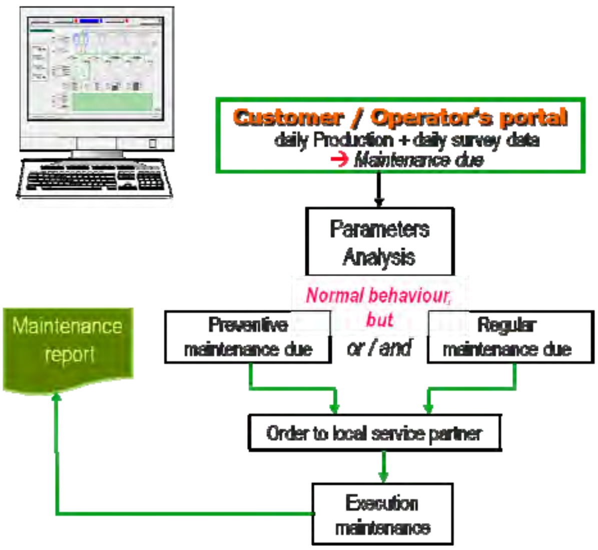

Fig. 1.3-2 Simple maintenance systematic

[b] Performance Ratio is a quality factor. It pictures the efficiency of the PV power plant by showing the relation of a yearly energy yield [MWhrs] to theoretically produced e.g. yearly yields [MWhrs] as percentage value

1.3.4 Logbooks: Important documents of operation

In a well organised operation of a PV plant three kinds of logbooks should be administered, as shown in Table 1.3-1.

Table 1.3-1 Structure of logbooks for PV plant operation

Logbook 1 Regular Maintenance	This logbook shall be used for each regular / preventive maintenance actions. A detailed checklist shall stipulate all checks and measuring required for assuring the undisturbed operation.
Logbook 2 Unscheduled Maintenance & Repair	This logbook shall be used for each unscheduled maintenance action respectively for repair actions also.
Logbook 3 Service	This logbook shall be used for each service action concerning service contracts for e.g. inverters, air-conditioning units etc.

Separate logbooks will structure actions to take place in a plant right from the beginning.

- Differentiate clearly actions in 3 groups
- Allow quick access for reports of companies and personnel involved
- Avoid ambiguity interpretation of actions to allocate
- Simplification for operators to track occurrences in the plant etc

In the operation logbook (logbook 1) of the plant all measures are to be filed carefully. It shall provide a picture the history of any actions executed like preventive and regular maintenance actions, trouble-shooting actions, any other repairs, regular services etc.

Having concentrated and replicable information from the operation logbook each year a critical analysis of operational related matters should take place. It allows drawing conclusions on the ongoing behaviour of the plant, week devices may be identified and optimisation measures should be discussed. So the log will be a living document and the chance to contribute to the goal of getting an appropriate financial return on investment.

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Chapter 2 Environmental and Socio-Economic Features of PV Power Plants

2.1 Environmental issues in developing large-scale PV plants

Solar photovoltaics (PV) have been deployed as a low carbon alternative to conventional electricity generation that also addresses the energy-water nexus (Figs. 2.1-2 and 2.1-2). In particular, large-scale, ground-mounted solar photovoltaic (PV) plants provide the economies of scale and rapid market penetration needed to achieve grid parity with fossil fuel-based electricity and further the transition to clean, renewable energy sources. When developed responsibly, large-scale, ground-mounted solar PV power plants can provide considerable environmental benefits. For example, replacing existing grid electricity with PV arrays can reduce emissions of greenhouse gases, criteria pollutants, heavy metals, and radioactive species by 89 to 98 %[1], as well as significantly reduce water withdrawal and consumption[2,3].

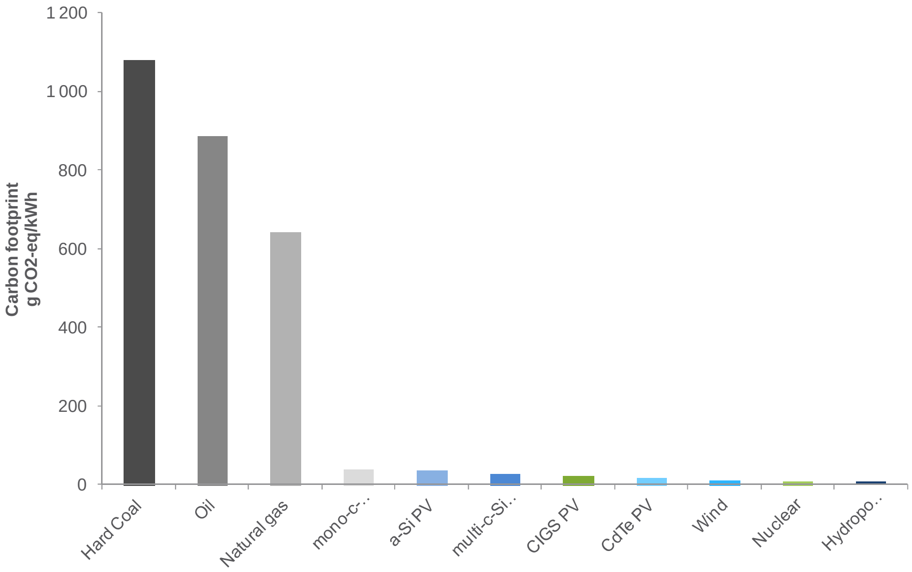

Fig. 2.1-1 Life cycle carbon footprint of electricity generation in Europe (southern Europe for PV, Norway for hydropower, and European average for other technologies)[4,5]

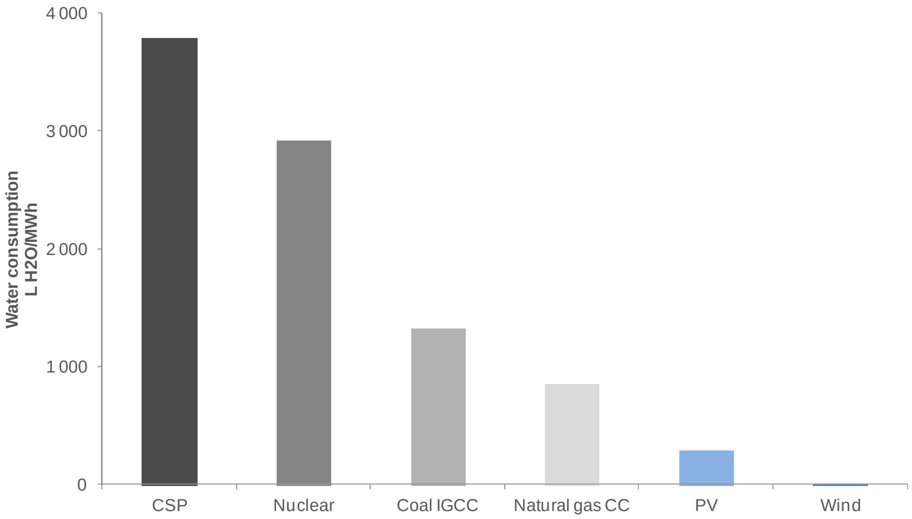

Fig. 2.1-2 Life cycle water consumption in electricity generation (with cooling tower for CSP, Nuclear, Coal, and gas)[2]

However, some stakeholders have raised concerns regarding the land impacts of PV systems. When considering the complete project life cycle (material sourcing, manufacturing, distribution, use, and end-of-life disposal or recycling), large-scale, solar PV plants in areas of high solar irradiance also use less land than some traditional energy sources (e.g., coal after land use for mining is taken into consideration)[6)]. In addition, when considered on a comparative basis, large-scale, ground-mounted solar PV power plants are largely beneficial with regards to wildlife and habitat environmental indicators relative to traditional fossil-fuel based power generation (Table 2.1-1).

Table 2.1-1 Impacts relative to traditional power generation[7)]

Impact category	Effect relative to traditional power	Beneficial / Detrimental	Priority	Comments
Exposure to hazardous chemicals				
Acid rain: SO_2 NO_x	Reduces emissions	Beneficial	Moderate	Solar power emits ~25x less
Nitrogen, eutrophication	Reduces emissions	Beneficial	Moderate	Solar emits much less
Mercury	Reduces emissions	Beneficial	Moderate	Solar emits ~30x less
Other: e.g., Cd, Pb, particulates	Reduces emissions	Beneficial	Moderate	Solar emits much less
Oil Spills	Reduces risk	Beneficial	High	Note: BP Horizon spill, Valdez spill
Physical dangers				
Cooling water intake hazards	Eliminates hazard	Beneficial	Moderate	Thermoelectric cooling is relegated
Birds: flight hazards	Transmission lines	Detrimental	Low	Solar needs additional transmission line
Roadway and railway hazard	Reduces hazard	Beneficial	Low	Road and railway kill is likely reduced
Habitat				
Habitat fragmentation	Neutral	Neutral	Moderate	Needs research and observation
Local habitat quality	Reduces mining	Beneficial	Moderate	Mining vs. solar farm; needs observation
Land transportation	Neutral	Neutral	Moderate	Needs research and observation
Climate change	Reduces change	Beneficial	High	Solar emits ~25x less greenhouse gases

To illustrate the potential land use benefits of solar PV, a multi-stakeholder project involving the German Renewable Energy Agency examined solar parks throughout Germany to identify conservation measures and best practices employed during planning, construction, and operation. The study established that solar parks can have a positive impact on biological diversity. Although construction projects always involve disturbance of existing flora and fauna, with solar parks there is a chance to improve the quality of habitats for various plant and animal species and even to create new habitats[8)]. In the U.S., Secretary of Interior provided perspectives on PV land use when approving the first large-scale solar energy plants built on U.S. public lands. He explained that large-scale solar plants built on public lands, while a significant commitment of public land, actually represent less than one-hundredth of one percent of that total area. Given the many benefits, the extensive mitigation measures, and the fair market value economic return, approval of these projects is clearly in the public interest[9)]. The World Wildlife Fund also confirmed this perspective in a multi-stakeholder solar atlas project that considered large scale solar PV deployment in multiple regions including biodiversity hot spots (Indonesia; Madagascar; Madhya Pradesh, India; Mexico, Morocco, South Africa, Turkey). The study found that less than one percent of a region's total land cover will be required to host solar PV generation in order to meet one hundred per cent of a region's projected electricity needs in 2050[10)]. The study also included best practices for responsible land use in large-scale PV projects (Table 2.1-2).

Table 2.1-1 Best practices for responsible land use in large-scale solar PV[10)]

		Sub-Category	Low Score	High Score
Category	Community	Dust	Little regard for dust generation, no control efforts	High regard for dust generation, worker education , control methods (palliatives, focused water use)
		Visual	Arrays adjacent to property lines or high traffic roadways; no screening or landscaping; night illumination	Completely out of sight from roads and neighbors
		Noise	Equipment backup alarms, post driving, heavy equipment, close to property lines or receptors; night work	Significant distance buffer; equipment selection; equipment noise shielding; weekday/daylight hours work only
		Stakeholder Engagement	Little to no engagement	Active local engagement through community organizations and governments; local educational or college programs tours; public outreach activities (meetings, tours)
		Labor	Non-local workers; minimum wage; minimum safety requirements	All local workers; prevailing wage; full personal protective equipment and extensive safety training and oversight; maximizing local economic development and job creation; focus on aboriginal and indigenous engagement and employment
	Biology	Species, Plants, Etc.	Design and construction with no regard to local biodiversity	Detailed surveys conducted; special interests and other stakeholders consulted; design and construction with high regard for biodiversity; appropriate mitigation measures; ongoing monitoring of impacts; maximizing buffer areas around the active site, providing improved habitat potential, visual buffer, etc.
		Environmental Impact Studies	Not performed; no awareness of any environmental issues	Environmental Impact Study /Assessment conducted, mitigation plan developed with stakeholder involvement
		Soil Protection	Little regard for protecting the grassland or site soils	Rigorous fire protection plans; topsoil conserved or replaced; adequate seeding of native grasses; compaction and permeable surfaces support growth
	Water	Usage	Little regard for water use	Usage measured and reported; ambitious water reduction goals set; Construction methods implemented to minimize water use
		Storm Water	Little regard for storm water or runoff onto neighboring properties	Appropriately sized and protected protection and conveyance measures (retention ponds; rip rap; silt fencing; etc.), effective measures to counter stormwater flow and runoff are in place; post event performance and condition assessment
	Design & Construction	Site Selection	Prime agricultural, biological, or cultural land used	Use of disturbed or previously used sites; superimposed on existing structures (roofs, landfills, parking lots, etc.); greenfield or prime agricultural land avoided, worn agricultural or contaminated land used to restore biodiversity; consider potential for 'dual use' of sites (e.g., agricultural/grazing) – this will depend on local climate and farm practices
		Grading	Heavy cut and fill; stripped topsoil; invasive seeds introduced; long-term drainage or dust issues	Minimizing grading, installation follows existing topography, minimizing built roads/gravel, minimizing trenching; topsoil retained or restored; no standing water or dust areas
		Footprint/ Layout	Inefficient use of space	Minimize project footprint with careful balance of ground coverage ratio, row spacing, module height, etc.
	Decommiss -ioning/ End-of-Life (EOL)	Site Restoration	No consideration of land restoration after project life	Ensure that a site can be restored to its original state (or better) at the end of project's useful life
		Recycling	No take-back and recycling at module EOL offered	Take-back and recycling of EOL modules and Balance of System products considered and addressed as part of project development and permitting phase

An example of an environmental success story is the Lieberose Solar Park in Germany (Fig. 2.1-3). It transformed a dormant military training ground into a native meadow providing a habitat to several endangered bird species. Among other benefits, the Lieberose project paid to decontaminate what had been one of the largest military training facilities in eastern Germany. In addition, after the solar plant is ultimately dismantled, and its modules recycled, the area will be returned to its original state as a natural meadow, sustaining and enhancing biodiversity in the area[8].

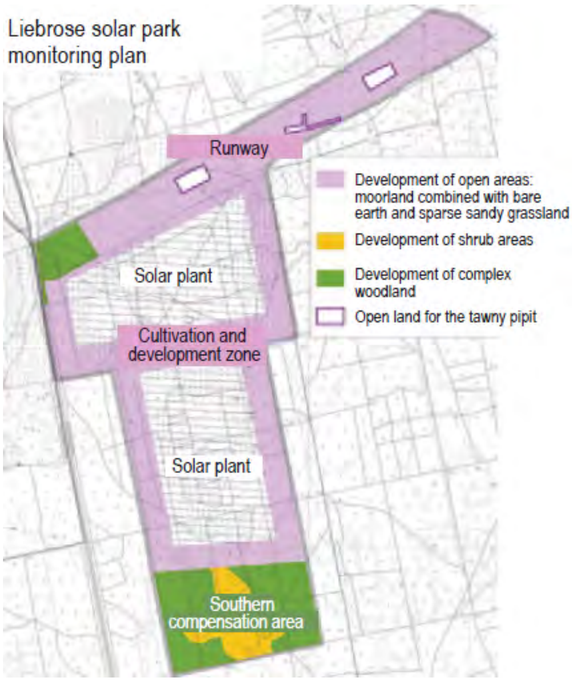

Fig. 2.1-3 Lieberose Solar Park brownfield redevelopment[8]

Another example of ground-mounted solar PV contributing to biodiversity is the Topaz Solar Farm in California. This project will restore highly disturbed agricultural lands to its native grass, and should, once again, become an inviting home to kit foxes, ground squirrels, badgers, burrowing owls, elk, and antelope. Project biological enhancements that focus on the endangered San Joaquin kit fox include artificial kit fox dens and escape tunnels, kit fox-friendly fencing, and discontinuation of the use of rodenticides[11]. The project also includes pre- and post-construction monitoring. For example, before and after testing of grassland vegetation productivity at a project site test array showed no statistical reduction in productivity after PV installation[12].

The 550 MW Desert Sunlight project in California significantly reduced the project footprint from the original study area of over 19 000 acres to approximately 3 800 acres. These reductions were based on survey results and advice from experts in a range of disciplines with the aim of minimizing the biological, cultural and visual impacts of the project, including avoiding critical habitat for the threatened desert tortoise. The reductions also minimized impacts to other sensitive resources such as Pinto wash and sand dunes, known migration routes for bighorn sheep, areas with high concentration of foxtail cactus, and known cultural resources, including significant prehistoric resources and key elements of General Patton’s Desert Training Center[10]. Construction efficiency was also improved with innovative disk and roll and micro grading site preparation techniques (Fig. 2.1-4), which led to a reduction in earth movement, resulting in reduced air emissions and water use during construction associated with dust control and soil preparation. Both the Desert Sunlight and Topaz projects benefited from extensive biological and cultural survey efforts and diverse stakeholder interaction involving the local County and State agencies, the U.S. Fish and Wildlife Service, the U.S. Army Corp of Engineers, Native American Tribes, and numerous environmental NGO’s.

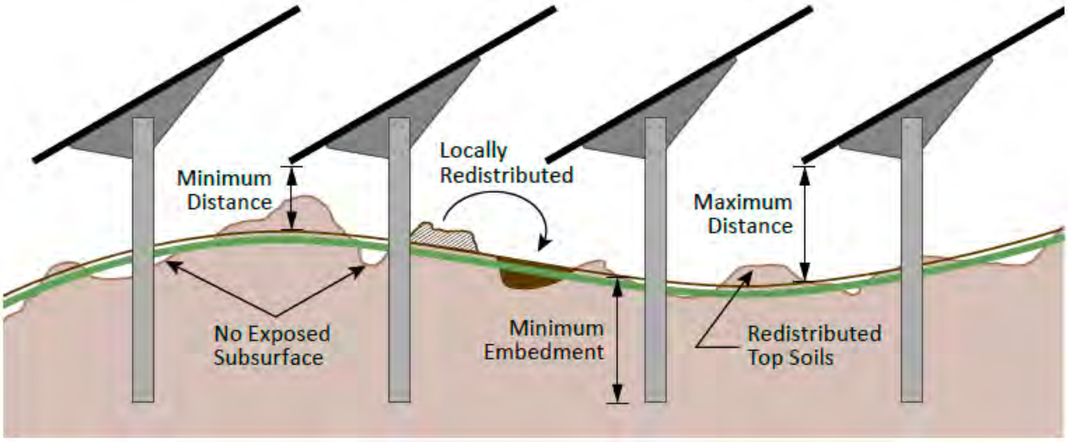

Fig. 2.1-4 Disk and Roll Micro Grading Site Preparation Technique (courtesy of First Solar Inc.)

In summary, large scale PV projects can be carefully designed and refined through collaboration with stakeholders to result in environmentally sensitive solutions to site selection, construction, and operation of land. This approach to responsible land use ensures that as much land as possible remains a productive habitat for animals and vegetation during a project's estimated 25+ year life span, and even creates new habitats, as described in the case studies above. The goal from an environmental perspective is to avoid, minimize, and mitigate impacts to the environment.

2.2 Socio-economic evaluation of localisation in photovoltaic value chains

This chapter assesses and evaluates the socio-economic impacts (benefits & burdens) of localized value chains in photovoltaic manufacturing, deployment, operation, maintenance and end-of-life recycling and reuse, citing a couple of case studies for different world regions and different photovoltaic technologies. It is shown to what extent business models based on localization are viable and to what extent regulatory and policy frameworks influence these.

2.2.1 The value chain concept

In general, the value chain of a product or service provides insight into the process of how certain activities add value to it, hence determine its total costs and price.

Each of the activities can be characterized by input-streams, processes, and output-streams. As such, the value chain follows the supply chain of a product from the raw materials to the end-consumer and even beyond if one considers dismantling, reuse, recycling and disposal of the product. Fig. 2.2-1 below depicts the photovoltaic supply chain, forming the basis for a value chain analysis.

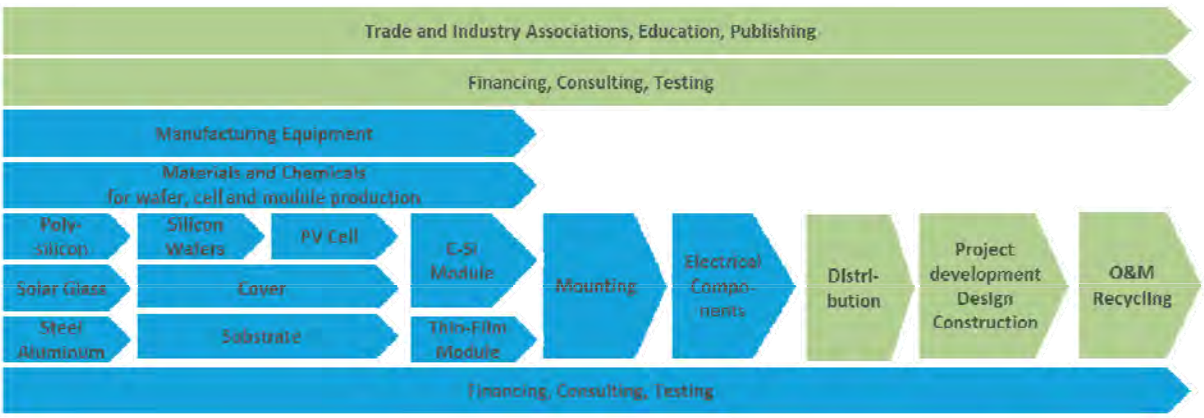

Fig. 2.2-1 PV supply chain[13)]

To analyse the potential effects of localization of certain parts of the value (supply) chain, it is helpful to distinguish the main hardware components of a PV system and the services of installation, operation, maintenance and dismantling – whereas the latter parts will be done locally. The focus of this analysis is set on the upstream part of the value chain – hence the manufacturing of the PV system components.

2.2.2 Case Study: European PV industry

A comprehensive analysis of the value creation of the European PV business and activities in 2012 in provided[14)]. They conclude that the value created by European PV activities is about 74 % of the total value of the European PV market in 2012 when it comes to the manufacturing and installation of photovoltaic systems. Distinguishing the two main technologies of crystalline silicon PV and thin-film PV the analysis depicts the value chain charts displayed in Figs. 2.2-2 and 2.2-3.

What becomes apparent through analysis of the different supply chains for the products (and manufacturing equipment) and services are local value creation potential in the system integration and installation part. In addition, the value creation of the upstream part still contributes more than 51 % to the overall value, even though only 14 % of cells and modules have been manufactured in Europe at this stage. This mainly relates to the diminishing contribution of cell production and module assembly costs, which were only 56 % at time of the analysis and are expected to continue to fall on a year by year basis going forward according to the well-known Price experience curve and the increasing production and deployment figures.

Another reason for this result was the strong manufacturing base for raw materials and photovoltaic manufacturing equipment – which to a large extend are exported out of the EU.

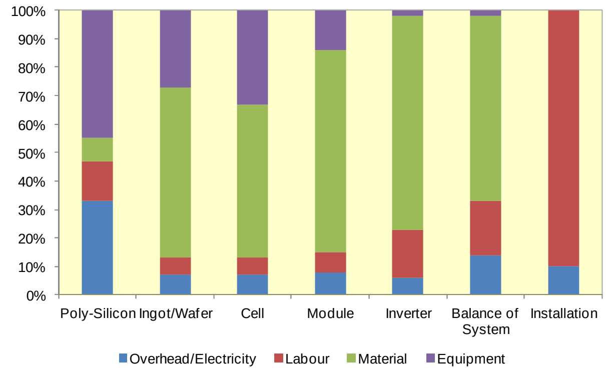

Fig. 2.2-2 Value chain chart for the c-Si PV value chain[14)]

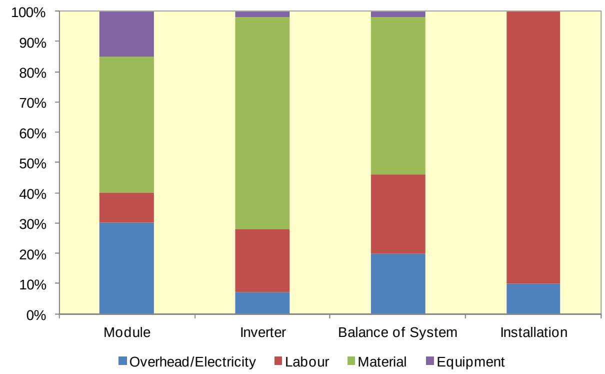

Fig. 2.2-3 Value chain chart for the TF PV value chain[14)]

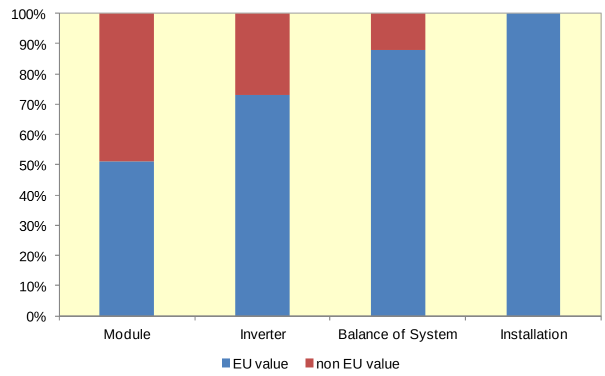

Fig. 2.2-4 European value throughout the PV value chain[14)]

2.2.3 Case Study: Utility-scale PV Power Plants: Creating Jobs and Economic Value for Local Communities

Large-scale solar PV's economies of scale are making solar power more affordable and because of this, the solar PV industry is creating thousands of new jobs and growing economies worldwide. Every renewable energy industry attempts to drive down the levelized cost of electricity (LCOE). As LCOE plummets and solar energy's market penetration increases, the result will be new jobs by the thousands. The growing affordability of solar power promotes the adoption of PV technologies not just in large-scale, ground-mounted solar power plants, but also in rooftop markets, thereby creating thousands of local jobs in sales, installations, maintenance, and eventually recycling—all jobs that cannot be out-sourced and which, therefore, help build a more sustainable economic environment. Numerous studies document how green energy job growth is far outpacing other sectors and that more jobs are created for each 1 million USD spent compared to fossil fuel resources[15)]. Job creation will continue to be important as the solar industry moves into markets such as India, South Africa, and the Middle East where employment is a key market driver.

As depicted by EPIA[16)], as shown in Fig. 2.2-5, the value chain of the PV industry comprises two categories of jobs. Direct jobs are provided by companies or individuals fully dedicated to the PV chain (see above). Indirect jobs support the PV industry by providing more generic components or services, like raw material suppliers. In 2012 the PV industry on average created between 3 to 7 direct jobs and 12 to 20 related indirect jobs per MWp produced, depending on the PV technology.

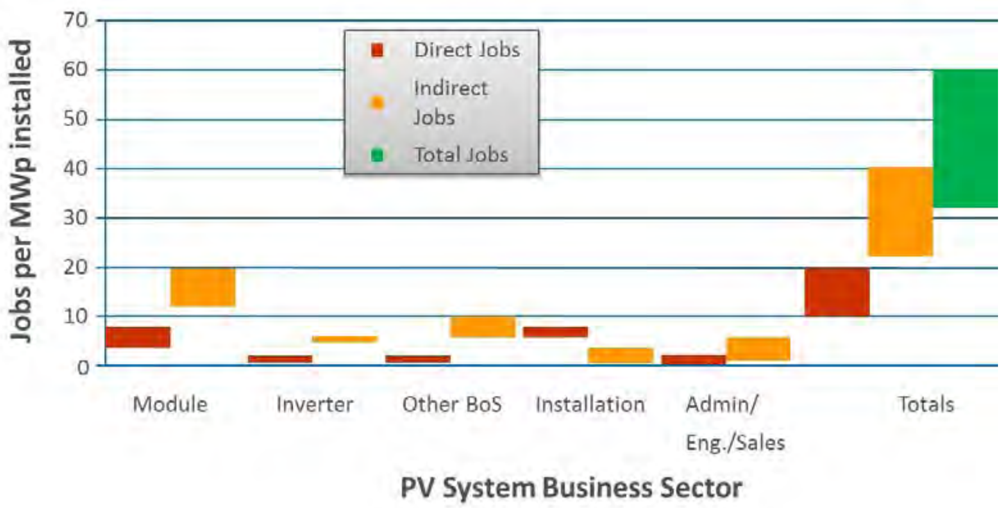

Fig. 2.2-5 Average Job creation of the PV industry in 2012[16)]

If one focuses on the value of localized products and services, it becomes apparent that the downstream part of the value chain holds the biggest share also in terms of job creation (Fig. 2.2-6).

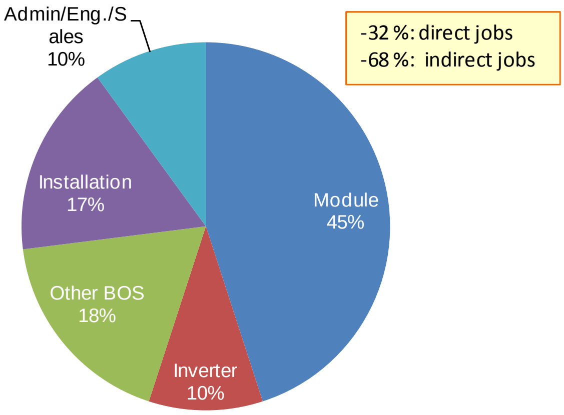

Fig. 2.2-6 Distribution of jobs in the photovoltaic industry value chain worldwide[16)]

Worldwide, it is estimated that there were approximately 225 000 people directly employed in the PV solar industry in 2009 - a figure that is projected to easily double by 2030 under current market conditions. As solar PV is adopted more broadly worldwide, employment will also soar —possibly as high as 3,55 million in the solar PV industry by 2030[17)]. As emphasized previously most of the jobs the solar sector creates are not from manufacturing but rather the construction, operation and maintenance of the power plants themselves. Construction employment will help to meet the job creation goals and the demand for jobs in places like China, India, and Australia.

In the U.S. *(2013: 142 698 solar workers)*, for example, manufacturing accounts for only ~21 % of solar jobs, while installation accounts for ~49 % and sales and distribution, project development and others accounts for ~30 % of all solar industry jobs[18)]. Besides creating direct jobs in areas such as construction and manufacturing, solar PV plants help to create indirect jobs through increased economic activity in the area. It is estimated that in the US about 435 000 additional jobs are supported and induced by the solar industry[18)].

Indirect jobs are created in the supply chain from local "business-to-business" transactions necessary to support the building or operation of a central-station solar project, for instance local purchase of building materials, engineering and consulting services, and other goods purchased from supporting industries. Job creation is also seen as an “induced impact” resulting when the increased earnings generated by the direct and indirect economic activity is spent on local goods and services, for example when workers at the facility spend their income on food, clothing, automobiles, real estate, and education, health and social services.

As an example, the 550 MW Desert Sunlight Solar Farm which is expected to be fully operational in 2015 provides estimated 336 million USD of indirect benefits to local businesses in the county, from engineering and design firms to construction subcontractors, supplier, and service providers[19)]. These figures do not even include the benefits due to avoided external costs over the 30 year lifetime of the plant. These external costs would burden the regional and local societies and could – in case of the above mentioned example – be estimated to be in the range of a couple of billion USD over the expected lifetime of the plant, using the methodologies applied as shown in Table 2.2-1[20)].

2.2.4 Summary

This analysis has shown that the most valuable way to localize the value chain of photovoltaics is actually the deployment (construction), operation and maintenance of photovoltaic power plants, as this phase of the value chain by far outweighs the economic value creation during raw material extraction, manufacturing and eventually take-back and recycling.

Table 2.2-1 Avoided External Costs / Benefits of using utility scale ground mount thin film PV electricity generation[20)]

Avoided External Costs / Benefits of using Thin Film PV electricity generation	Avoided cost range [USD/kWh]	Desert Sunlight Solar Farm example (550 MW AC / 1 100 GWh p.a. / 30 year lifetime)[a)] [million USD]
Benefits with regard to impacts on climate, air quality, and water resources[b)]	0,02 – 0,05	660 – 1 650
Opportunity costs from not using renewable energy related to energy infrastructure[c)]	0,06 – 0,51	1 980 – 16 830
Opportunity costs related to non-energetic uses for fossil fuels[d)]	0,21	6 930
Total	**0,29 – 0,77**	**9 570 – 25 410**

[a)] Based on fixed-tilt utility-scale installation in the southwest United States with 2012 average module conversion efficiency of 12,7 %, performance ratio of 0,812, plane of array irradiation of 2 199 kWh/m^2/year, 0,70 %/year module degradation rate, and 30 year lifetime

[b)] relative to conventional gas and coal electricity

[c)] i.e. value of saved energy being lost in the conventional system due to inherent inefficiencies in the transmission and distribution system, value for avoided generation capacity, value for avoided transmission and distribution capacity upgrades, value for grid support services, value for financial fuel price hedging, value for market price response to higher renewable energy supply contribution, value for grid security, value for additional economic development due to the use of renewables; also refer to Hansen, Lacy, & Glick[21)]

[d)] In addition to energy infrastructure, there are opportunity costs related to non-energetic uses for fossil fuels. Kroll[22)] developed an approach to calculate the opportunity costs incurred when the use of a free and abundant commodity (solar radiation) is supplanted by the use of a finite commodity (fossil fuels), which is destroyed and thus unusable in the future. Through substitution of fossil fuel energy generation, the value of the finite resource is preserved for future non-energetic uses.

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Chapter 3 International Tendering of PV Power Plants

3.1 Introduction

During recent years it has been noticed that much of the market of large PV power plants requires a form of contract where certainty of final price, and often completion date, are of extreme importance. Employers[a] on such turnkey projects are increasingly willing to pay more for their projects if they can be more certain that the agreed final price will not be exceeded. Among such projects can be found many projects financed by private funds, where the lenders require greater certainty about project's cost to the Employer than by traditional forms of contract with the Contractor[b].

In the following a tendering systematic is leaned on common procurement procedures used by international financing institutions like e.g. World Bank WB, European Bank for Reconstruction and Development EBRD and other International Development banks - considering procedures developed by the FIDIC[c] organisation which is a fair and systematic approach.

Furthermore the consecutively presented tendering process refers to EPC[d] Projects, common in the PV business. Because tendering of large scale PV power plant project completely designed by the Employer is presently an absolute exception.

3.2 Tendering from a general view

A call for bids or a call for tenders or invitation to tender (ITT) (often called *tender* for short) is a special procedure for generating competing offers from different bidders looking to obtain an award of business activity in works, supply, or service contracts.

Tenders are initiated by public entities. Government procurement policy seeks to maintain high standards and to ensure value for money in the delivery of public works projects. A lot of governments have own *Public Works Procurement Process Rules* in place which regulate the terms of references.

The meaning of the here used word "project" covers all stages from the initial idea to construct a physical asset (like PV power plant) to the final taking-over by the Employer of the completed installation ready to normal operation.

Like other international tenders in the energy sector large scale PV (VLS-PV) power plants have special features to be considered. Since the Employers normally expect acceptable quality, high efficiency and reliable long-term operation of his energy asset the quality of the tendering process may already at the beginning play an important role to reach his goal. Although VLS-PV power plants already have conquered its place in many of the minds of energy experts it is not yet comparable with conventional energy techniques and numerous experienced commercials and engineers knowing how to deal with them.

3.2.1 Assessment of resources of a VLS-PV power plant project

Nowadays the situation of power supply of electrical energy in nearly each country is characterised in any case mid-term by an increase of demand. The referring energy master plan has to consider that. Additional conventional power plants are mostly going along with increasing imports of fossil fuel as

[a] Employer = The party who receives and accepts the Tender, who is responsible for providing the Site and paying the Contractor and for whom the Works are provided by the Contractor

[b] Contractor = The party whose Tender has been accepted by the Employer, and who is responsible for providing the works and the legal successor in title to such party

[c] FIDIC = Fédération International des Ingénieurs-Conseils, International Federation of Consulting Engineers

[d] EPC = Engineering, Procure & Construct, a procurement procedure under which the Contractor or supplier provides works which are fully complete and ready for operation by the Employer

well as mid- and long-term negative influence of the gross national product Gross National Product GNP, not talking about damaging the sensitive atmosphere. Among other Renewables VLS-PV power plants could be the way out of this dilemma[1)]. Or oil producing countries realise that electrical energy based on the sun can more and more replace burning of oil at daytime in conventional power plants. Substituted oil could then better be sold on the world market.

This situation is increasingly stimulating governments world-wide to invest in large scale PV power plants – and the start for procurement of PV power plants by tendering processes. This process usually starts with the initial idea. It normally is followed by the identification of the financial (re)sources and a feasibility study or a so-called Front End Engineering & Design (FEED[e]) phase.

3.2.2 Feasibility study / front end engineering design for a PV power plant

The feasibility assessment predominantly revolves around the technical and commercial analysis. It allows the proponents to decide whether to proceed with implementation of the scheme.

Typical scope and items of this phase are

- Selection and identification of a suitable site for a grid-connected PV plant
- Production of a detailed site plan
- Identification and calculation of local solar resource and local environmental characteristics
- Geotechnical evaluation of local ground / soil conditions
- Assessment of mid to long-term *external* shading (horizon and nearby buildings and other objects)
- Assessment of technology options providing cost/benefit for the project location
- Type / nominal power of PV Module
- Basic concept of mounting system for PV modules
- Outline of system design
- Application for outline planning permission
- Grid connection – more detailed assessment of grid capability / capacity, cost and timing
- Predicted energy yields
- Assessment of mitigation (mitigation assessment during construction and operation) - Environmental and Social Impact Assessment ESIA (if required)
- Financial modelling

By FEED accomplished by experts respectively by experienced consultants around 80 % of the overall project costs for an industrial plant project are defined at a very early planning stage.

3.2.3 Accomplishment of feasibility study

Start of this phase mostly is a pre-selection of Consultancy companies / offices. The referring authority of the country intends to contract for consulting services to perform a feasibility study of the VLS-PV power plant. For this intention among other places the internet is used too. The usual title is

CALL FOR EXPRESSION OF INTEREST (CEI) FOR CONSULTANCY SERVICES

or directly:

CALL FOR CONSULTANCY SERVICES FOR FEASIBILITY STUDY OF A LARGE SCALE GRID-CONNECTED PHOTOVOLTAIC POWER PLANT

[e] FEED = Front End Engineering & Design stands for basic engineering which comes after the Conceptual design or Feasibility study. The FEED design focuses on the technical requirements as well as on rough investment cost for the project.

The CEI entitles the Terms of Reference (ToR), describes the scope of the authority and specifies among others required qualifications / special skills or knowledge of the Consultant.

After having got several answers the selection process starts to identify the appropriate Consultant. After the successful selection the Consultant will get the order to carry out the study.

3.2.4 Scope / result of services

The consultancy service to be provided under the ToR usually will result in:

a. Proposed site for the power plant, rough technical design, capability of the local electrical infrastructure and the grid-connection, assessment of the investment cost and cost of operation
b. Calculation of the irradiation conditions and a prediction of the energy yield of the power plant
c. Recommendation of special measures for upgrading technical knowledge of the local staff / operators in regard of running the PV power plant to in advance be prepared for

The referring report for the top management is the basic for evaluation of own financial resources as well as evaluation of international financing institutions allowing a substantial financial backing. A positive result of the evaluation then will be the starting point for preparation of the tendering process.

3.2.5 Know how enrichment of the Employer

In many governments PV experts are not available. It has shown that an in-house seminar / training on large scale PV power plants is an enrichment of the basic understanding of typical issues of large scale PV and is very helpful and effective in regard of forthcoming projects. It will enable the procurement party, engineers as well as commercials to be on a par with the bidders. Main Benefits of the training course are:

- *Early* introduction in state-of-the-art design and engineering of large scale grid-connected PV power plants *e.g.* *before* implementation of first large PV projects – *good knowledge pays*
- Obtaining exhaustive technical backgrounds will provide a broader understanding of PV power plant issues which cannot be got at conferences, common seminars etc. – except from an independent experienced professional
- Obtaining information which are helpful in assessing risks of large scale PV related issues
- Seminar basics provided will be very helpful in coming PV related procurement / tendering processes

3.3 Tendering Process

3.3.1 Organisation of Tendering Process

After the feasibility study result and report of financial backing the *Project Strategy* has to be appointed together with a Project organisation to manage the Tendering process. A successful project organisation implies a set up of a *Tender Task Force Team* TTF and referring *Terms of References*. Within the TTF an external experts so-called Engineer (normally a Consultant) supports the works. Projects may be implemented and organised in line with different strategies. The TTF may recommend an establishment of procurement method and form of tendering.

As soon as the strategy has been confirmed method and form of tendering to be used in the project should be established.

A lot of governments have already *Public Works Procurement Process Rules* in place which regulate the terms of references.

3.3.2 The role of the Engineer

It is common that the Employer at an early stage of the project appoints an Engineer[f] (and its staff if so) who has special PV know how and expertise the Employer not has. The engineer's job is temporarily and often ends after final signature of a project agreement / contract. He shall carry out the duties assigned to him in the *Engineer Contract*. The Engineer shall be competent to carry out the duties described in the Contract.

3.3.3 Restricted Call for Tenders / Open Call for Tenders

By usage of pre-qualification method the subsequent process is a *Restricted Tender* or *Restricted Call for Tenders* or Invited Tenders only open to selected prequalified vendors or Contractors. It reduces remarkably time and money compared with an open tender process.

In contrary to pre-qualification method *Open Tenders* or *Open calls for Tenders*, or *Advertised Tenders* are open to all vendors or Contractors who can guarantee performance. Much higher efforts for evaluation and processing them are required.

The World Bank (WB) as well as the European Bank for Reconstruction and Development (EBRD) has developed Guidelines for *Pre-qualification and competitive Bidding Process* available from the internet.

3.3.4 Pre-qualification of bidders

The process of detailed assessment of relevant experience and capabilities and selection of potential Tenderers who would be internationally invited to tender is known as Pre-qualification. It requires preparation of pre-qualification documents. The documents should give information about the project, the tendering procedure and pre-qualification procedure.

The aim of Pre-qualification is to assess and pre select potential Tenderers already established in the market of large PV power plants having the requisite resources and experience to perform the intended works satisfactorily.

The requirement for Pre-qualification will be reasonable and efficient and must not unnecessarily cause constrains. The procurement entity will evaluate the expressions of interest and verify that the interested firms comply with the Pre-qualification requirements on operational and technical expertise, and financial capability.

The responsible Ministry will review and issue a letter of no objections, in parallel the financing institution will undertake the same review.

The Pre-qualification requires a *preparation period* for establishing the Project Strategy, preparations of documents, which ends with the submission of the tender documents. The call is normally titled like

PROCUREMENT GUIDANCE NOTE – Invitation to Pre-qualification for design, engineering and delivery of a grid-connected x Mega Watt Photovoltaic power plant

The Invitation to Pre-qualification provides information that should enable potential applicants to decide whether to participate.

The request for Pre-qualification shall be announced and published well in advance of the date of submission. Usually it is submitted in two or more national and international newspapers, on the

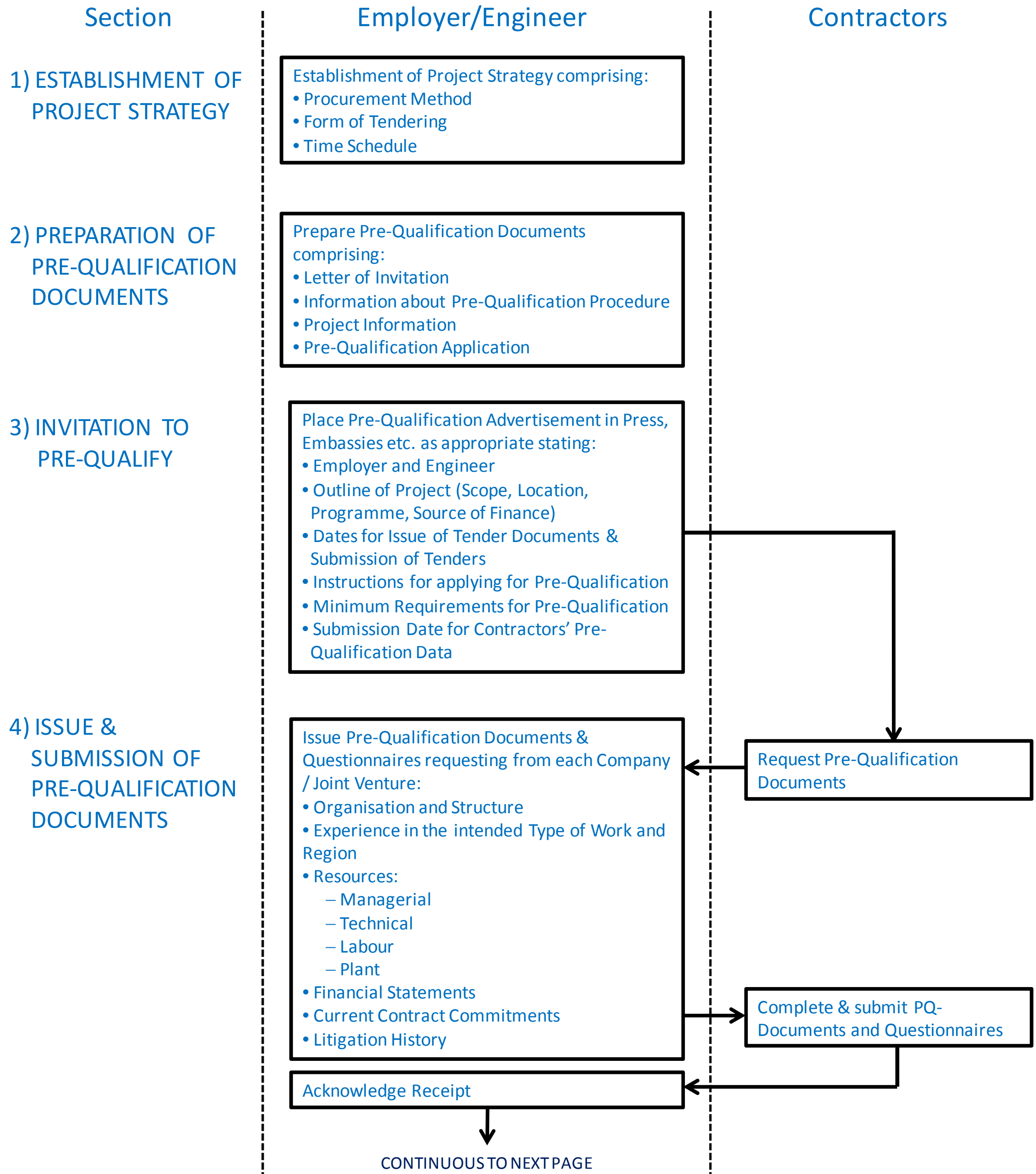
[f] Def.: The consulting engineer or other professional, whom the Contract requires the Employer to appoint, and who may be a person, an engineering firm or Consortium (or other Joint Venture) of such firms.

website of re relevant Ministry and any website available of the Procurement Entity.

According to e.g. WB rules the Invitation for Pre-qualification must be published not earlier than 45 calendar days after the publication of the General Procurement Notice for the project on the Bank's Procurement Opportunities web-site as well as the Client's own procurement website, or official government procurement portal in the Client's country.

Having got within the limited time the tenders they are to be carefully analysed, selected in a list of accepted tenderers. In connection with the decision which of the tenderers are accepted and which not written notification of all is required.

Following flow-chart (Fig. 3.2-1) shows an example of internationally recommended procedure for the Pre-qualification of Tenderers.



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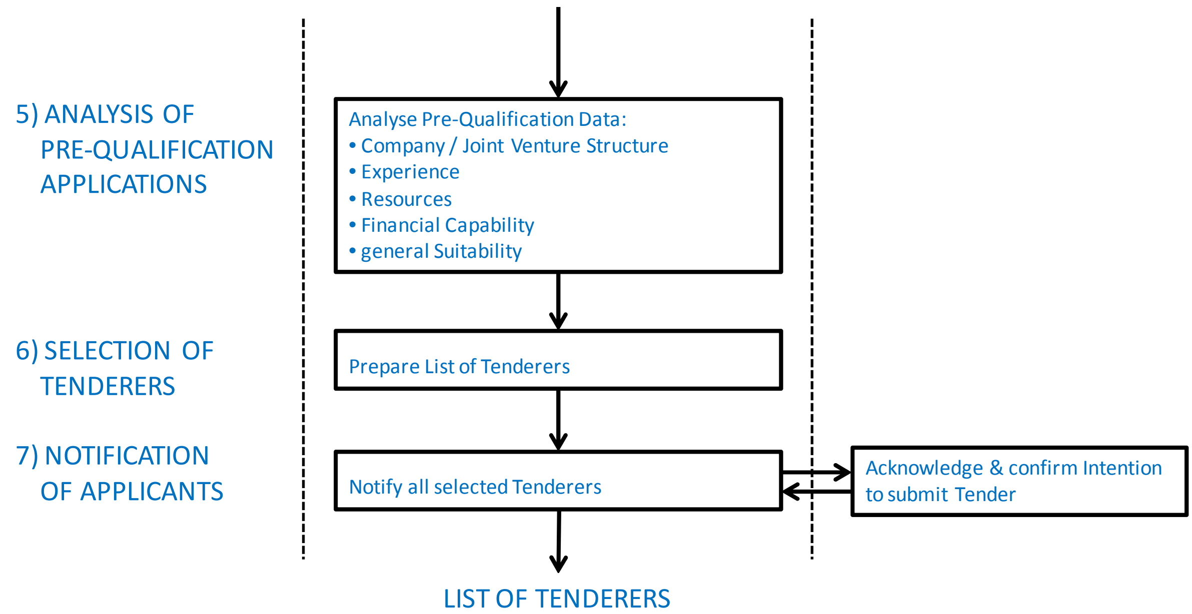

Fig. 3.3-1 Example of tendering process

Result of the selection of accepted pre-qualified bidders the procuring entity will publish the list of pre-qualified bidders on its website.

By having now a shortlisted suitable companies respectively interested parties the tendering process for getting bids starts.

Objective of the *Request for Proposals (RFP)* is to establish a format / formats to be followed by all bidders submitting proposals and thereby ensure a uniform evaluation and ranking of each proposal.

The procuring entity will now send to each of the qualified firm the request for proposals for the project. It will be entitled to charge a reasonable fee for the RFP and procurement documents. The fee has to be approved by the responsible Ministry.

The RFP will be based on internationally bidding process commonly used documents forms which are drafted by independent experts.

Above described procedure may be not necessary if the Employer already has a good overview of some already established EPC firms in the market segment of large scale PV power plants. This procedure will reduce cost and time.

The willingness of providing tenders could upfront be clarified by the management. However such procedure should not get in conflict with internal procurement rules respectively should be approved by the management.

3.4 Common procedure for a Call for Tenders (CFT)

3.4.1 Preparation of tender documents

Procurement departments of countries are familiar with the regular international tendering process. Like other tender documents the documents for VLS-PV power plants must be well prepared. The documents will normally include:

- Letter of invitation to tender
- Instructions to tenderers
- Tender form and appendices

- Conditions of contract
- Specifications (Scope of work, mostly minimal requirements) *see also chapter "Scope* of *Work – an attachment / Appendix of CFT*"
- Drawings, additional photos from the site
- Soil analysis report
- List of additional information required from tenderers

Provided documents shall enable tenderers to generate qualified tenders / bids. Usually the bidders accept Employer's offer for visiting the project site and to discuss not yet clear issues before issuing their tenders.

Among others the support in preparations of tendering documents requires good knowledge about state-of-the-art situation of design matters, main electrical components like e.g. PV module technology situation, inverters, construction elements, price/cost information etc. This knowledge is last but not least mirrored in the *Scope of Work and Supply* (SoW) section of the tendering document.

3.4.2 Call for tender notes

Below only the main headlines for a CFT are listed. Internal rules are governing the way how to prepare, publish, communicate with bidders, evaluate the bids and last but not least place an order.

a) *Announcement of the Tender*
Bidders / tenderers: Deadline for getting tender documents

PROCUREMENT GUIDANCE NOTE – Call for Tenders for Design, Engineering and Delivery of a grid-connected x Mega Watt Photovoltaic power plant

or in case of an applied Pre-qualification method:

PROCUREMENT GUIDANCE NOTE – Restricted Call for Tenders for Design, Engineering and Delivery of a grid-connected x Mega Watt Photovoltaic power plant

In case of an already accomplished Pre-qualification some information out of the list below are already provided within the process.

b) *Correspondence phase*
Communication between issuing party and bidders
Experience: mostly questions referring provided technical details
Answers normally spread to all other bidders (equality of opportunity)

c) *Quotations*
Opening of quotations internally (4-eyes principle)
Submission with presence of all bidders

d) *Formal check and evaluation of quotations*

e) *Second stage of evaluation*
Qualification / performance test of the bidders

f) *Third stage of evaluation*
Correctness of delivered quotation
Matching with budget

g) *Fourth stage: Economic evaluation*
Main offer (and alternative offer?)

Re-negotiation (not allowed)
(Eventually with external experts)
End of fourth / evaluation stage:

h) *Placing the order*

3.5 Issues on tendering PV power plants

3.5.1 What are other special PV-issues in tendering PV power plants?

First it is large PV power plants in general. For most of governments' purchase organisation it is a new theme. Usually in-house experts for large-scale PV applications are not available. Off-grid experts also have no experience and market information of VLS-PV. Therefore external support is necessary as long as own personnel / experts not available.

Like in a usual CFT the competition element of the tender is provided on the basis of price and quality. What makes a CFT for a PV power plant different from usual CFTs? It is the core requirement "Quality" at nearly all levels. Quality elements at all stages of a project should be described by the bidders. Starts from the well chosen technical design, well balanced selection of main components, professional execution on site controlled by an experienced project manager responsible for quality control on site.

The conversion device of solar power directly in electricity is the PV module. In multi MW PV power plants several ten thousands of modules are applied differing slightly in power. Securing the quality of the modules especially check of the rated power within the specified power range in the data sheet of the modules is a challenge to make sure that the ordered rated power of the PPP will be really installed. An indispensible appropriate measure is a procedure which consists of sampling checks of PV modules by an independent and certified testing institute. Sampling requirements are often described in "Special Conditions / Special Conditions of Contract". Designing of details of the requirements demands special knowledge experienced consultants have. They may recommend PV certified institutes as well.

Another feature lifts out PV CFT from common other procurement projects: importance of service and maintenance of PV inverters. To cover or minimise risks of failures – accompanied by energy / monetary losses – mid- or long-term service contracts are appropriate measures.

Therefore a PV CFTs often include the requirement of an offer of a service contract. The contract shall assure a short reaction time (to be individually defined time) for trouble shooting of PV inverters, describe normal service intervals and may define a guaranteed set of spare parts the supplier of the inverters.

A secure operation and well keeping (or even exceeding) initial calculated energy yields is the requisite of the success of the long-term investment of 20 or even more years.

A for PV power plants typical issue is the so-called *Performance Ratio*[g] (PR) *Guarantee Contract* (PRGC). The Employer should discuss with the Consultant whether a PRGC shall be part of the CFT or not.

Such a contract commits the EPC to a minimum guaranteed efficiency of the PV power plant over to be defined number of years. A PRGC automatically includes a service contract for inverters.

[g] Performance Ratio (PR) is a kind of quality factor or efficiency of a PV power plant. It is the result of an input / output calculation considering the theoretical performance versus the in the economic calculation expected practical performance. During operation a yearly PR calculation is the performance behaviour the reference of trend of plant performance. Performance terms are MWh usually related to an operational year

Here it is necessary to spend some words on the importance of the PR for the investor / operator in general. Professional monitoring / SCADA systems are able to calculate and monitor PV values. Values often are available as daily / monthly / yearly figures, as well as total figure of the summed up time of operation so far.

PV modules in the mid- and long-run are subject of more or less little power degradation. An evaluation of tendency of PR figures over some years from the SCADA system may provide a picture of the behaviour of PV modules in regard of power losses by power degradation. Should the indicated degradation seems to be below the guaranteed values or even a result of proof by an independent testing institute the investor may check whether he should draw to the power guarantee of the supplier and discuss with him any kind of compensation caused by the underperforming PV modules.

Referring to what was said before among others within the *Scope of Work* (SoW) the Employer should want the bidders to disclose beside the data sheet of the preferred type of PV module also the power guarantee conditions of the module supplier. They at last will be one of several annexes part of the commercial contract.

3.5.2 External support

External support is more or less necessary already from the very early stage of a project. It should be also used from the feasibility study stage, pre-qualification as well as tendering stage with all its phases.

3.5.3 Scope of Work – an attachment / Appendix of CFT

Among several other attachments of the tendering documents for *EPC / Turnkey projects* SoW is listing all items, hardware, software and works to be performed in an e.g. EPC contract.

The SoW sometimes contains many details from the feasibility study, items then are already specified or even special suppliers for them are named. Such a way of *constructive* SoW design may be helpful for Employers in already consolidated construction markets. Often the idea behind is to settle already individual preferred quality levels (and product brands) and mainly to have later less efforts in the phase of comparing and ranking the tenders. Tenderers then have only little room to move in their bids.

The PV business today cannot yet be described as a consolidated business. A progress in technologies, products, new requirements and approaches which overtakes what was more or less standard in the recent past, and supply bottle necks which makes it necessary to in due time chance the type of PV module and supplier etc. is still reality. Therefore the kind of SoW should reflect this fact by creating a so-called *functional tendering*. Such *functional technical specifications* are addressing the frame of the programme of the construction works, whereas the Employer disposes the tenderers with their bids to fill the frame. Functional technical specifications open tenderers a certain scope to offer their individual best considered solution. It is a certain competition of ideas and the Employer may get with the bids more interesting technical solutions.

An important role of success of the tendering results is at the beginning of the tendering process well accomplished description of the functional technical specifications.

The content of SoW tells bidders the minimum technical requirement of the PV power plant. It usually reflects state-of-the-art system technology as well as requirements of the key technical components and SCADA (supervisory control and data acquisition) respectively the monitoring system. It furthermore takes into account special local conditions of the referring country.

SoW of a CFT of a PV power plant often is performed by technical advisors / consultants who have extensive experience in the PV field. The Appendix shall contain a description of the Deliverables, the Contract Object and the work that is to be carried out pursuant to the Contract, along with any circumstances that may have a bearing on the performance of such work. Consultant and Employer usually develop not precise specifications. It should be specified *minimum requirements* of main components. By this it offers the bidders a certain freedom in their selection of the components and – if expressively noted – *alternative proposals*.

The words *Deliverables and Contract Object* are defined in the Conditions of Contract. These words are to be capitalised in order to make the description clearer.

Table 3.5-1 is an example of a price form out of the tendering document, summed up prices for main price elements. What behind the price elements is (in this Price form the headlines are listed) has to be detailed described according to the minimum requirements of the Employer.
Price forms simply provide an overview for the Employer to compare total prices as well as of individual price elements.

Table3.5-1 Price form

Pos.	Specification / main price element	Sum
1	Photovoltaic modules	
2	Module support structures	
3	Foundations:	
	- for support structures	
	- for container / buildings	
4	Field connection boxes (AJB, GJB)	
5	Inverters incl.	
6	Inverter Containers	
7	MV connection	
8	Transformers:	
	- for MV grid connection (step-up)	
	- for auxiliary service power supply (step-down)	
9	Monitoring system	
10	Meteorological station, incl.RCs	
11	Cabling:	
	- DC cabling	
	- AC cabling (LV, MV)	
	- cabling for signalling and communication	
12	Grounding and overvoltage protection	
13	Technical documentation	
14	Spare parts	
15	Fencing system	
16	Alarm system / theft protection measures	
17	Training of personnel	
	Total Bid Price	

3.5.4 Special Conditions of Contract

This chapter is related to special conditions of a VLS-PV power plant contract[3)]. It among others contains detailed information on the site important for the bidders to one one hand consider them in the design and technical calculations of the offer. On the other hand they may provide information regarding transportation logistics etc. relevant for other costs to be considered and calculated for the bids.

It futhermore is to issue necessary instructions to the bidders with regard to keeping organisational and general boundery conditions as well as to obey labour laws and HSE requirements and also embedding the same to the contracts.

3.5.5 General obligations

This chapter is concerned with special obligations to comply with. It for example addresses allowances of inspections, obtaining approvals and permits, or assiting the Employer in obtaining approvals and permits, organisation of security servoce during the period of construction, etc.

3.5.6 Quality assurance

The Contractor is to have an implemented and sufficiently documented quality assurance system in accordance with the requirements stipulated in an Appendix – Administrative Requirements.

Bidders are requested to describe their principles and system assuring an acceptable quality level for different stages of the contract execution. On the other hand the Employer may state its own conception and measures on how to secure the quality he has in mind e.g. especially for check of the ordered PV power, maximal accepted DC losses in the systems and so on.

3.5.7 Requirements as to documentation

Special Conditions also refer to technical documents. Often Employers already want to be informed on technical issues at the detail-design phase. They want to get drawings and calculations for information not to be surprised later. It always does not mean the Contractor / EPC would be released from its responsibilities. Later on acceptance test of main components are of interest e.g. like quality inspection protocols of power measuring of PV modules or / and tests of inverters before they are shipped to the site.

As-built-documents: Last but not least the Employer normally lists the content of technical documentation in detail. As-built-documents are of high relevance for the owner as well as for the operator of the PV power plant. The documents will accompany the operator for the whole operation period. Therefore its importance should under any circumstances not be underestimated.

The technical documentation shall among others also comprise the Operation and Maintenance Manual. The manual should cover a trouble-shooting guide as well as instructions for regular and pro-active measures to avoid failures or downtimes by duly change of consumable devices which should be described by the Contractor / EPC.

3.5.8 Personnel

The Contractor shall ensure that only sufficiently qualified personnel are used, and shall, at the Employer's request, hand over detailed information on the personnel's qualifications. Personnel's qualification requirements as to special electrical works should be described by the Employer.

3.5.9 Health, safety and environment (HSE) and the relationship to the natural environment

The Contractor shall have documented systems that comply with the Company's requirements regarding the management and monitoring of health, the working environment and safety as stated in another Appendix - Administrative Requirements.

The Contractor shall also become familiar and comply with the Employer's environmental regulatory. Waste management is one of the important issues since a lot of package materials from PV modules will be on site. Another issue especially in countries of the Sunbelt is the high ambient temperature in which the personnel on site has to face and assembly works for metal structures and PV modules.

3.5.10 Testing the Facility, start-up and Takeover

This chapter deals with conditions as to testing of the PV power plant, start-up and take-over procedure.

Following text may serve as an example: “As part of the Deliverables, the Contractor shall, in cooperation with the Employer and if necessary with other suppliers start-up the PV power plant. The Contractor shall carry out the contractually determined function tests and trials and make adjustments until the Contract Object operates according to specification.”

As soon as all the function tests, trials, start-up and adjustment work have been completed, the Contractor shall give written notice to the Employer that the PV power is ready for a Test Operation. The Company shall not start to use the PV power plant or any part of it until such notice has been given.”

3.6 Evaluation of tenders

3.6.1 Criteria of evaluation

The evaluation criteria, which will form the basis for the selection of the most advantageous tender, should be specified.

If a specific method of evaluation is to be used in selecting the successful tender, the method should be described in the ITT.

The evaluation of tenders can generally be considered to have three components. The components may include

- Technical evaluation
- Financial evaluation
- General contractual and administrative evaluation

While adjudication generally will be primarily on the basis of the tender price, other factors which may be relevant include:

- time for completion
- suitability of technology
- life cycle cost of construction of the plant
- environmental impact during the lifetime of the project (including assumed dismantling)
- quality and serviceability of plant
- operation and maintenance cost

For detailed evaluation (single-stage bidding assumed) bid evaluation forms has been prepared by international financing banks. Especially the use of the *Technical Bid Score* requires support an external experienced Consultant. He can offer special PV knowledge about state-of-the-art situation of design matters, main electrical components like e.g. PV module technology situation, inverters, construction elements, price/cost information etc.

Since pace of technical development on the PV module level is still rather fast and the market offer of PV inverter firms and products is also altering only experts from outside are mostly in the position to assess the current market situation and are able for a qualified scoring.

Table3.6-1 Example of combined evaluation[4)]

Bidder	Evaluated Bid Price (C) *(a)*[1]	Technical Bid Score (T) *(b)*[2]	$(C_{low}/C)\times X$ *(d)*[3]	$(T/T_{high})\times(1-X)$ *(d)*[4]	Evaluated Bid Score (B) *(f)=(c)+(d)*
etc.					
Award Recommendation[5]	Award to highest Evaluated Bid Score: Bidder's Name:				

[1] From table Evaluated Bid Price (C)
[2] From table Technical Bid Price (T)
[3] C_{low} is the lowest Bid Price (C)
[4] T_{high} is the highest Technical Bid Score (T)
[5] Bidder with Highest Evaluated Bid score will be termed the "Lowest Evaluated Bidder" as indicated in referring ITB chapter, and be eligible for award subject to referring chapters (Post-qualification and Award Criteria)
*ITB Instructions to Bidders
Weight for the Price (X) has to be inserted as indicated in the Bidding Documents (BD)
Weight for the Technical Score (1-X) to be inserted as indicated in the BD.

3.6.2 Award Phase

The award must be during the period of tender validity or any extension hereto accepted by the tenderers.

As result of the evaluation process the evaluation team recommends the most favorable bidder. The tendering authority / Employer then has to finally decide which bid to take. The next formal step is to forward the formal *letter of acceptance* as well as the contract price which the Employer will pay to the Contractor in accordance with the terms of contract.

Depending on the ITT conditions the Employer may wait with issuing the winner of the bidding process until he has received the formal acceptance of the confirmation / acceptance note of the selected firm.

The notification by *the letter of acceptance* will create an immediately binding contractual relationship between the Employer and the successful tenderer prior to entering into a formal contract. The performance security / bond should be furnished before the expiry of the validity period of the tenders.

The performance bond is usually valid throughout the life of the contract and normally may have amounts to ten per cent of the order price up to preliminary acceptance.

3.6.3 Preparation of Contract agreement

The Contractor should normally be required to sign a contract agreement with the Employer he who should have prepared the contract agreement.

3.6.4 Notification of unsuccessful tenderers

Upon furnishing of the performance security by the successful tenderer in accordance with e the conditions of contract, the Employer should promptly notify the other bidders in writing that their tenders have been unsuccessful. At the same time any other tender securities which have been provided must be returned to the unsuccessful tenderers.

3.6.5 Tendering of Internationally funded Projects

Publishing CFT of projects with financial support of international Institutions like IFC[h], World Bank or e.g. European Union's external aid programmes are subject of special procedures. Such procedures usually specify approaches in detail from EOI phase up to procurement rules, contract specifications to award of contracts.

In case a tender includes e.g. a service contract it is also regulated by referring conditions.

[References]

1) K. Komoto, C. Breyer, E. Cunow, K. Meghergi, D. Faiman and P. van der Vleuten, *Energy from the Desert: Very Large Scale Photovoltaic Power - state of the art and into the future*, Earthscan from Routage, 2013
2) *The FIDIC Contracts Guide*, First Edition, 2000
3) *FIDIC Conditions of Contract for EPC/Turnkey Projects*, First Edition, 1999
4) *Evaluation of Bids – Standard Bid evaluation Form, Single-Stage Bidding*, The World Bank, October 2004

[h] IFC International Finance Corporation

Chapter 4 Potential of Concentrator Photovoltaics (CPV)

4.1 State-of-the-Art of Concentrator Photovoltaics

4.1.1 Introduction

The fundamental idea behind concentrator photovoltaics (CPV) is to concentrate sunlight so as to enable a reduction in the amount of photovoltaic material needed to generate a given amount of power. Fig. 4.1-1 illustrates the idea in which an array of large Fresnel lenses concentrates all of the light it receives from the sun onto an array of much smaller solar cells. For example, if the optical concentration factor of the lenses is 1 000 X and other things being equal, we could reduce the area and with it the cost of photovoltaic (PV) material by a similar factor.

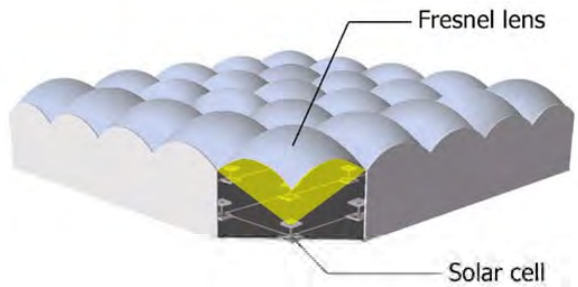

Fig. 4.1-1 Schematic of the illumination of a small CPV cell by a large Fresnel lens

Naturally, “other things” are not equal. First, the kind of PV cells that are capable of withstanding the intensity of concentrated solar light requires materials, such as gallium arsenide, that are much more costly than silicon. Second, in order to achieve the highest possible efficiency, CPV cells have a complicated multi-junction internal architecture that further increases their cost. Third, there are various kinds of losses associated with fabrication of the optical concentration system (whether lenses or mirrors). Finally, the CPV cells and their associated optics must be mounted on a tracker that follows the sun’s apparent motion with great accuracy. All of these factors raise the cost of the resulting CPV system to such an extent, that a careful tradeoff is necessary in order for the final cost per watt of electricity to be economically competitive with alternative simpler systems.

In the past, simple flat-panel PV systems were sufficiently expensive that CPV seemed to be an economically attractive alternative. However, as the cost of silicon PV cells has fallen - rapidly in the past few years, reflected in a corresponding decrease in PV system costs (Fig. 4.1-2) - CPV companies are finding it increasingly hard to compete.

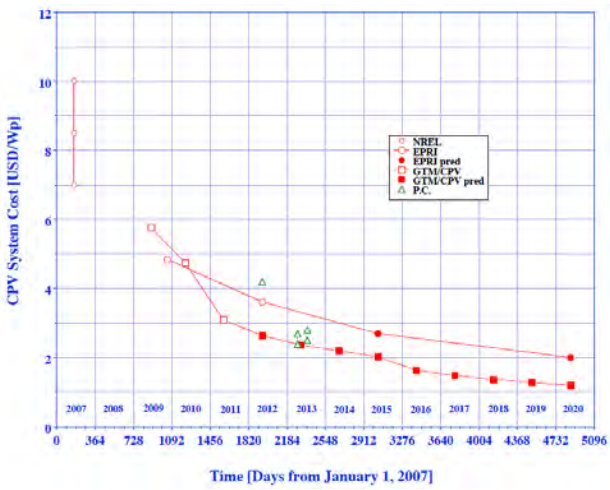

Fig. 4.1-2 Recent installed cost trends for residential and commercial PV systems in the USA[1)]

Another economic challenge that is confronting the entire PV industry was caused by the recent discoveries of large amounts of fossilized gas and oil - the so-called shales. Fuel may now be extracted from them economically, thanks to recently developed technologies designed for this purpose. The CPV industry has been hit particularly hard by this new-found availability of gas because the latter has discouraged investors from venturing into less mature solar technologies than standard flat-panel PV.

In the light of these developments, one must ask whether there is any hope of a future for CPV. This question is highlighted to an even greater extent by a number of recent technological developments within the world of PV. These include: the possibility of increasing the efficiency of low-cost silicon cells by the addition of various thin film layers[2)]; methods for producing thin-film, high-efficiency, non-silicon, multi-junction cells that might allow the economic fabrication of non-concentrating flat panels[3)]; the sudden appearance of perovskite cells[4)]. It is thus possible that standard, low-cost, flat panel efficiencies around the 40 % level - which is presently the sole domain of CPV cells[5)] - may become a reality.

However, there is one feature of CPV technology that no amount of increase in PV cell efficiency can come anywhere near. It is the vastly smaller floor area that is required for a cell fabrication plant. For example, by reducing the amount of cell material per watt by a factor of 1 000, one effectively reduces the floor area of a fabrication plant by such a factor. Thus, a factory that was originally designed to have an annual PV cell throughput of, say, 10 MWp, could be re-tooled to produce 10 GWp per year of CPV cells[6)].

Of course, with the availability of low-cost gas in large quantities, investors will ask: Who needs a 10 GWp per year throughput? The sobering answer to this question, as discussed in greater detail in Chapter 6 of this volume, is that the world is rapidly reaching a stage when, for environmental reasons, it will be necessary to cease the construction of all new fossil-fuelled plants, whether by coal, oil or gas. Such a situation will then require the *annual construction* of typically 500 GWp of VLS-PV[6)]. In as much as desert areas will be available for this purpose, CPV cells will be, by far, the easiest to manufacture at this scale.

4.1.2 Market prices

As in the case of conventional PV systems, it is difficult to pin down actual prices, because one usually cannot know precisely how the costs are calculated. For example, are they “overnight” capex costs for a turn-key system? How much ground preparation and other infrastructure costs are involved? Are there subsidies? We have therefore adopted the approach of taking the past projections through the year 2020 of two independent research bodies; the Electric Power Research Institute (EPRI) - circles, and Greentech Media (GTM) Research - squares, and comparing them with a number of recent actual system costs that were communicated to the authors under conditions of confidentiality - triangles. The analysis of EPRI was performed in 2010[7)] and the GTM predictions, commissioned by the CPV Consortium, were published in 2011[8)]. These trends are plotted in Fig. 4.1-3. On that graph, open circles, squares and triangle indicate actual system costs, whereas filled circles and squares represent predicted costs. In order to give an idea of the way CPV costs have fallen in recent years, an NREL number[9)] is also shown, for the year 2007. A valuable and more comprehensive survey of system costs from 2007 through 2012 may be found in Haysom et al[10)]. Perusal of Fig. 4.1-3 shows that the three 2013 prices, indicated by the triangles (respectively: 2,4-2,7, 2,5, 2,8 USD/Wp) all fall close to the trend lines. At the time of writing, the best CPV modules may be purchased for 0,74 USD/Wp, and the best trackers for 0,5 USD/Wp. As for the future - system costs of around 2 USD/Wp and possibly lower were predicted for the year 2020 back in 2011/12. However, it is too soon to tell the extent to which the two negative market developments referred to above, namely low-cost non-concentrator PV panels, and new sources of gas, will affect these predictions.

Fig. 4.1-3 Market prices (open circles = EPRI; open squares = GTM/CPV; triangles = private communications) and predictions (filled circles = EPRI; filled squares = GTM/CPV)

4.1.3 Major CPV manufacturers

The years 2013 and 2014 took a major toll on the CPV industry, many companies, small and large filed for bankruptcy, for the reasons given above. As of the time of writing, there are four large CPV companies in the world: *Arzon Solar* in the USA, *Daido Steel* in Japan; *Soitec* in Europe, and *Suncore* in China. Fig. 4.1-4 shows an *Arzon* system in Alamosa, CO, USA; Fig. 4.1-5 shows a *Daido Steel* system on Kyushu Island, Japan; Fig. 4.1-6 shows a *Soitec* system in Touwsrivier, South Africa, and Fig. 4.1-7 shows a *Suncore* system in Golmud, Qinghai, China.

Fig. 4.1-4 A 30 MWp *Arzon* CPV system at Alamosa, CO, USA [Courtesy of *Arzon Solar*]

Fig. 4.1-5 A 160 kWp *Daido Steel* CPV system on Kyushu Island [Courtesy of *Daido Steel*]

Fig. 4.1-6 A 44 MWp *Soitec* CPV system at Touwsrivier, South Africa [Courtesy of *Soitec*]

Fig. 4.1-7 A 50 MWp *Suncore* CPV system at Golmud, Qinghai Province, China [Courtesy of *Suncore*]

The lesson to be learned from Figs 4.1-4 to 4.1-7 is that CPV systems at the multi-megawatt scale are already a reality and that this kind of technology should play a significant role in the planning of future energy systems.

4.1.4 Recent advantages in CPV technology

In spite of great uncertainty in the commercial sector, research developments in CPV continue to be spectacular. Only a few years ago it was considered that it would not be feasible to go from triple junction (3J) CPV cells to quadruple-junction (4J) cells.

However, in 2014, 4J cells became a reality, Fraunhofer ISE announcing a record efficiency of 44,7 % for a GaInP/GaAs/bonding/GaInAsP/GaInAs 2J+2J wafer bonding structure[11)]. Correspondingly, a module made from 52 such cells, of area 7 mm^2, illuminated by a like number of 4 cm x 4 cm Fresnel lenses achieved a record module efficiency of 36,7 %[12)]. These cells and modules currently outperform the previous 3J record holders. This realization of 4J cells has prompted a new roadmap for low-cost CPV cells, shown in Table 4.1-1[13)].

Table 4.1-1 Roadmap for expected progress in CPV technology[13)]

Year	2014	2015	2016	2017	2018
Best commercial CPV cell	42,9 %	43,5 %	46,5 %	47,7 %	49,5 %
Best commercial CPV module	33,9 %	35,0 %	38,0 %	39,5 %	41,8 %

4.1.5 Conclusions

Spectacular technological progress continues to be made in the area of CPV R&D. Quadruple-junction cells have provided a paradigm change as regards efficiency, with 50 % cell efficiencies in sight. Module efficiencies are correspondingly high and are expected to exceed 40 %. The industry is nevertheless facing serious economic challenges, both from low-cost non-concentrator PV panels, and from the gas industry, which threatens the future of both kinds of technology. However, as explained in Chapter 6 of this volume, high-concentration CPV cells will provide an economically simple pathway for increasing annual production levels from tens of GWp to hundreds of GWp - the rate at which the world will need to be introducing VLS-PV if any serious reduction in atmospheric carbon dioxide is to be attempted.

4.2 Possible approaches for local assembly of CPV

Unlike the flat-plate PV technology, CPV technology is an integration of various common industrial technologies. There may be wide varieties of designs and some constrains by local environment. In this situation, the strategy commonly accepted in PV industry by relying on simple scale-expansion is not always effective. An alternative but practical and low-risk approach is local assembly. CPV is the only technology that can achieve low-cost power generation not relying on scale-merit.

4.2.1 Expected advantages of local assembly of CPV

The CPV manufacturing technology is an integration of plastic, metal and machine technologies. Although technology itself contains high and sophisticated contents, most of the manufacturing may be done by local workforce (See Fig. 4.2-1). This is particularly true in tracker and system assembly step. The next candidate is module assembly and lens manufacturing step. Going backward to the technology river, the barrier to local assembly may be high but the upstream products can be transported easily and have more chances of reduction of the cost by volume production (see Fig. 4.2-1). Another advantage of local assembly is the technologies grown by downstream CPV products can be converted to local commodity industries.

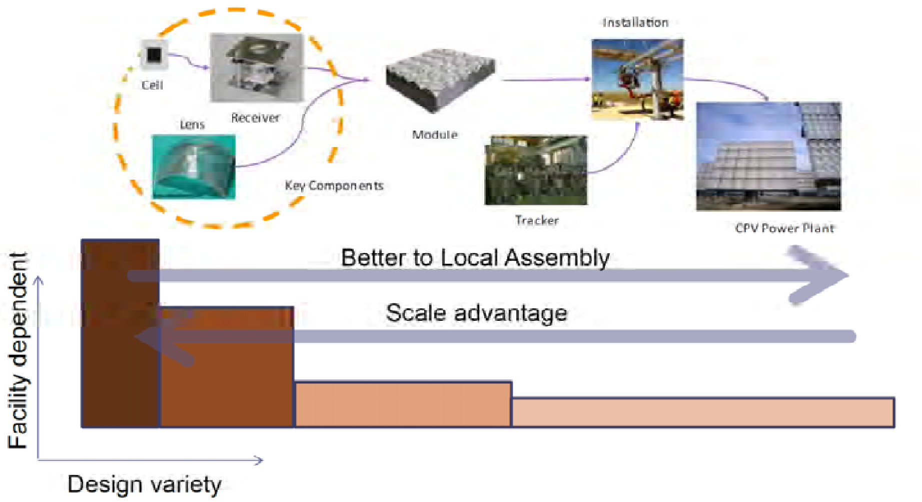

Fig. 4.2-1 Concept of local assembly

Another aspect that needs to be considered is the logistics. Typical CPV modules are bulky and have fragile optics. This particular structure increases both packaging cost and transportation cost (see Fig. 4.2-2 and Fig. 4.2-3).

Local assembly in PV usually leads to higher cost and less competitiveness and thus not sustainable (see Fig. 4.2-4) .On the other hand local assembly in CPV does not always leads to higher cost (Fig. 4.2-5). This is because of the fact that downstream technologies can be done by local workforce by less barriers (see Table 4.2-1).

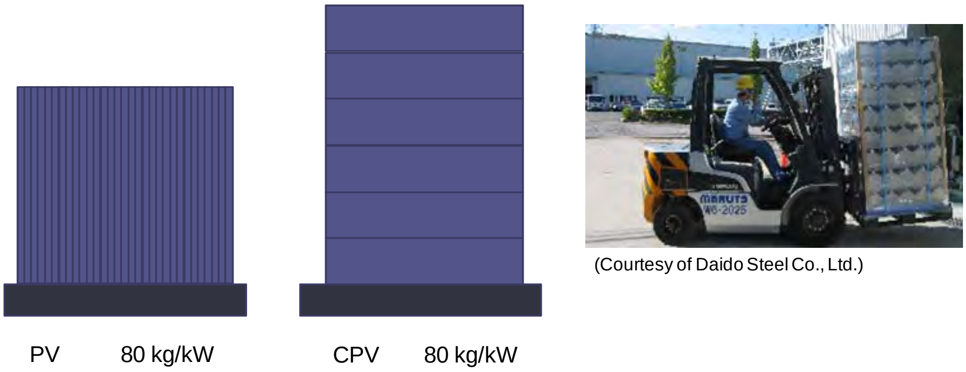

Fig. 4.2-2 Comparison of mode of packing between PV and CPV and actual package of CPV module (right)

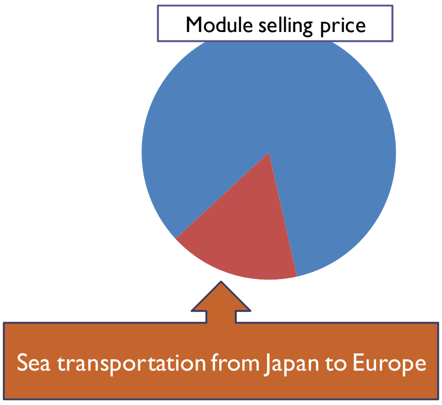

Fig. 4.2-3 Ratio of transportation cost in CPV module in overseas market, based on actial cost in 201

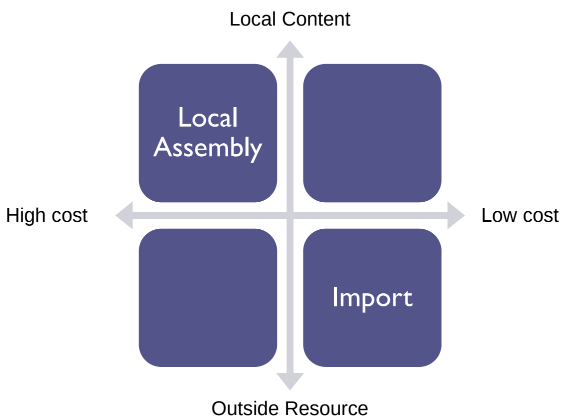

Fig. 4.2-4 Market positioning in typical PV

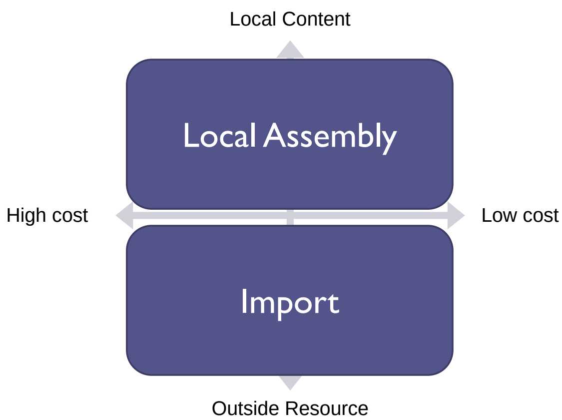

Fig. 4.2-5 Market positioning in CPV

Table 4.2-1 Advantages in CPV cost by local assembly

Local cost	Transportation Cheap labours Cheap low materials
Low barrier	Less capital cost for manufacturing Pre-mature technology Flexible manufacturing

Utilizing the above cost advantages, CPV system, at first, should be designed with ease of assembly in mind. One possible solution is that all the technologically complex components are packaged into key components such as a receiver so that a series of receivers and lenses can be assembled with standard tools, using local materials and workforce absorbing possible assemble and alignment error by assemble environment by relatively small local work places. The concept is similar to the computer and automobile assembly industries, where key components are imported but the product assembled locally. CPV system has more number of components. This complexity is desirable to encourage local industries. Most of the components do not require special facilities and can be produced in the local industries after appropriate technology transfer is done. CPV technology does not rely on huge but mono-purpose production facility. Varieties of components industries can be converted to basis of other industries such as commodity industry and automobile industry meaning less risk of local investment.

4.2.2 Considerable approaches for local assembly of CPV

(1) Business relationship

The 1st gate is definition of business relations and start-up of small scale of management. There are two examples.

i) Licensor provides assemble technology and system integration knowledge for promotion of sales of key components (example of key components are cells, receivers, optics, tracking control etc.). This scheme may be called "XXX Inside" concept and XXX is the name of licensor.

ii) Licensor forms a kind of consortium among components and local manufacturers. Technology of the licensor is shared by consortium members. Royalty may be small, say 1 % but collects from many consortium members, say one local company in each country. This is a kind of open-resource relationship and each local manufacturer is free to do local business. One advantage of this scheme is that local assemble manufactures can have more chance of purchasing components by lower cost by competition among components manufacturers in consortium members. The low key components cost is important to the early stage of local manufacturing because they will have to compete to relatively lower cost of imported conventional PVs. Possibly the number of component manufactures is small and they can find bigger market in supplying common design components thus leads to better production cost. This scheme may be called "Small One Hundred", implying that small but many local assemble manufacturers can compete to a few big giants relying on volume production for exporting.

It is always good to Licensee to make full of its resources but it is not always true that resource can be competitive in business. Compromising discussion based on mutual trustfulness is essential.

It is not always true that the knowledge and technology provided from Licensee covers entire CPV technologies. The knowledge and technology are not always matured. CPV is still emerging technology that covers great many aspects of technologies. Some mutual understanding of risk-sharing and trustful relationship is essential. The one-sided relationship or one-sided technology transfer contract may be always wanted by business people but that one-sided relationship will not be successive to risk-sharing relationship challenging with emerging technology. Sometimes relationship by more than 3 companies, for example, two Licensors and one Licensee may be practical for covering wide range of technology with more mature technology solutions.

(2) Criteria needed

The following criteria will be needed to pass.

a) Local market

There is some local market. Preferably, there is some early-adaptor market to CPVs. The typical early-adaptor market is R&D installations, demonstration installations prepared by Government, leading utility companies and public research institute. Note that the first product may have some problems and those problems are to be solved by collaboration of users like leading utility companies and public research institute. It is also a good idea to encourage sales to "test installation" to the market by introducing "special CPV-preferred FIT" like the one in France. In this case, the timeline by completion and commissioning should be long enough for giving sufficient ramp-up time for the entry.

b) Cost advantage

The local assembly has cost-advantage. It is also important to know that the initial stage of production of Licensee has advantage of production cost. Table 4.2-2 summarizes the pros and cons of local assembly in production cost issue.

Table 4.2-2 Cost advantage and disadvantage of the local assembly

	Cost	Remark
Initial investment	-	Generally speaking, initial investment for module assembly is not significant
Labor cost	+	Depending on country
Productivity	-	Although production technology is transferred, the production equipment in the local will be “small pilot production”. Typically the productivity is more than 20 % less.
Material cost	-	Pro: Sometimes, local materials are cheap. Con: Purchase will be small lot size.
Tooling cost	+	Initially, the production is labor-intensive and the production scale is small
Transportation cost	-	CPV modules is like a box. Transportation of modules in the long distance costs a lot.

c) Advantage in the value chain

The Licensee should have some advantage in the value chain. The best case is that the licensee is able to cover entire downstream value chain. For example, if the Licensee assembles modules in local, the best partner will be either system integrator with its own tracker solutions. It is common to give some exclusivity in production in some geometrical region to Licensee. Unless Licensee has some advantage in value chain, Licensor will be preferred to look for alternative partners in the specific region.

d) Agreement in structure of business functions

It is important to define the basic business structure. For example, if the brand name is kept, the Licensor will have more control to the quality and technology but will have to give more profit to the partner.

Note that this point is important to business contract. The case study will be case-by-case. Although many cases can be possible, it may be wise to take one example for detailed study.

e) Involvement of local research institute

Since CPV is emerging technology and performance and downstream technology is local-dependent, the knowledge from Licensor will not cover entirely. The involvement of the local (public) research institute will be helpful for the local second opinion, and assessment of technology in local.

f) Scenario to further expansion of business

The CPV-preferred early-adaptor market will not last for long time. It is important to have strategy to compete in open-market. If the Licensor supports Licensee for long-term technology support and key components supply, it will be important to discuss in long-term technology development scenario, cost-roadmap, royalty and expansion policy.

(3) Process and timeline

The first, discussion between Licensor and Licensee should be done intensively to define relationship. Next, prior to start-up of local assembly, technology transfer should be done from Licensor to Licensee. Then, the licensee will be able to start small-size production and local sales.

Discussion period

: It should be a case-by-case. However, if the collaboration is done by technology transfer agreement and long-term commitment of two parties, the discussion period will be needed for at least one year.

Based on the discussion, actions for actual technology transfer will be implemented.

Documentation-based technology transfer (incl. Q&A)

: One month.

Administrator and Engineer’s training in Licensor’s site

: Two months.

Preparation of production environment

: Two to six months, dependent on the initial condition of the Licensee’s production environment. The preparation is not only hardware but also documentation and establishing organization including quality control system.

Preparation of local purchase of materials and components

: Three to six months. Most of the cases, some of the materials and parts described in manuals from Licensors will not be able to be purchased in the local market. It is likely some material in the standard of the Licensor’s country does not have compatibility to that of Licensee’s. Another possibility is that some material (direct or indirect) may not be permitted in Licensee’s area by laws for environmental or labor-safety reasons. Even if Licensee finds compatible material and parts, they may not be common one and difficult to find in the market with reasonable price and delivery conditions. When this kind of “incompatible problem” happens, Licensee with cooperation from Licensor will have to find alternatives and test compatibility. Sometimes it is necessary to modify the design.

Prototype and in-house (local) test period

: Two months. After local environment in production is prepared, it usually takes two months until Licensee makes its first product and does necessary adjustment, improvement and its own in-house test. This first prototype is important and Licensee needs to be patient to do many adjustment and improvement so that it completely understand the process and own improvement.

Examination by Licensee including reliability test

: Four months.

Outdoor demonstration and recognition by local third-body

: Four months.

Note that some steps can be practiced in parallel depending on the available resources of both Licensee’s and Licensor’s. Depending on business contract, the work of technology exchange, examination and feedback varies. For example, if the product brand is owned by Licensee, Licensor does not have 100 % of responsibility of product quality and product reliability. Therefore, the pass/fail criteria of the product quality will be controlled by Licensee. In this case, the steps of recognition and approval by Licensor are not very important and thus Licensee may skip this step.

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Chapter 5 Geographic Dispersion and Curtailment of VLS-PV Electricity

5.1 Introduction

With the extraordinary recent growth of the solar PV industry, it is paramount to address the biggest barrier to its high-penetration across global electrical grids: the inherent variability of the solar resource. This resource variability arises from largely unpredictable meteorological phenomena and from the predictable rotation of the earth around the sun and about its own axis. To achieve very high PV penetration, the imbalance between the variable supply of sunlight and demand must be alleviated. The widespread geographically distributed deployment and electrical interconnection (geographic dispersion) of VLS-PV is one of three primary supply-side solutions to solar variability that when used in concert, can minimize the aggregate cost of electricity generated therefrom. The other two primary supply-side solutions are storage (where excess solar generation is stored when it exceeds demand and is released when it does not meet demand), and smart curtailment (where solar capacity is oversized and excess generation is curtailed at key times to minimize the need for storage.)

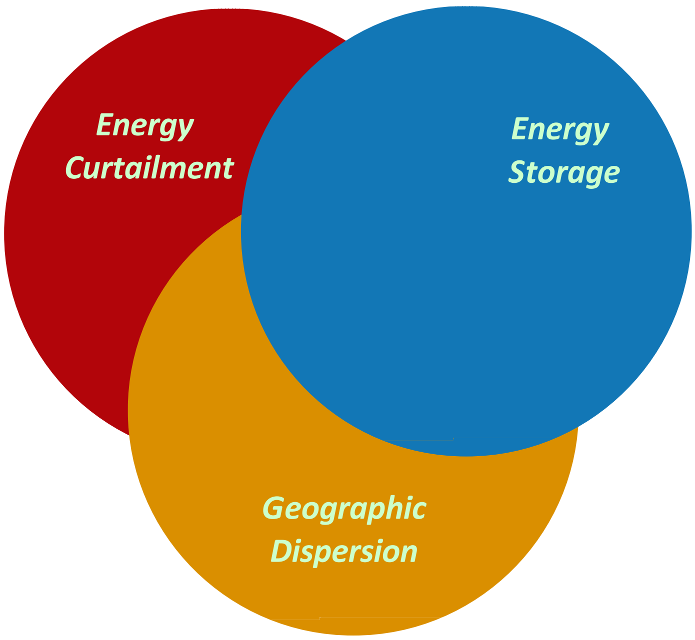

Fig. 5.1-1 Considerable issues to be considered for the entire energy systems

Underpinning the effectiveness of geographic dispersion as a variability-mitigating strategy is the fact that - as at shorter timescales—cloud/weather-induced solar variability correlation between two distinct geographic locations decreases with spatial extent. Aggregate variability between *N* decorrelated sites decreases as $1/N^{1/2}$. Thus, identifying the distance required to achieve decorrelation is critical to determining the reduction in variability from geographic dispersion. Recent research has shown that solar variability up to the scale of 30 days is decorrelated across a distance of only 1 500 km if north to south. What this translates to is that 100 PV plants separated by an average of 1 500 km N/S and interconnected experience less than 10 % the variability experienced by a single one of these sites when taken individually.

Despite the cost of supplementary electric transmission, geographically dispersed VLS-PV has the potential to reduce the levelised cost of electricity (LCOE) of solar PV by over 65 % compared to when only storage is used. Curtailing PV generation, despite the obvious costs of capacity underutilization, has the potential to reduce the total cost of electricity by over 75 % compared to when only storage is used.

These three variability mitigation strategies are thankfully not mutually exclusive. When combined at their ideal levels, the levelised cost of electricity can be reduced by over 80 % compared to when only energy storage is used if the goal is to provide baseload power. When using current costs for VLS-PV (2USD/W), transmission and energy storage, an optimum configuration can conservatively provide guaranteed baseload power generation with solar across the entire continental United States (equivalent to a nuclear power plant with no down time) for less than 0,19 USD/kWh. If solar is preferentially clustered in the US southwest instead of evenly spread throughout the United States, and we adopt future expected costs for solar generation of 1 USD/W per watt, meeting a 100 % predictable output target with solar will cost no more than 0,08 USD/kWh.

5.2 Solar resource variability at long temporal and large geographic scales

Examining the behavior of inter-day solar resource variability helps to frame the feasibility of different variability-mitigation strategies at high levels of PV penetration[a]. In order to understand the utility of geographic dispersion at reducing unpredictable solar resource variability at these longer timescales, we examine the correlation between changes in cloud index[b] at pairs of distinct geographic locations. If the changes in cloud index between these two locations are completely uncorrelated, this means that PV spread across these same two sites will experience '$1-1/2^{1/2}$' less unpredictable variability than were the same amount of PV only installed at one of the two locations.

The way in which distance and geographic bearing affects the degree of correlation between pairs of locations can help define the size and shape of the spatial region across which VLS-PV should be dispersed in order to begin reducing variability. Each subplot in Fig. 5.2-1 shows the way in which cloud index variability on a particular timescale (Δt) changes as a function of spatial extent (in km) and spatial orientation (ω). The red vertical lines indicate the geodesic distance in kilometers at which the correlation between pairs of sites reaches zero: indicating the spatial extent at which their aggregate variability is reduced by '$1-1/2^{1/2}$'. The aggregate variability of a group of *N* sites separated by this distance is reduced by '$1-1/N^{1/2}$' [1)].

What these plots show us is that:

- Aggregate unpredictable variability of the solar resource decreases exponentially with increasing geographic extent no matter the timescale.
- The longer the timescale, the larger the spatial area over which PV needs to be dispersed to begin to eliminate this variability.
- This variability is eliminated over much shorter distances if these distances are traveled in a North-South direction versus an East-West direction.

As an illustrative example from Fig. 5.2-1, imagine 100 PV plants of equal size are separated by an average of 1 500 km N/S and interconnected. As an aggregate, they experience a 90 % reduction in variability from month to month vs. the variability experienced by a single one of these sites when taken individually. By the same token, these same 100 PV plants only need to be separated by an average of 1 000 km N/S and interconnected in order to see a 90 % reduction in variability from one two-day period to the next.

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[a] Variability of the solar resource from one day to the next and on a seasonal basis engenders 'ramps' in PV production of a much larger magnitude (on an energy basis) than those at sub-daily timescales.
[b] Cloud index is synonymous with 'clear sky index' and reflects the cloudiness of the sky.

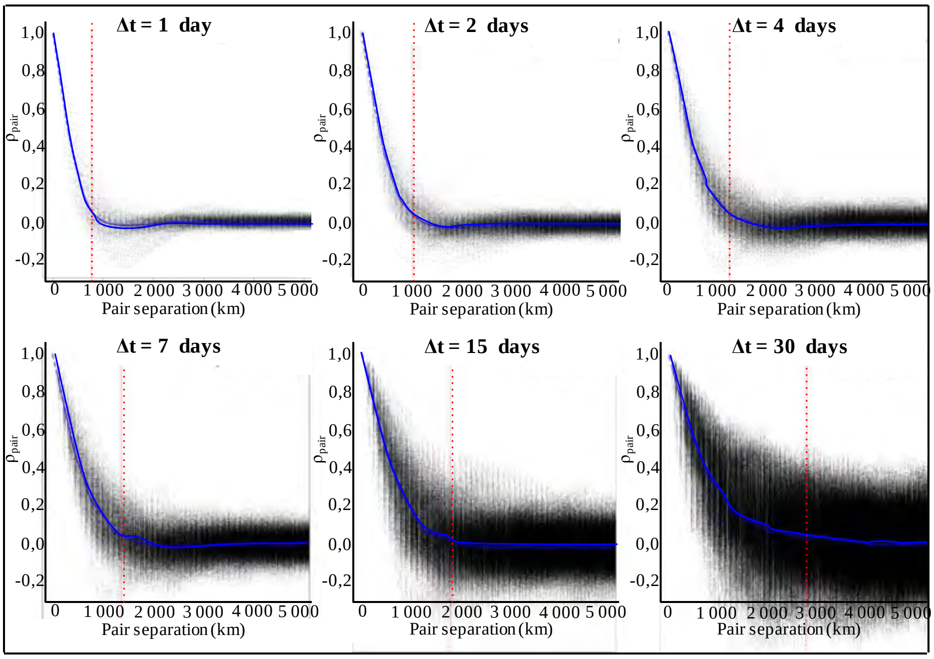

Fig. 5.2-1 Station pair correlation (ρpair) of changes in the clearness index (ΔkT) as a function of pair separation (km) and Cartesian pair orientation for three distinct time-averaging intervals (Δt) (Blue lines are locally-weighted regression trends and red vertical lines indicate the distance at which correlation between pairs of sites first reaches zero. The top three plots represent all pair correlations where the pairs are on a general E/W bearing (ω) while the bottom three plots represent all pair correlations where the pairs are on a general N/S bearing.)

5.3 Baseload with solar PV: a pipe dream?

What does it take to transform the highly variable output expected from a PV generator based in New York City (an illustrative year of which is shown in Fig. 5.3-1(i) to the baseload output shown in Fig. 5.3-1(ii)?

If PV is needed to produce a flat output day after day like a conventional nuclear power plant, not only does the random variability in production arising from passing clouds need to be addressed, but so too do the seasonal variations in the solar resource.

Each of three supply-side solutions—curtailment, storage and geographic dispersion—when used in concert at optimal levels, can help achieve this goal. In the sections below, we consider the case of providing baseload power with VLS-PV in New York City and investigate the effectiveness of these strategies for reducing the levelised cost of electricity generated therefrom.

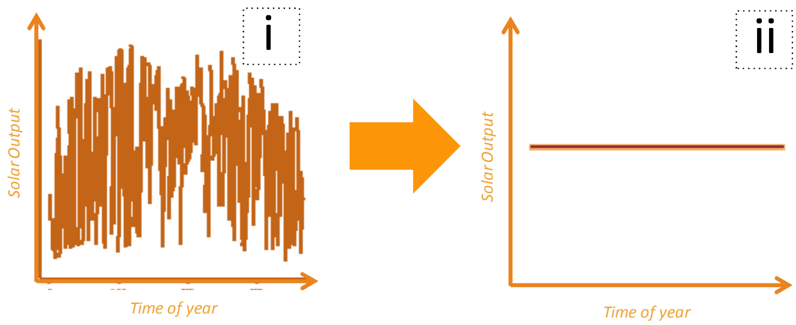

Fig. 5.3-1 Daily PV output at NYC over the course of a single year (i), and Output of an ideal baseload power plant (ii)

5.4 Energy storage

Fig. 5.4-1 compares capital cost per unit watt (USD/W) to capital cost per unit energy storage capacity (USD/kWh). For the purposes of smoothing supply/demand imbalances engendered by solar variability on the timescale of 1-day and beyond, we focus on technologies that combine long discharge times, high rated power capacities and low capital costs per unit energy[c].

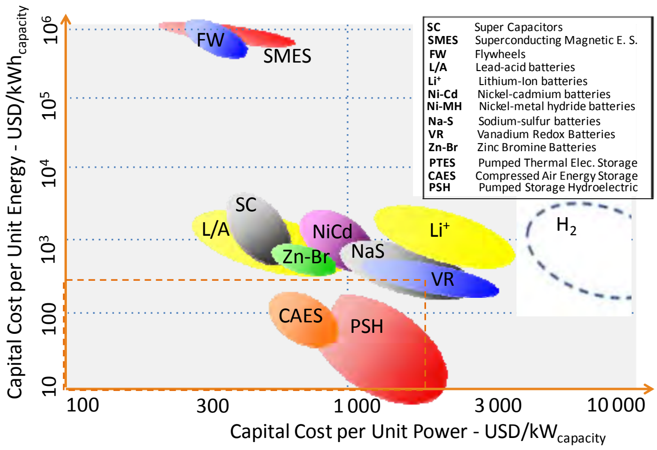

Fig. 5.4-1 Economic parameter comparison between different energy storage technologies (Figure is original but cost parameters are again sourced from ESA[2)], NREL[3)] and DOE/EPRI[4)].)

Energy storage as gravitational potential in the case of pumped-storage hydroelectric (PSH) and as pneumatic potential in the case of Compressed-Air Energy Storage (CAES) represent the best combination of these economic parameters for meeting longer-timescale variability. In order to achieve baseload output with solar using *just* energy storage alone, as can be seen in Fig. 5.4-2, storage capacity must be large enough on an energy basis to take all of the surplus PV electricity generated during the summer months and correspondingly fill the winter deficits.

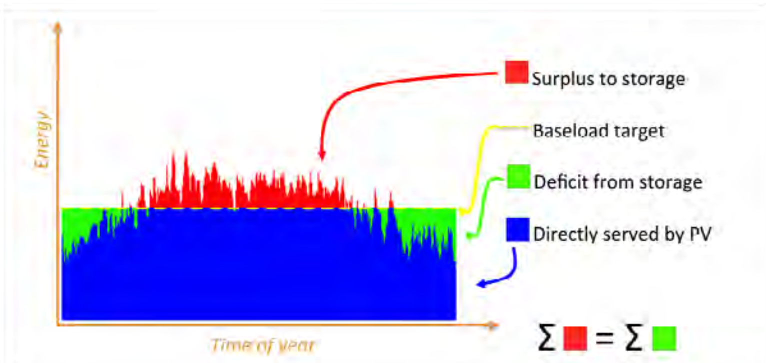

Fig. 5.4-2 Daily solar PV output in New York City over the course of a year along with surpluses and deficits relative to a baseload output target

(Storage charges from the surpluses during the summer (red) and discharges during the winter (light green). Baseload directly met by PV is highlighted in blue.)

For New York City, with PV at 2 USD/W and storage at PSH-equivalent prices, the sizing of storage capacity necessary to overcome the seasonal imbalance and generate baseload power drives the levelised cost of electricity (LCOE) to 1,12 USD/kWh[d]. While certainly unaffordable on its own, when storage is combined with geographic dispersion and curtailment, baseload with PV approaches the level of economic feasibility.

[c] The orange dotted line in Fig. 5.4-1 highlights a subset of storage technologies that claim relatively low capital costs per unit power and energy.

[d] 5 % discount rate, 30 year lifetime with no resale.

5.5 Geographic dispersion

We know through the relationship between aggregate variability correlation and distance that geographic dispersion can have a significant smoothing effect on aggregate solar output. But how we go about capturing this in practice? In order to leverage this spatial smoothing effect, the existing electric power transmission grid must be made more robust to allow for significantly more power transfer. Quantifying the cost of making our existing transmission grids more robust requires information about the spatial layout and capacities of the existing power grid[5] as well as information regarding the costs of new transmission lines and associated infrastructure.

Using present-day costs for High-Voltage DC (HVDC) and High-Voltage AC (HVAC) technologies[6] and a detailed map of existing HV lines across the US via NREL[7], we are able to determine the minimum-cost way by which to interconnect spatial regions of different sizes. We examine what this geographic region looks like in terms of aggregate PV production and new transmission grid layout in Fig. 5.5-1[8].

Each of the scenarios in this figure shows the mean radiation; ergo the estimated aggregate PV production across each highlighted region of increasing spatial extent. The spatial extents are visible along the right-hand side of the plot in Fig. 5.5-1 is defined by a fixed geodesic radius (in km) around NYC, and interconnected in an estimated least-cost fashion using a minimum-spanning tree algorithm[9].

Clearly visible as the region is expanded through the subplots in Fig. 5.5-1 is a decrease in amount of inter-day variability. The required storage capacity savings resulting from distributing the same quantity of PV that was located at the smallest spatial region in Fig. 5.5-1(i) across the region in Fig. 5.5-1(iii) are significant. But will these storage cost savings make up for the increased costs of interconnection?

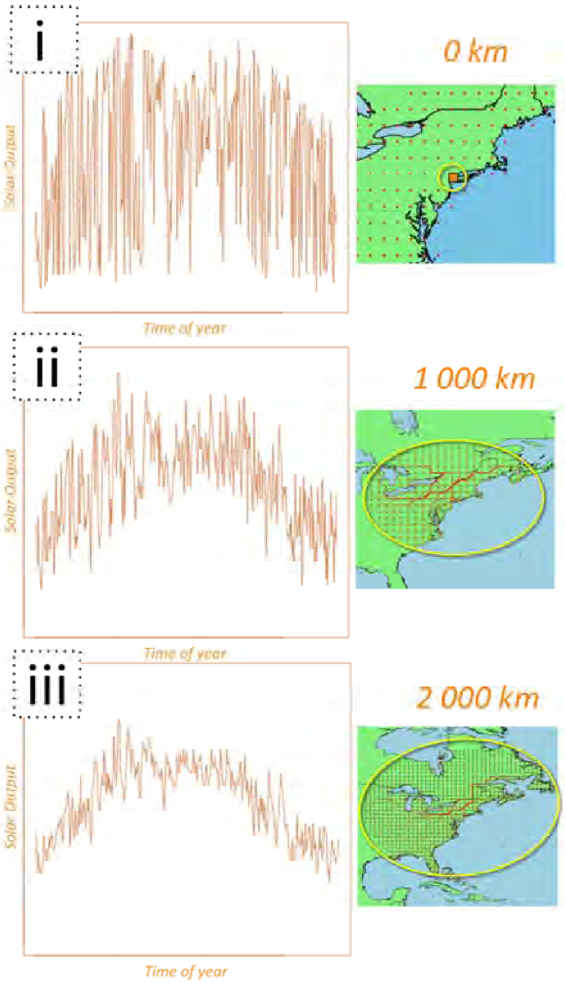

Fig. 5.5-1 Mean solar resource ergo mean solar PV production over the course of one year across 3 geographic regions of varying spatial extents: i) 0 km, ii) 1 000 km, iii) 2 000 km
(Each diagram shows the spatial extent in question, defined by an equidistant radius in km around NYC.)

Fig. 5.5-2 is a stacked area graph that shows the total levelized cost of electricity (LCOE) of meeting a baseload output target 100 % of the time with PV, storage and increasing amounts of geographic dispersion. The marginal contribution of grid expansion costs to the LCOE is in black, and clearly increases with expanding geographic extent. As expected, the corresponding decrease in marginal contribution of storage costs to the LCOE more than makes up for this increase and total LCOE is decreased.

What Fig. 5.5-2 shows is that if the same quantity of PV which was centered in NYC was evenly spread evenly across a region bounded by a 2 500 km radius around the city and interconnected, the LCOE of meeting a baseload output target drops by nearly 40 %. While 0,71 USD/kWh is still unaffordably expensive, this number reflects the cost of providing the same output as a conventional nuclear power plant with PV at 2 USD/W. If we consider a future PV capital cost of 1 USD/W and preferentially geographically disperse towards sunnier areas, the LCOE of generating baseload output with PV, storage and electrical interconnection drops a further 50 % to 0,40 USD/kWh.

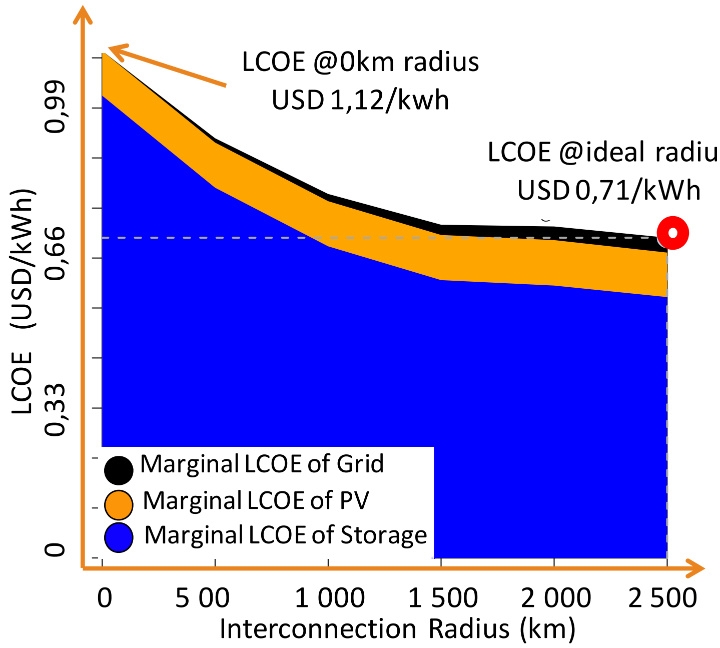

Fig. 5.5-2 Total Levelized Cost of Electricity (LCOE) for meeting a baseload output target when PV is spread about increasing interconnection radii around NYC
(Highlighted are the LCOE for meeting a baseload output 100 % of the time with no interconnection (0 km radius) and the LCOE when the PV is spread across an 'ideal radius' that minimizes this total LCOE.)

5.6 Curtailment

Curtailment is an intuitive strategy: by oversizing PV capacity, supply deficits (where PV generation is lower than a specified output target or actual demand) are reduced. The surpluses that result from oversizing PV capacity can be correspondingly curtailed at key times in order to reduce the required size of storage that would otherwise be needed. One intelligent way to go about this is to use historical solar and demand data to predict exactly how much storage is needed to meet a specific output profile. If the storage capacity is sized correctly, there will always enough stored energy within the storage to deal with supply deficits and PV generation only needs to be curtailed when the storage is full.

Fig. 5.6-1 demonstrates the curtailment principle when attempting to achieve a baseload supply target with PV centered at New York City while not relying on inter-day storage at all. In this case, PV capacity is oversized to such a degree in Fig. 5.6-1(ii) that no individual day has a supply deficit relative to the baseload target to be achieved (the yellow dotted line). Storage is still required for correcting the intra-day imbalance caused by the diurnal rising and setting of the sun. Luckily, the maximum energy needed to be stored to account for this diurnal effect is much smaller than the storage capacity required to meet fluctuations on longer timescales arising from macro-scale meteorological phenomena and the seasonal shift.

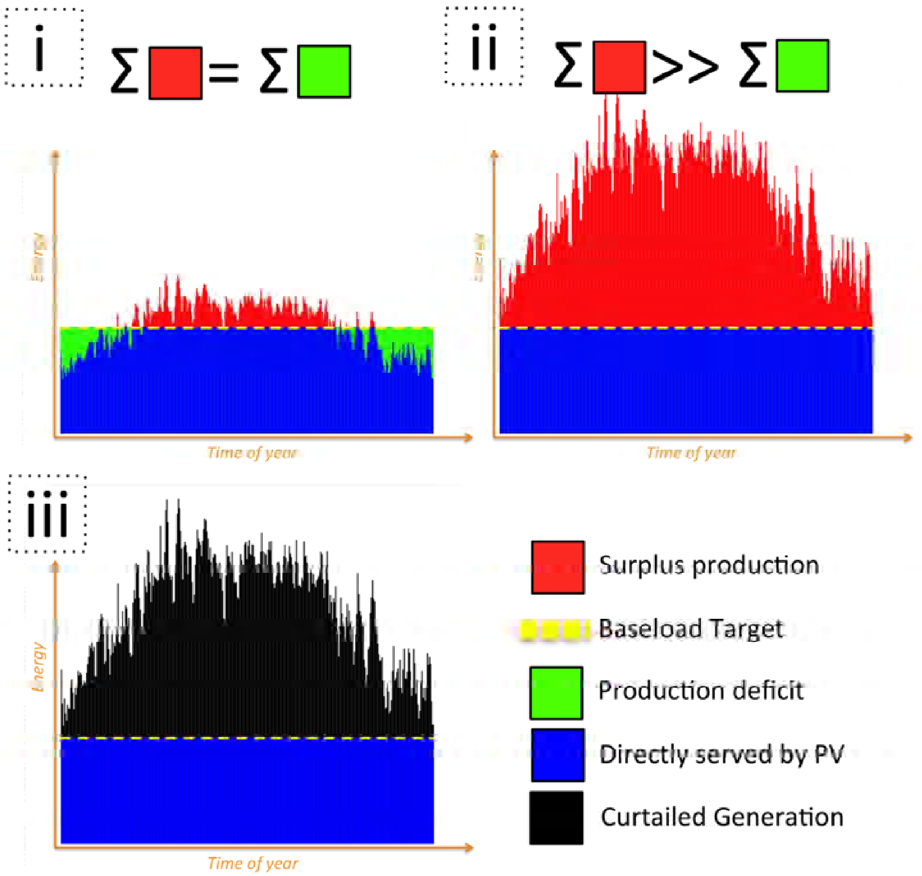

Fig. 5.6-1 Sequential diagram showing:

i) PV production over the course of a single year with surplus production being equal to supply deficits relative to a baseload output target

ii) PV production over the same year if PV capacity is greatly increased such that days with production deficits are no longer present

iii) The same scenario as in the previous subplot but highlighting the fact that surpluses are curtailed

Reducing the amount of required storage such that it only needs to have enough capacity to cope with the diurnal imbalance greatly reduces its marginal contribution to the resulting LCOE. In order to achieve this level of curtailment while maintaining the same output target, PV must be greatly oversized. If the same the same electricity is resulting from a much greater capacity of PV, the marginal contribution PV costs to the resulting LCOE is correspondingly increased. An optimal amount of oversizing and curtailment on an economic basis seeks to find the 'sweet spot' before an increase in marginal PV costs overtakes the reduction in marginal storage costs.

This 'sweet spot' is highlighted in Fig. 5.6-2. As can be seen, the reduction in the amount of inter-day storage (ergo the marginal contribution of storage to total LCOE) decreases rapidly with increasing quantities of PV generation curtailment. Correspondingly, the PV's contribution to total LCOE steadily increases and there is a crossover when 44 % of PV generation is curtailed. Curtailing PV generation at this 'sweet spot' level is incredibly effective and succeeds in reducing the LCOE of providing baseload power with PV by 75 % versus if storage were the only supply-side tool in use. The price reduction potential of curtailment alone as a supply-side strategy for coping with variability is much greater than geographic dispersion when taken alone.

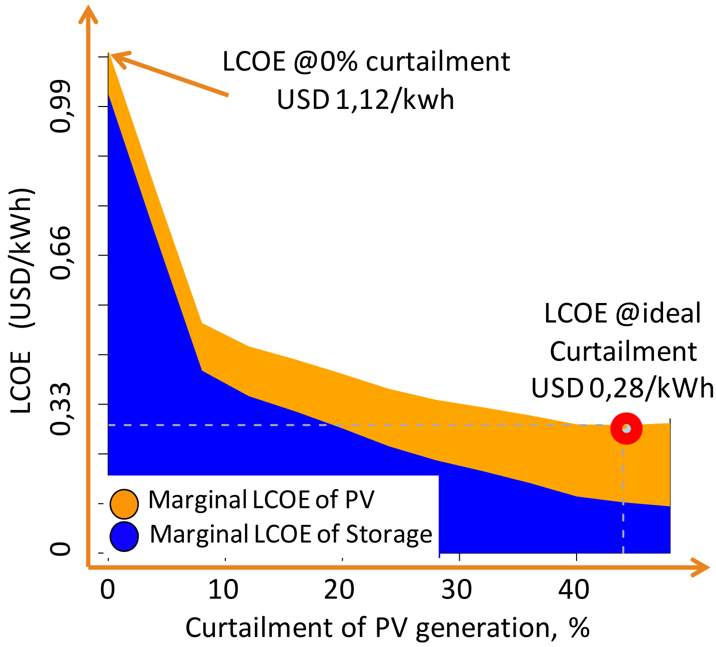

Fig. 5.6-2 Total Levelized Cost of Electricity (LCOE) for meeting a baseload output target when PV is curtailed at increasing amounts while PV is centered at NYC
(Highlighted are the LCOE for meeting a baseload output 100% of the time with no interconnection (0km radius) with both 0% PV curtailment and with the amount of PV generation curtailment that minimizes the total LCOE.)

Providing baseload power with PV curtailment and storage alone in NYC at capital costs for VLS-PV of 2 USD/W and gravitational potential storage costs amounting to 200 USD/kWh can be had for a total LCOE of 0,28 USD/kWh. With future VLS-PV costs at 1 USD/W, the LCOE for providing baseload drops to 0,18 USD/kWh.

5.7 Conclusions

Curtailment as a strategy on its own has significantly greater cost-savings potential than geographic dispersion when the goal is to provide baseload power with PV. When taken together, the cost savings are even greater. The third largest circle in Fig. 5.7-1 shows the impact on aggregate LCOE for meeting baseload with PV using both ideal levels of geographic dispersion and curtailment (a reduction of 79,5 % in LCOE versus using storage alone to the same end). If we predict a future PV cost of 1 USD/W, this same strategy of optimizing curtailment and geographic dispersion to minimize net LCOE yields costs of only 0,18 USD/kWh.

But what if we were trying to meet a load profile with PV more closely matched to the profile of the solar resource than a baseload profile? Mitigating the imbalance between PV energy supply and demand would cost correspondingly less. Furthermore, not only would the costs be lower, but the price-reduction potential of strategies like curtailment and geographic dispersion would be lower because there is less supply/demand imbalance to correct.

If, for example, we are not required to produce baseload and can instead use demand-side management to further match demand to the relative amount of solar resource on a daily basis, we can reduce the LCOE of electricity serving this demand to 0,08 USD/kWh[e], a 93 % reduction in the costs of meeting baseload with only PV and storage.

[e] Demand-side management reflected in this figure uses a load target to be met by dispersed PV, storage and curtailment that is an exponentially-weighted trailing average of the previous 30 days of PV production.

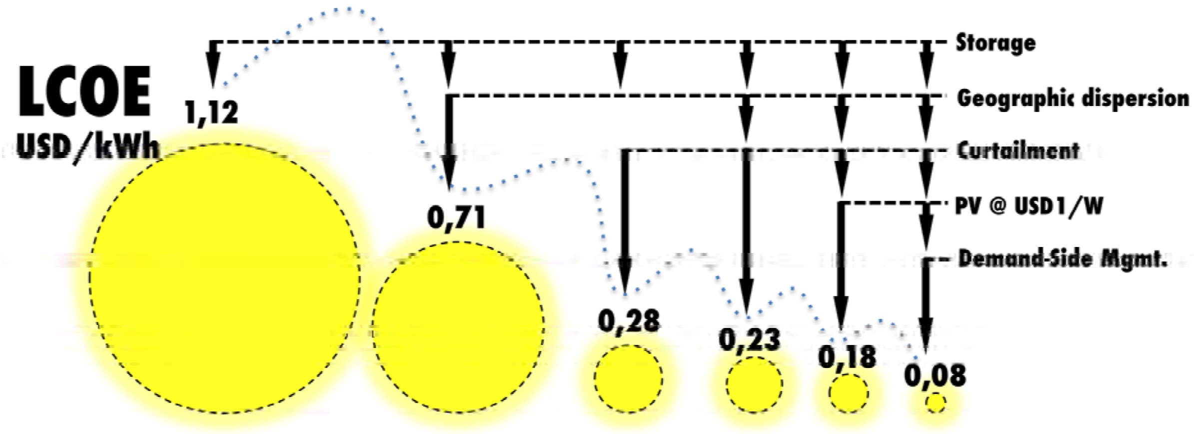

Fig. 5.7-1 Total LCOE in USD/kWh of PV + intermittency solutions for meeting a baseload output target in New York City with 100% availability

(The arrows indicate which intermittency solutions or cost assumptions are being used in each cost scenario. Unless otherwise noted, PV is assumed to be at 1 USD/W, storage is assumed to be at 200 USD/kWh the discount rate is 5 % and a 30 year lifetime is assumed with no financing. Note that if demand-side management is used to the extent reflected in this level of cost reduction, PV, curtailment and geographic dispersion are no longer meeting a purely baseload target.)

As electrical demand profiles in many major cities - including New York - are more positively correlated with the solar resource than baseload, true costs for mitigating variability will be correspondingly smaller than those detailed here.

In practice, although the macroscopic cost of electricity is greatly reduced through curtailment, geographic dispersion and demand-side management, each strategy presents its own unique challenge under current regulatory schemes. By designing fair public policy to incentivize the adoption of these strategies we can reduce aggregate electricity cost under a high-penetration of VLS-PV paradigm. Thereby, we can enjoy truly tap into the myriad environmental, geopolitical, economic and social benefits that a world relying on the sun for energy has to offer.

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Chapter 6 Potential of VLS-PV Development in China and Africa

6.1 China as a role model to the world for the massive introduction of VLS-PV

6.1.1 Why the world needs a role model

There is some controversy in the world regarding global warming and its connection with the increasing use of fossil fuel. On the one hand, atmospheric carbon dioxide is rising: a fact that must certainly enhance the natural greenhouse warming effect of the earth's atmosphere. But the controversial question is whether the observed increase in atmospheric CO_2 is causing the presently observed global warming, or whether the latter is being caused by some extraterrestrial effect which, in turn, is causing the oceans to give off some of their dissolved CO_2 into the atmosphere.

The controversy is itself fueled to a large extent by various economic interests. However, two numerical facts argue strongly that fossil fuel consumption is indeed responsible for the increase in atmospheric CO_2. The first fact is the annual published data on CO_2 emissions from fossil fuel, which go back as far as the year 1965[1]. Fig. 6.1-1 plots these data, together with an imposed least-squares exponential fit. Fig. 6.1-1 indicates that an exponential rise is both a reasonable fit to the data (R^2 = 0,962), and that the rise started to become noticeable around the beginning of the 18th century, when the so-called "industrial revolution" started in Europe. Integration of this curve from 1700 through 2013 enables us to estimate that the total CO_2 emission from fossil fuel usage over this time period has amounted to 1 743 Gt. Of this total, approximately 1 100 Gt have been emitted since 1965[1].

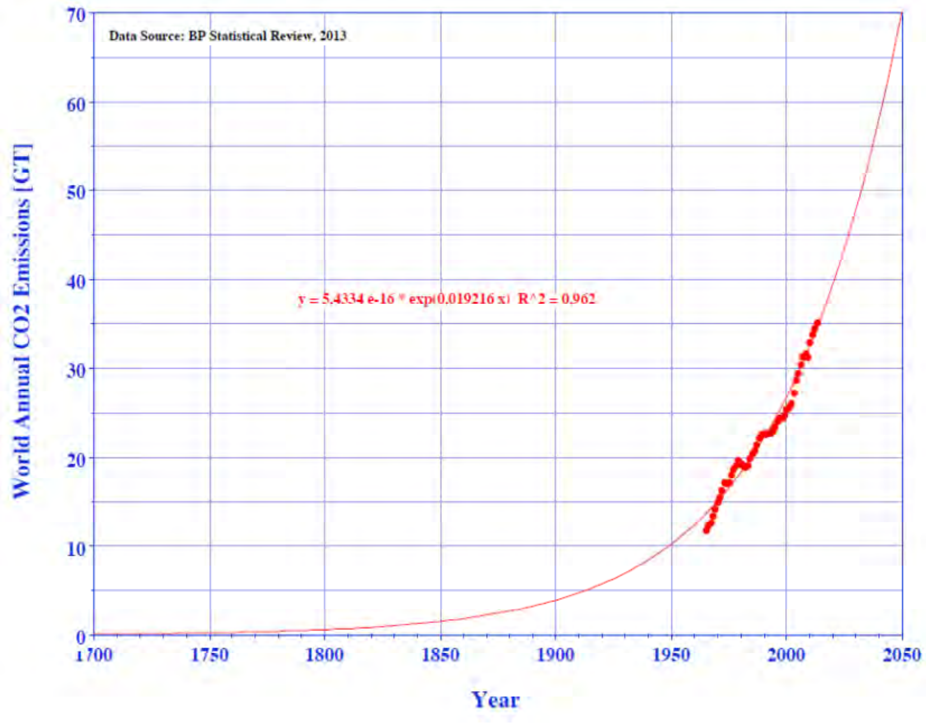

Fig. 6.1-1 Exponential least-squares fit to annual CO_2 emissions from Fossil Fuel, from 1965 - 2013

The second fact is the present atmospheric concentration of close to 400 ppmv[2]. This is 130 ppmv above the pre-industrial revolution level of 270 ppmv that can be estimated from ice-core measurements[3,4]. The 130 ppmv difference between these two levels translates into 1 014 Gt of CO_2 by weight. Where has this difference come from? As can clearly be seen, fossil emissions are more than adequate to account for it. So there is no need to make a convoluted argument in which some unknown terrestrial mechanism may have caused global warming which, in turn, could have caused the oceans to emit into the atmosphere an amount of CO_2 that, by chance, closely resembles in magnitude a known terrestrial source of that gas, namely, the burning of fossil fuel.

Never the less, as already mentioned, there are powerful economic forces at work which, by their nature, would prompt the world to do very little, if anything, to change the present situation. The biggest problem is that economic stability rests heavily on energy availability and its concomitant influence on employment in all sectors of the economy. To stop burning fossil fuels and to switch to any other energy source could consequently be expected to cause a major perturbation to economic stability. But there is one precedent for taking such a step: In the 1950s, France decided to switch most of its electricity production from fossil fuel to a nuclear energy base. This demonstrates that a radical change can be made in the electrical sector of the energy economy. Today, after a rising number of accidents at nuclear power plants around the world, most countries are hesitant to move in the direction that France took. On the other hand, VLS-PV is clearly a less potentially dangerous alternative to nuclear technology. So, let us take a look at what kind of magnitudes would be needed.

Fig. 6.1-2 shows a breakdown according to technology type, of the world's electric power generation over the past 20 years[1)].

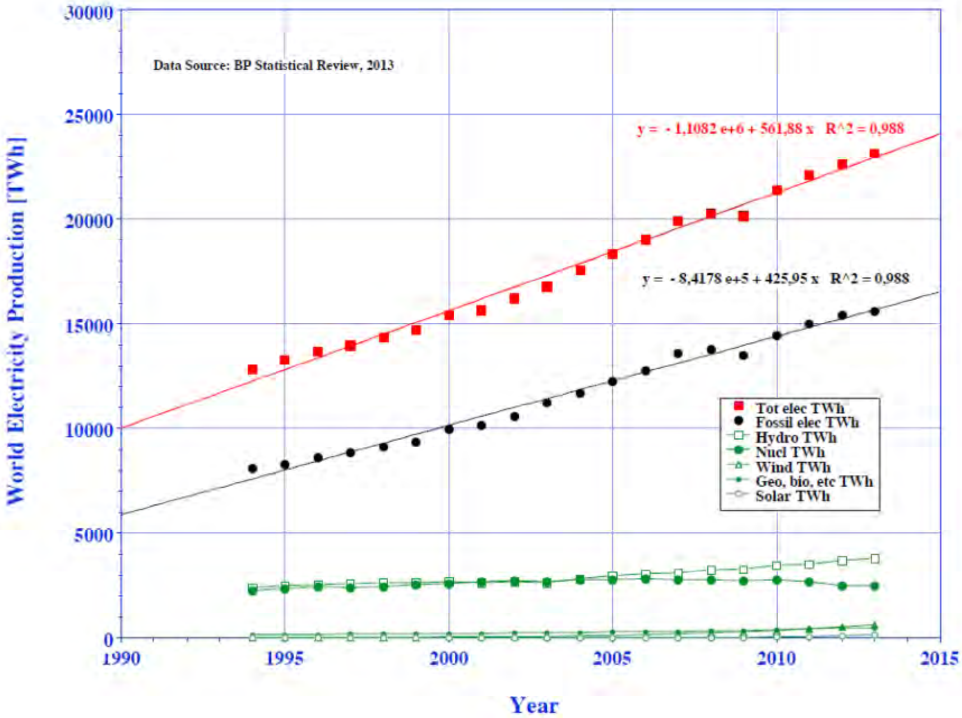

Fig. 6.1-2 Recent trends in world electricity production according to technology type[1)]

Fig. 6.1-2 illustrates at least two facts that should be a major cause for concern: First, that power generation *from fossil fuels* is continuing to rise, at an average rate of 426 TWh per year, *in spite of* widely expressed environmental concerns. Secondly, that the present implementation of solar and wind technologies is almost negligible on the overall scale of electricity generation.

The realization that CO_2 emissions need to be seriously reduced, coupled to the fear of rocking the economic boat, have led to a situation in which the world desperately needs a role model to lead it into an energetically clean and economically sound future.

This chapter will examine the power-generating sector of the Chinese economy and demonstrate that economic forces are already at work in that country that could encourage the widespread internal implementation of VLS-PV and wind. Moreover, the ramifications of such a step, both for the Chinese economy and for those of the other major power-producing countries, could well result in China presenting the role model that the rest of the world needs.

6.1.2 China's position in the world of power generation

In recent years China has become the world's leading power producer. This can be seen from Tables 6.1-1, 6.1-2 and 6.1-3, which list in descending order, the world's top ten power producers in terms of fossil fuel consumption, electricity production, and the resulting CO_2 emission, respectively. China and the USA are the only countries whose global percentages have reached double figures (together, exceeding 40 % of each of the global totals), but China leads in all three categories.

Table 6.1-1 World's ten largest fossil fuel consumers in 2013[1)]

Country	Fossil Fuel Consumption in 2013 [Mtoe]	Percentage of Global Consumption [%]
1. China	2 578,2	23,4
2. USA	1 957,7	17,7
3. Russian Federation	618,7	5,6
4. India	545,8	4,9
5. Japan	442,7	4,0
6. Germany	268,7	2,4
7. Iran	239,6	2,2
8. South Korea	237,6	2,2
9. Saudi Arabia	227,7	2,1
10. Canada	216,9	2,0
World	11 032,2	100

Table 6.1-2 World's ten largest electricity producers in 2013[1)]

Country	Electricity Production in 2013 [TWh]	Percentage of Global Production [%]
1. China	5 361,6	23,2
2. USA	4 260,4	18,4
3. India	1 102,9	4,8
4. Japan	1 088,1	4,7
5. Russian Federation	1 060,7	4,6
6. Germany	633,6	2,7
7. Canada	626,8	2,7
8. France	568,3	2,5
9. Brazil	557,4	2,4
10. South Korea	534,7	2,3
World	23 127.0	100

Table 6.1-3 World's ten largest CO_2 emitters in 2013[1)]

Country	CO_2 Emission in 2013 [Gt]	Percentage of Global Emission [%]
1. China	9,524 3	27,1
2. USA	5,931 4	16,9
3. India	1,931 1	5,5
4. Russian Federation	1,714 2	4,9
5. Japan	1,397 4	4,0
6. Germany	0,842 8	2,4
7. South Korea	0,768 1	2,2
8. Saudi Arabia	0,632 0	1,8
9. Iran	0,630 6	1,8
10. Canada	0,616 7	1,8
World	35,094 4	100

Looking now more closely at China's energy statistics, Fig. 6.1-3 shows a breakdown of that country's use of fossil fuel during the past 20 years. It shows that electricity generation constitutes approximately 36 % of the nation's use of fossil fuel. Moreover, a linear least-squares fit to the electricity data (R^2 = 0,939) indicates an annual rise at the rate of 189 TWh y^{-1}. However, a quadratic curve fits the data better (R^2 = 0,992) and has a slope of 355 TWh y^{-1} for the year 2013.

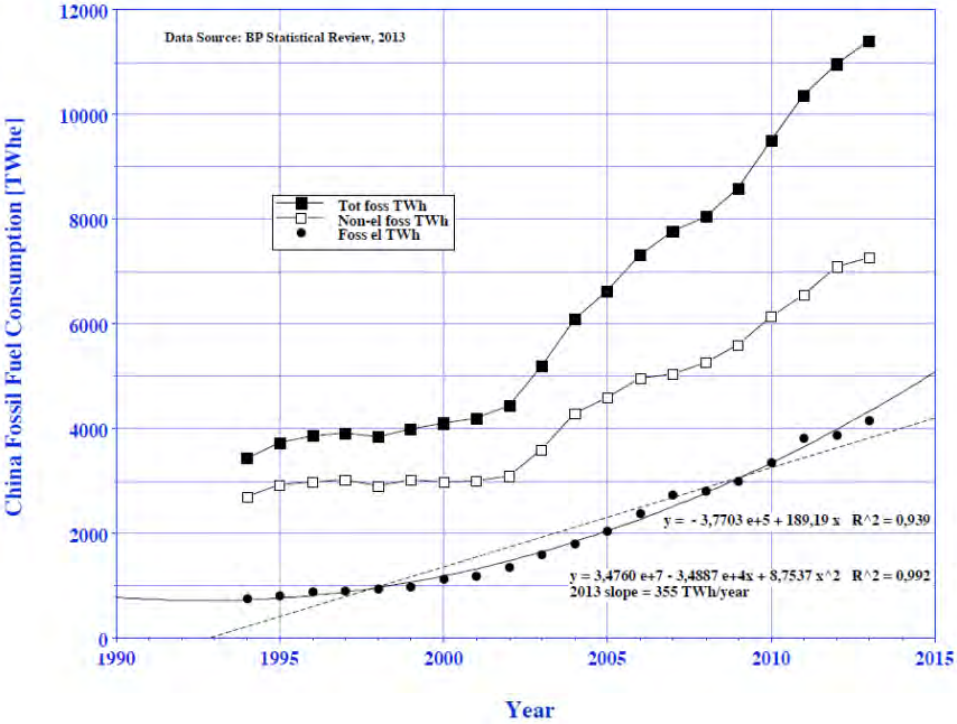

Fig. 6.1-3 The past twenty years of China's fossil fuel consumption, showing linear and quadratic fits to the electricity data[1)]

Not all of China's electricity is generated from fossil fuel. Fig. 6.1-4 Shows a breakdown of the country's electricity production by fossil and renewable sources.

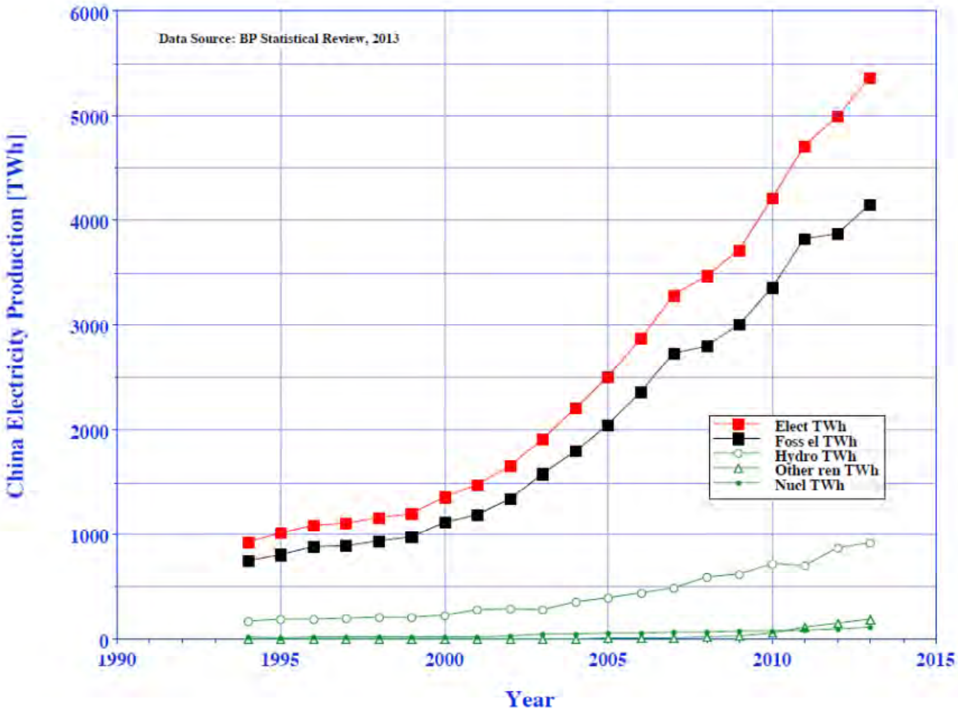

Fig. 6.1-4 Past twenty years of China's electricity production[1)]

In Fig. 6.1-4, the green triangles, labeled "Other ren TWh" includes mainly wind energy, but also some solar and biomass usage as can be seen more clearly in Fig. 6.1-5. One sees that wind power started to rise in 2005, and solar in 2010.

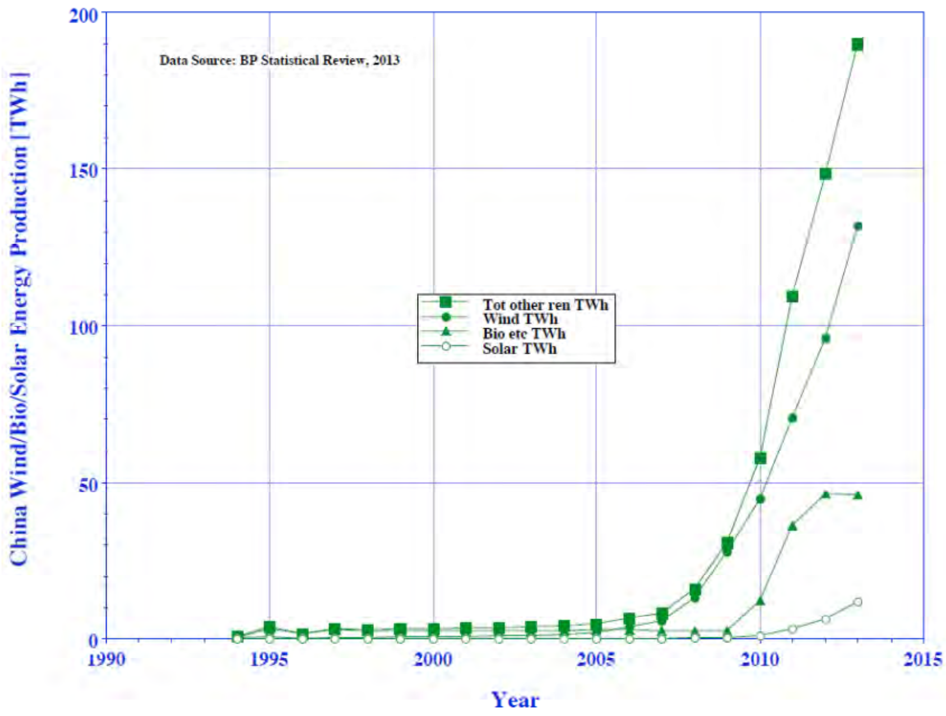

Fig. 6.1-5 Breakdown of "Other renewables" into wind, solar and biomass, etc[1)]

Qualitatively, Fig. 6.1-4 for China is not too different from Fig. 6.1-2 for the rest of the world, in that the major source of electricity production is fossil fuel and that renewables presently play an extremely minor role. However, Figs. 6.1-4 and 6.1-5 obscure a major difference with any for the rest of the world: Namely, that China has become the first (and so-far the only) country to implement VLS-PV systems on the gigawatt scale (Fig. 6.1-6), and if, by "very large scale" we mean gigawatts, then China is also the first country in the world to implement VLS-Wind systems (Fig. 6.1-7).

Fig 6.1-6 Part of a 1 GWp VLS-PV plant at Dunhuang, Gansu Province, China
(Photographed by DF in July 2012)

Fig. 6.1-7 Part of a 1.74 GW VLS-Wind plant at Yumen, Gansu Province, China
(Photographed by DF in July 2012)

With this encouraging technological development, we now examine whether it could be *technically* feasible for China to cease building new fossil-fuelled plants altogether and, instead, to provide for all of the country's projected future electricity needs by VLS-PV or some combination of VLS-PV and wind.

6.1.3 A VLS-PV alternative: How large, and at what rate?

If we assume an average annual VLS-PV productivity of 1 500 TWh per GWp for China, then in order to discontinue the construction of new fossil-fueled plants, which, as we have seen from Fig. 6.1-3, are being installed at a rate of at least 189 TWh per year, China would need an annual installation of at least 126 GWp of VLS-PV plants. On the other hand, if the quadratic fit to the data in Fig. 6.1-3 is more realistic, then the present annual growth rate of 355 TWh per year would require the annual installation of 237 GWp of VLS-PV.

In order to assess how realistic such a program would be, one must ask: (a) Whether GW-scale plants can be constructed on an annual basis; (b) Whether there is enough available land area to support such growth, and for how long; (c) Whether the manufacturing capability exists.

(1) Rate of introduction

Information published by China's New Energy Agency (NEA) indicates that by the end of 2013 the country's cumulative installed PV power had reached 19,42 GWp, of which 12,92 GWp had been installed that year. Furthermore, of the 12,92 GWp of new capacity installed during 2013, large-scale, grid-connected systems constituted 94% of all installations. Table 6.1-4 lists the 6 provinces that had more than 1 GWp of installed capacity by the end of 2013, together with the amount of new capacity that was installed that year.

Table 6.1-4 Installation statistics of the 6 provinces with more than 1 GWp installed capacity[5)]

Province	Capacity installed in 2013 [GWp]	Percentage of total 2013 installation [%]	Cumulative capacity through 2013 [GWp]	Percentage of total cumulative installation[%]
Gansu	3,842	31,7	4,317	26,5
Qinghai	0,963	8,0	3,103	19,0
Xinjiang	2,320	19,1	2,570	15,8
Ningxia	1,183	9,8	1,614	9,9
Inner Mongolia	1,133	9,4	1,405	8,6
Jiangsu	0,789	6,5	1,049	6,4
All China	12,119	100	16,317	100

Table 6.1-4 demonstrates that China would have no problem in constructing, on an annual basis, GW-scale VLS-PV plants of the kind shown in Fig. 6.1-6 at Dunhuang. In fact, a bill board prominently on display at the Dunhuang VLS-PV site[6], indicated that a total of 8 GWp were planned there for the 8-year period 2012-2012. From the progress indicated in upper-left entry in Table 6.1-4, such a plan does not appear unrealistic. On the contrary, reports[7] indicate that by the end of 2013, Gansu province was so far ahead of its projected VLS-PV installation plans, that steps were being taken to encourage it to slow down during 2014. It is also encouraging news that present estimates from within China are looking ahead to an annual PV installation rate of 100 GWp per year by 2050. This figure is of similar magnitude to the estimates we have made above that would enable China to replace the construction of all new fossil fueled electricity generation by plants fueled by renewable sources.

(2) Land requirements

Another important item of information on the bill-board at Dunhuang[6] relates to the amount of land area that has been allocated for PV in that part of China. It is 254 km^2 for the 8 GW of VLS-PV. This means that each GW of VLS-PV requires 31,75 km^2 of land. Adopting the linear (alternatively, the quadratic) growth rate indicated in Fig. 6.1-3, we may consequently infer that in order to install 126 (alternatively, 237) GW per year, China would need to allocate 4 000 (alternatively, 7 525) km^2 of land per year. *An assumption here is that, if the quadratic curve is the more realistic fit to past growth, future growth need continue only linearly, albeit at the 2013 rate, rather than continuing to rise quadratically*. This assumption will be justified below.

An important question, whichever growth rate is decided upon, is: How long is such growth possible, or even necessary? In order to be able to make an intelligent guess at the answer to such a question, the case of Germany is perhaps instructive.

In 2013, Germany had a population of approximately 81.1 million[8] and generated 633,6 TWh of electricity[1]. This translates into a *per capita* generation of 7 810 kWh per year. Now Germany is an example of a fully industrialized country, whose electricity needs are not being driven by population growth. In other words, it is likely that the country has as much electricity as it needs for a comfortable life-style and a productive economy. It is therefore interesting to calculate, as a test case, how many years it would take China to reach the same *per capita* electricity generation that Germany enjoys today, and what the land requirements would be for VLS-PV if this were to be the technology of choice. The corresponding 2013 population and growth rate figures for China were 1,35 billion and 0,44 % y^{-1} respectively[8]. Fig. 6.1-8 accordingly plots the projected annual *per capita* electricity generation of that country under the two electrical growth scenarios of 126 GW and 237 GW of VLS-PV per year. The two curves start at the year 2012 and are continued until they meet the assumed German target.

In the case of annual installation of 126 GWp of VLS-PV plants, the test-case target would be met by the year 2051. However, at the higher installation rate of 236 GWp y^{-1}, the target would be met by the year 2030. In terms of land coverage, the shorter-term target of 17 years would require 128 000 km^2, equal to 1,4 % of the total 9 326 410 km^2 land area of China[8]. The longer-term target of 38 years would require 152 000 km^2, equal to 1,6 % of the country’s land area. These percentages of land coverage are comparable to the percentage coverage of the USA by highways[9] and hence, not unreasonably large. Either of these strategies would result in VLS-PV providing more than 50 % of China’s electricity needs by the time the country had reached the test-case target of 7 810 kWh/capita.

We may therefore conclude that by covering 1 - 2 % of the country’s land area with VLS-PV plants, China could achieve similar *per capita* electricity generation as Germany without needing to construct any more fossil-burning power plants. Such a target could be achieved within 17 years, by continuing the country’s 2013 rate of electricity growth *linearly*, instead of at the quadratic growth exhibited by the previous 20-years of China’s development.

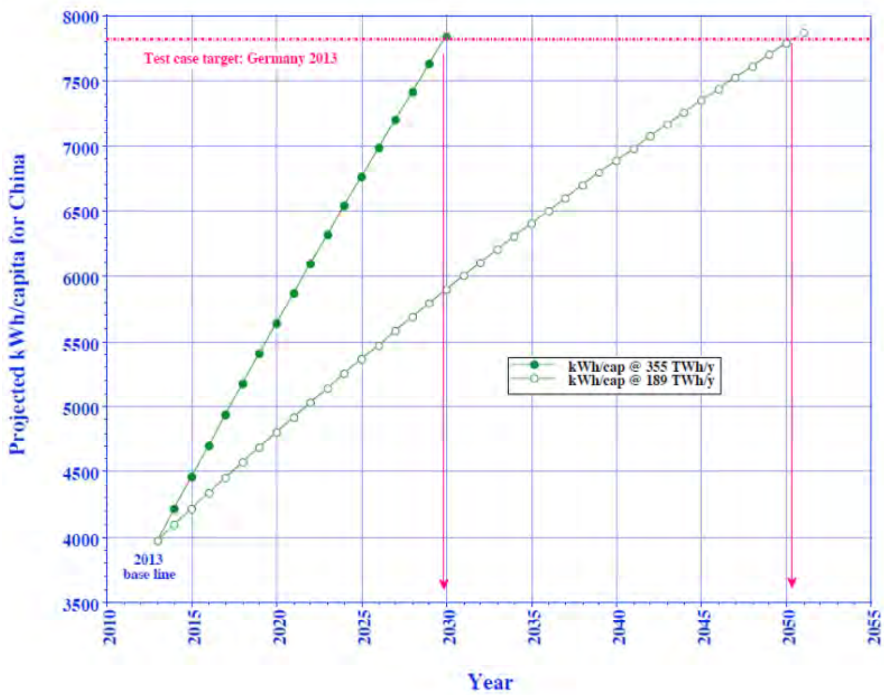

Fig. 6.1-8 Projected growth in China's per capita electricity production, assuming annual introduction of VLS-PV plants at 126 GW per year (open circles) and 237 GW per year (filled circles). Dashed horizontal line = test-case target of Germany's 2013 per capita generation. Starting point is China's total electricity generation of 5 361,6 TWh for 2013[1)] and population estimate of 1,356 billion for that year[8)].

(3) Manufacturing capability

During each of the years 2011 and 2012, Chinese industry manufactured 20 GWp of PV modules[10)]. Such a production rate is clearly too small to enable the annual construction of VLS-PV plants with even 116 (not to mention 233) GWp name-plate ratings. However, remember that all the world would need to install 426 GWp per year of VLS-PV in order to emulate a Chinese lead. Thus the Chinese PV industry could have a potential export market of 310 GWp per year, plus an internal market of 116 GWp per year; or an export market of 193 GWp per year with an annual internal market of 233 GWp. Either way, this represents an annual turn-over of the order of 0,5 trillion USD per year. So the expansion of China's present PV manufacturing facilities is something that could be taken into consideration.

If such a huge expansion of the existing PV industry is considered too risky at the present time, there is also another direction, which takes into account the likelihood that concentrator photovoltaic (CPV) systems will become more suitable for desert sites than are today's non-concentrator systems. CPV systems typically require three orders of magnitude less photovoltaic material than do conventional PV systems of the same power rating, because mirrors or lenses magnify the light intensity of the sun by typically 1 000 X. This proportion translates approximately into the amount of floor space per GWp of the required cell fabrication plant. Therefore, if China were to convert 2 % of its existing PV fabrication facilities to CPV, a single facility that today produces 400 MWp y^{-1} of silicon cells could produce 400 GWp y^{-1} of concentrator cells: enough, in principle, to supply the entire world, even if the quadratic fit in Fig. 6.1-3 is taken.

China has already constructed a CPV two systems of, respectively, 50 MWp and 60 MWp ratin, at Golmud in Qinghai province (Fig. 6.1-9). The individual modules at Golmud consist of 15 CPV cells, each illuminated by a 1 090 X silicone-on-glass fresnel lens. Quartets of such modules share a single horizontal tracking axis, with a common mechanism for tracking about the second axis as can be seen in Fig. 6.1-10.

Fig. 6.1-9 Part of a 60 MWp CPV system at Golmud, Qinghai Province (Photo courtesy Suncore Corp)

Fig. 6.1-10 Suncore's passively-cooled sun-tracking CPV modules (Photo courtesy Suncore Corp)

It should thus be clear that China has or could have all of the necessary manufacturing capability for enabling itself - and even the rest of the world - to employ VLS-PV technology in order to forego the need to construct any more fossil-fueled power plants. It should also not be forgotten that China also has a well-developed wind turbine manufacturing industry and much experience at operating VLS-Wind farms. So, although our present emphasis is on VLS-PV, the ultimate mix both for China and the rest of the world would also include wind.

6.1.4 China's path to VLS-PV

2011 was the first year in which China started to install grid-connected PV systems on the GW-scale, 2 GWp of such plants being installed during each of the years 2011 and 2012. However, by the end of 2013, as already indicated, China's cumulative installed PV power had reached 19,42 GWp.

There are a number of objective reasons why China has very rapidly taken the lead with regard to the implementation of VLS-PV. First, is the realization in government circles that further economic growth based upon coal is no-longer sustainable. This fact was emphasized to the rest of the world during the 2008 Olympic Games for which it was found necessary to shut down coal-burning power plants in the vicinity of Beijing in order to preserve the lungs of the competing athletes. As reported in the New York Times on July 7, 2008[11)]:

> Beijing's air quality remains a major concern for the Games as the city continues to struggle with pollution, despite a 20 billion USD government cleanup campaign. Beijing is also a victim of its neighborhood: pollution blows in from surrounding regions that are dotted with coal mines, coal-fired power plants, steel mills, cement factories and other clusters of heavy industry.

Second, is the highly flexible structure of China's energy policy, which proceeds in 5-year steps. For example, the ongoing 12th such 5-year plan, due to end in 2015, stipulates a 50 GWp PV target for 2020. However, construction has proceeded more rapidly than anticipated, with the result that the 2020 target is likely to be increased to 100 GWp[7)]. This flexibility is important because it enables a given 5-year plan to evolve as part of a self-learning experience. For example, when it became clear that the existing Chinese power grids could not handle too many VLS-PV plants, emphasis in the highly populated east of the country was re-focused on smaller, distributed, PV systems.

A rapid improvement in transmission infrastructure may be expected thanks to the flexibility of China's energy planning. In this regard, a publication in, May 2014, of a document by China's National Development and Reform Commission (NDRC), outlined 80 energy, information and infrastructure projects in which "society" is encouraged to invest. "Society" now includes the private sector, both domestic and foreign[7)]. Clean electricity infrastructure projects such as VLS-PV plants, UHVDC lines, etc. should, as previously emphasized[6,12)], constitute attractive long-term investments for pension funds.

However, China's flexibility also involves much questioning. For example, in addition to insufficient transmission infrastructure to enable a 100 % emphasis on VLS-PV (as opposed to smaller, distributed PV systems), quality control was found to be a major weakness in some PV fabrication plants. This was due to a lack of well-defined standards. Naturally, when the standards become available, it should be possible to improve the quality control of these factories and thus enable them to participate in the massive drive towards VLS-PV implementation advocated in this chapter.

Other aspects of VLS-PV that have occupied Chinese scientists have included: studies of the most cost-effective methods for keeping PV panels reasonably free from desert dust; the possibility of ecological issues caused by large areas of ground covered by VLS-PV; various grid-integration issues, etc.

6.1.5 Conclusions

In this chapter we have employed electricity production data through the year 2013[1)] and current population statistics[8)] to project that China could achieve the same *per capita* electricity generation by the year 2030 that Germany enjoys today, if it increases its electrical generating capacity *linearly* at the 2013 rate of 355 TWh each year (and not quadratically, as has been the situation for the past 20 years). Furthermore, this increase could be achieved *without the need to build another fossil-fueled generating plant* if VLS-PV were to be introduced at the rate of 236 GWp per year. By that time, 1,4 % of China's land area would be devoted to solar technology.

Although this is a massive rate of introduction compared with anything that has yet been undertaken even in China, it is not too dissimilar to internal Chinese projections that are currently being made for the year 2050. Furthermore, we have shown that China already has all of the necessary manufacturing capability – particularly if it were to convert 5 % of its existing PV fabrication facilities to CPV fabrication. Such a step would also enable China to manufacture enough PV and CPV cells to allow the rest of the world to stop building new fossil-fueled generating plants.

We have emphasized that economic forces in the rest of the world would most likely work to prevent the elimination of new fossil-fueled plants. On the other hand, environmental concerns about the increased burning of fossil fuels are well recognized. The world accordingly needs a role model to demonstrate that a switch can be made from fossil fuels to VLS-PV. China could naturally present such a role model for the following reasons:

First	:	China was the first and, to date, only country to achieve VLS-PV at the genuine GWp scale. Thus, if the world needs a role model, it already has one.
Second	:	China has an internally perceived environmental need to increase its employment of VLS-PV, including considerations of ceasing the construction of new fossil-burning plants.
Third	:	China has the necessary industrial capability to provide for all of its own future VLS-PV requirements *and* for those of the rest of the world.
Fourth	:	China's internal growth needs could buffer possible fluctuations in the export market during the initial stage when, no-doubt, the rest of the world will need to be making many adjustments to its existing energy policies, while observing how successful the Chinese experiment is.
Fifth	:	The success of widespread deployment of VLS-PV in China could help break down the natural conservatism of the energy industry in other parts of the world. Such success would not only help stabilize its own economy, but would do likewise for the economies of all countries that would follow suite, because solar energy is a commodity that comes at an unfluctuating price. It would thus be a major business success for China to be able to play such role.

The only question that remains is whether the world will take the CO_2 threat sufficiently seriously to initiate VLS-PV on the scale at which it needs to be implemented, viz, hundreds of GWp of new systems every year. However, with China forging ahead, it is hard to believe that the rest of the world could close its eyes to the manifest advantage of introducing VLS-PV on a scale that could obviate the need for ever building another fossil-burning power plant.

6.2 Development of VLS-PV systems in the West Africa

6.2.1 Situation in the West Africa

(1) Sub-Saharan overview

The first striking number when looking at the situation in Sub Saharan Africa is the proportion of the number of people without access to electricity: out of around 940 million people living in Sub Saharan Africa, more than 620 million do not have access to electricity (Fig. 6.2-1). Nearly 80 % of these people are in rural areas.

Although the continent shows some disparities, with in particular the case of South Africa and Nigeria – each of them for different raisons[a] - when it comes to access to electricity and the development of the power sector almost all countries face the same difficulties that prevent their population to have access to modern equipment relative to health or daily life tools, such as cooking equipment, and prevent their economies to grow. When connected to the grid, the consumers have to pay electricity prices which are among the highest of the world. And the reliability of the grid is so low that in some countries, even in the capital, the disconnection can last several hours per day (Fig 6.2-2).

Despite the fact that the Sub Saharan economies are growing at a very fast rate (over 6 % on average over the past decade), with 6 of the ten's highest GDP growth rate country being in Sub Saharan Africa, the size of the economies remain small, with an overall economic output below the one of Germany. The electricity consumption per capita is at a very low level, just above 300 kWh/y, and it corresponds to only 20 % of that of Europe and 7 % of that of the US. The economies still rely heavily on agriculture (around 20 % of the regional GDP) and the industry (30 % of the GDP), while the service sector accounts for around 50 % of the regional GDP. The agricultural sector in Africa still remains archaic and therefore employs more than 60 % of the active population.

One of the biggest challenges sub-Saharan Africa has to face is its demographic growth, with a population which has more than triple since 2000, while only 37 % are leaving today in urban areas. Although it has represented an opportunity, the growing urbanization of this population and offering

[a] Nigeria is one of most important Oil &Gas producer in the World while South Africa is by far the most developed economy of sub Saharan Africa

to the new generation an acceptable economic and social environment is a key objective of the governments which requires tremendous investment especially in the infrastructure (waste management, energy, health). Needless to say that the development of the power sector is a major factor of success of the management of this strong demographic growth, and this is no surprise if, as the sub-Saharan region is energy poor, you will find most of the countries in the region belonging to the least develop countries in the world. As shown in Fig. 6.2-3[14), the relation between HDI (Human Development Index) and access to electricity is in line with the historical elasticity between the GDP growth and the energy consumption, which was for example equals to 1 during the economic growth of OECD countries during the 50s and 60s (during this period, 10% of GDP growth required an increase of 10 % of the energy consumption[15)).

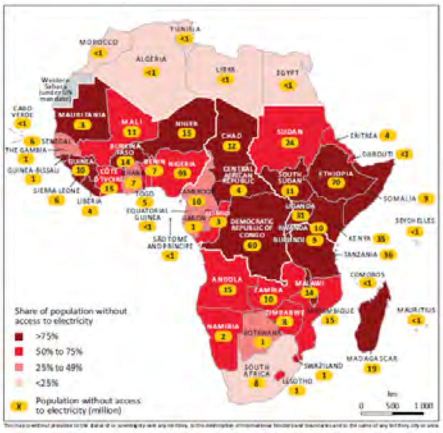

Fig. 6.2-1 Number and share of people without electricity in 2012[13)

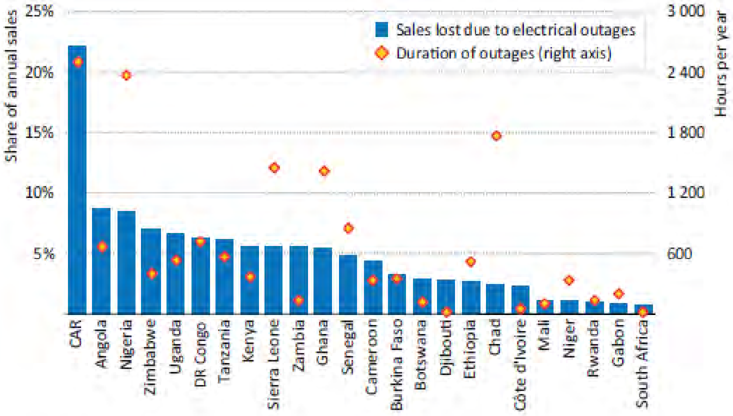

Fig. 6.2-2 Duration of electrical outages and impact on business sales in 2012[13)

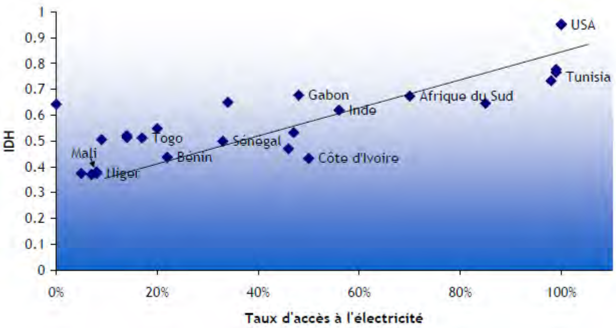

Fig. 6.2-3 Correlation between HDI and access to electricity in 2007[14)

(2) West African overview

The key features outlines for sub Saharan Africa work also for West Africa. The capacity installed in this region is 20 GW and the current energy mix relies essentially on gas fired plants based in Nigeria for half of the regional capacity, the other half being split between Oil (30 %) and Hydro (20 %). The average cost of production is around 140 USD/MWh (see Figs. 6.2-4 and 6.2-5), while the average electricity prices offered by the utilities in the ECOWAS (Economic Community of West African States)(see Fig. 6.2-6) for the mid voltage tariff) are between 141,5 USD/MWh (social tariff) up to 191,5 USD/kWh (semi industrial tariff), leading to strong financial losses and preventing the utilities to grow and make new investment.

The demand is mainly driven by the residential consumption which account for more than 50 % of the demand, in particular for cooking facilities (see Figs. 6.2-7 and 6.2-8), the rest being driven by the industry and service electricity needs, since the agriculture sector in West Africa does not consume electricity. The energy access is between 20 % up to 70 %, while Nigeria still have more than 50 % of its population (around 90 million people) not connected to the grid.

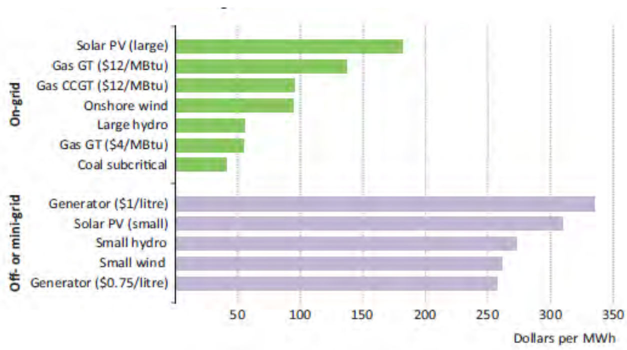

Fig. 6.2-4 Indicative levelised costs of electricity for on-grid and off-grid technologies in sub-Saharan Africa in 2012[13)]

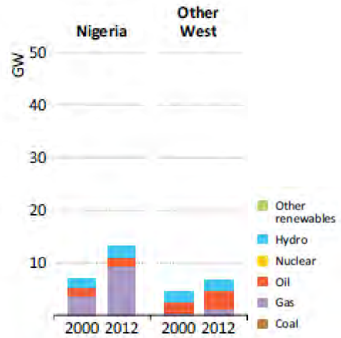

Fig. 6.2-5 Installed grid-based capacity by type in West Africa (2000 vs 2012)[13)]

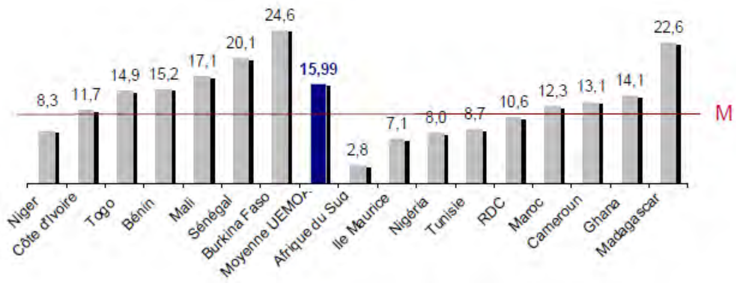

Fig. 6.2-6 Mid voltage prices in Africa in 2007 (M: average)[14)]

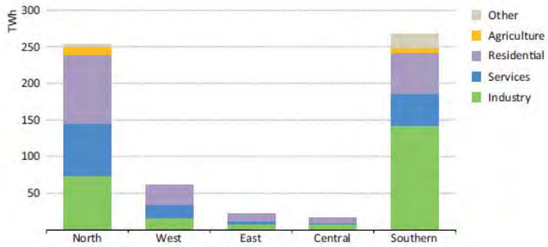

Fig. 6.2-7 Electricity consumption in Africa by end-use sector and sub-region in 2012[13)]

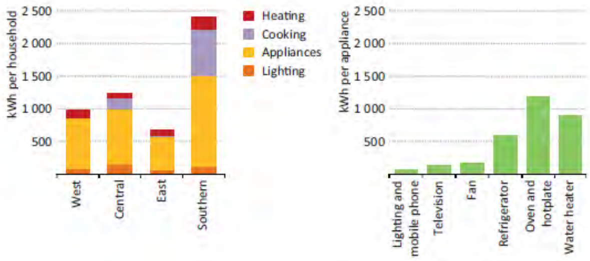

Fig. 6.2-8 Average electricity consumption per household in sub-Saharan Africa, and indicative consumption levels by appliance in 2012[13)]

These high electricity costs stem from a number of parameters, among which are found the poor maintenance of the plants which led to high rate of unavailability, the low efficiency of the technologies chosen, the dilapidation of the production park which is mostly composed of old plants and the transportation losses which are above 20 % on average in West Africa (see Fig. 6.2-9). These additional costs, together with the T&D and distribution investment costs are estimated to be at between 50 and 100 USD/MWh, in addition to the production costs of the plants.

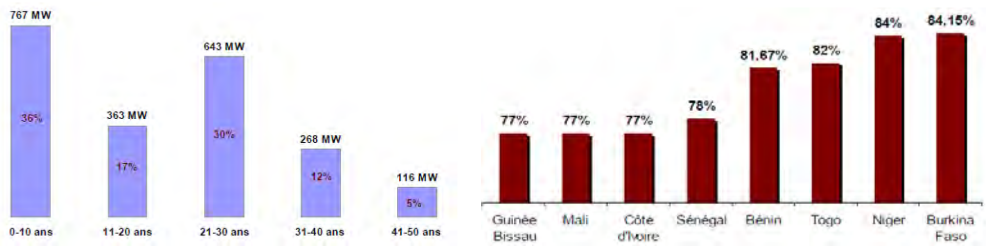

Fig. 6.2-9 Age of the plants connected to the grid in West Africa and efficiency of the grid of selected countries in 2007[14)]

The interconnections are still underdeveloped in West Africa and the quality of the transmission and distribution systems are low, due to poor maintenance and bad design. Not only this situation leads to an increase in the import prices, but it also makes the development of big regional power project difficult, the local markets being too small in many cases to absorb a large capacity, as the case in Benin or Togo. While the key objective is to be able to disseminate the electricity coming from large dams, this absence of strong interconnection lines is one of the key problems to overcome in the next years. Today the large portion of the hydro production is consumed locally and therefore import prices tend to increase since they are linked to either gas plant production (Ivory Coast to neighborhood countries) or Fuel plant (Mauritania to Mali for example, or Togo to Benin). This situation obliges the States to heavily subsidize the Oil & Gas sector, with more than 10 billion injected across sub Saharan Africa (whose 7,5 billion injected by Nigeria and Angola only) in order to regulate the prices, destabilizing the balance of payments of the countries and the benchmark of the power sector which does not rely on the real cost of production of the electricity. Most of the utilities know important deficits, which are amplified by the difficulty in recovering the payments from the consumers (see Fig. 6.2-10).

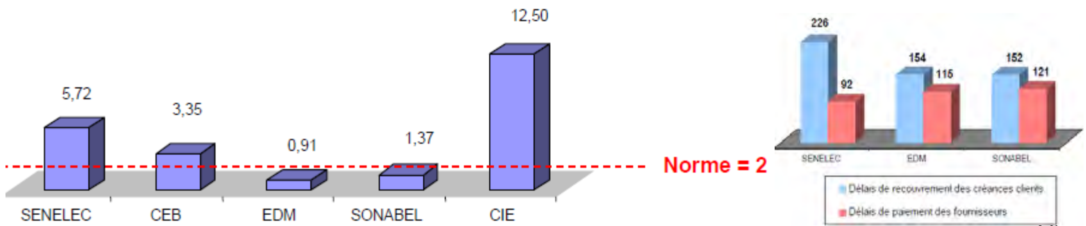

Fig. 6.2-10 Receivables and payables (2007) and debt to equity ratio (2006) of utilities[14)]

Many consumers are using their own generators, increasing their monthly bills by a tremendous factor, since the average cost per kWh of this off grid solutions are above 300 USD/MWh (see Fig. 6.2-11). The land locked countries rely today mainly on fuel and electricity imports, such as Niger, Burkina Faso or Mali. The grid being still poorly interconnected, although tremendous efforts are made to improve this situation with in particular the key role played by the WAPP (West African Power Pool), these countries have to import fuel from the closest port by truck, for distance above 1 000 km most the time using roads in extremely bad shape, leading to higher cost and risk of supply.

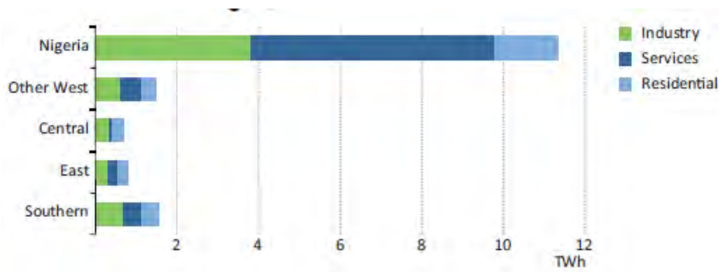

Fig. 6.2-11 Energy demand met by diesel generators[13)]

Given this situation, many countries in West Africa have started to consider the development of large scale PV programs. There is no regional approach today concerning the development of renewable and policies and support mechanism, if any, vary from one country to another. As for example, Mauritania has adopted an EPC approach where the utility own the plant. Mali has tested a hybrid systems of 250 kW with batteries. Senegal tried to manage bilateral negotiations with several promoters without any success. Burkina Faso has successfully close a 22 MW project with a private promoter under a BOOT scheme and is testing at the same time a tendering process with private promoters as well as an EPC approach. Ghana has launched a feed in Tariff system. Nonetheless, it is too early to say that any of these initiatives will lead to a steady development of the renewables in West Africa.

6.2.2 Future scenarios: case for VLS-PV systems

(1) Conventional scenarios – a timid role of solar PV

Four people out ten are expected to live in Africa before the end of the century, and the population of West Africa is expected to double before 2050. The population of Nigeria is expected to double in the next 20 years and to be the fourth most populous country in the world in 2040 (see Figs. 6.2-12 and 6.2-13). This demographic trend is probably the most important driver to take into account when designing the energy policies of the countries, and therefore making forecasting scenario regarding the electricity sector in sub Saharan Africa.

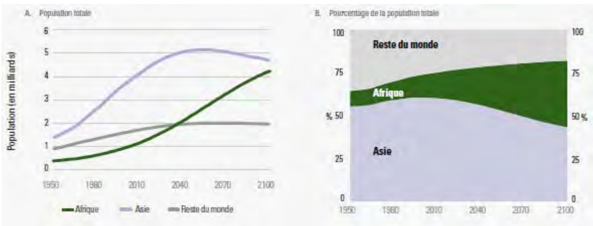

Fig. 6.2-12 Total population per region (1950 – 2100)[16)]

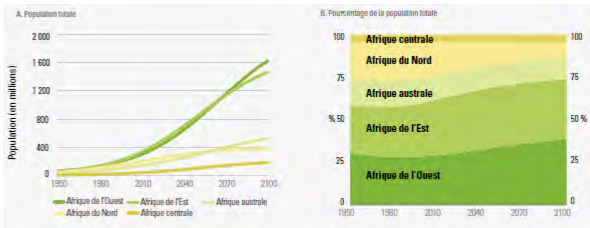

Fig. 6.2-13 Total population in Africa per region (1950-2100)[16)]

The current policies for the development of the power sector in West Africa are mostly based on the gas pipeline between Algeria and Nigeria, on the development of the huge hydro potential of Inga in Republic Democratic of Congo and the interconnection of the West African Pool and the Central African Pool to export the hydro electricity produced in Central Africa towards all countries up to Senegal and the development of the gas and hydro potential in the West African countries which benefit from these resources (see Figs. 6.2-14 and 6.2-15).

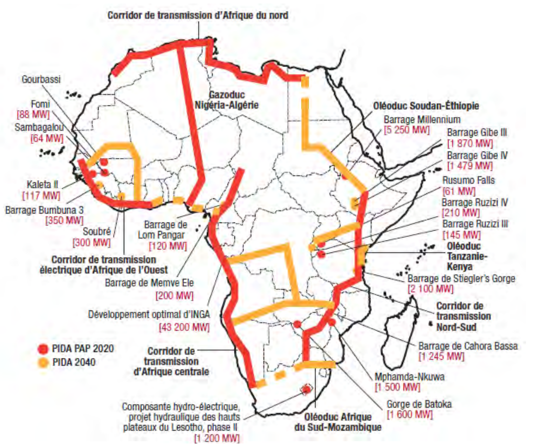

Fig. 6.2-14 Program of energy development in 2020-2014 by PIDA (Programme for Infrastructure Development in Africa)[17)]

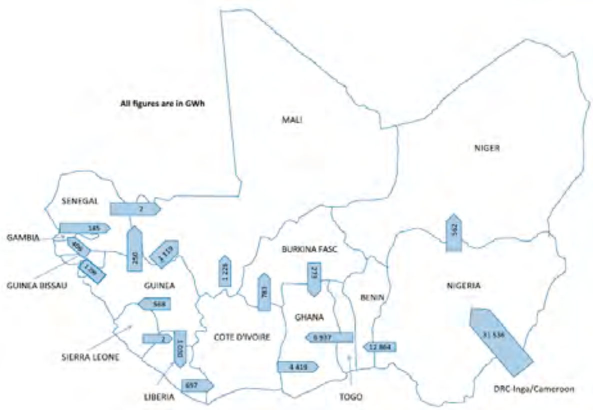

Fig. 6.2-15 Regional Trade in 2030 in the "Renewable Promotion Scenario" of IRENA[18)]

Under these conditions, solar PV plays a little role, although IRENA (International Renewable Energy Agency) has proposed a vision where, under the scenario "No Central Africa Import", which excludes all imports from the Central African Pool, solar PV presents a penetration rate of around 10 % (see Fig. 6.2-16). Same goes with the scenario "New Policies Scenarios" of the IEA (International Energy Agency) for the period 2012 – 2040: les than 3 GW of solar are expected to be installed during this period, which represent 20 % of the renewable capacity to be installed and a penetration rate of around 5 % (see Figs. 6.2-17 and 6.2-18). Even the ECREEE (ECOWAS Centre for Renewable Energy and Energy Efficiency) scenario, by far the most optimistic concerning the development of the renewables in the next years, proposes a vision where solar account for 14 % only of the total renewable capacity in 2030, which represents around 1GW of capacity (see 6.2-19).

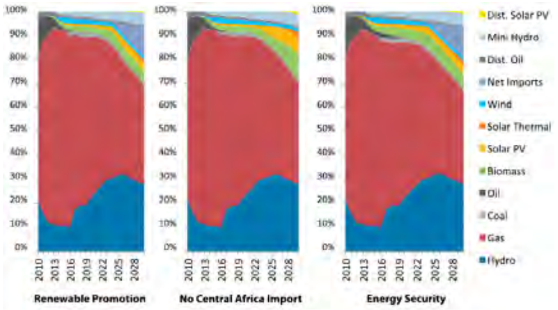

Fig. 6.2-16 Electricity Supply Shares under Three Alternative Scenarios[18]

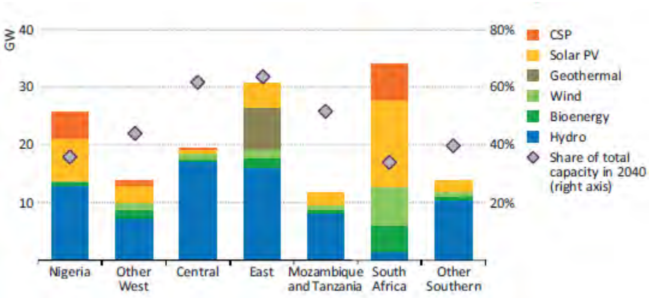

Fig. 6.2-17 Increase in renewables-based capacity by sub-region and type in sub-Saharan Africa in the New Policies Scenario of the IEA, 2012-2040[13]

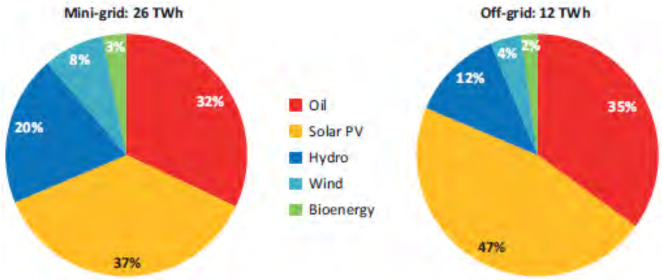

Fig. 6.2-18 Technology mix for mini-grid and off-grid power generation in sub-Saharan Africa in the New Policies Scenario, 2040[13]

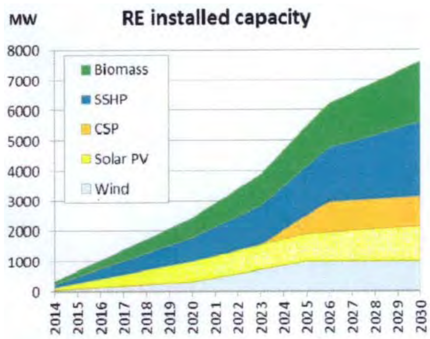

Fig. 6.2-19 RE installed capacity 2014 – 2040 (projections)[19]

Thus solar PV does not play a leading role in the development of the grid connected capacity, whatever the scenario is considered. In all scenarios solar PV remains the technology of choice only for off-grid applications, which tend to be less critical as the transmission and distribution systems evolve. However, VLS-PV systems benefit from several key advantages which should put this technology at the top of the agenda, since PV plants are easy to construct and maintain, they do not rely on inputs beside the sun to function and they can be rapidly deployed at specific points in the grid, where it matters the most and in therefore limiting transportation losses and congestion of the lines. All the same, there are some issues regarding the massive use of gas in Africa, such as CO_2 emissions and volatility of international prices leading to fluctuation of the opportunity costs. All the same, the massive development of hydro systems may, in some cases, lead to strong environmental impacts and makes the energy production dependent on water flows whose fluctuations may increase in the next years due to global warming, global warming that will not really disappear if our economies still continue to rely on carbonic solutions. What's more, the development of hydro and gas plants are far more complex than solar to structure: development costs are higher and the legal and financing structures of the projects are more complex.

To explain this secondary (although important) role, the main raison identified is economic. Compared with a LCOE of 80 USD/MWh for small hydro or between 90 and 110 USD/MWh for combined cycle gas turbine, the PV LCOE, set at between 95 USD/MWh and 150 EUR/MWh, appear to be a high cost which largely compensate its advantages (see Fig. 6.2-20 and Table 6.2-1).

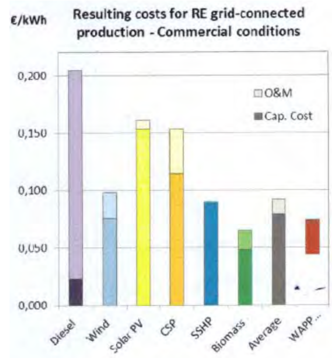

Fig. 6.2-20 Costs for RE grid-connected production (commercial conditions) – assumptions from ECOWAS (Economic Community of West African States)[19]

Table 6.2-1 LCOE: assumptions from IRENA[20]

LCOE (USD/MWh)	Generation		Industry		Urban		Rural	
	2010	2030	2010	2030	2010	2030	2010	2030
Diesel centralised	291	339	328	376	433	440	516	557
Dist. diesel 100 kW	320	371	320	371				
Dist. diesel/gasoline 1 kW	604	740			604	740	604	740
HFO	188	216	217	245	298	299	369	389
OCGT (domestic gas)	141	161	167	187	236	235	301	315
CCGT (imported gas/LNG)	111	126	134	150	196	195	258	269
CCGT (domestic gas)	90	102	112	124	168	167	229	236
Supercritical coal	101	106	124	127	183	172	244	241
Supercritical domestic coal	81	93	102	114	157	157	216	224
Hydro	62	62	82	81	132	122	189	183
Small hydro	107	89					107	89
Biomass	104	86	127	107	187	149	249	215
Bulk wind (20% capacity factor)	149	117	176	139	247	184	314	256
Bulk wind (30% capacity factor)	102	81	125	101	185	143	246	208
Solar PV (utility)	121	84	145	104	209	146	272	212
Solar PV 1 kW (rooftop)	143	96			143	96	143	96
PV with battery (1 hour storage)	250	151			250	151	250	151
PV with battery (2 hour storage)	323	192			323	192	323	192
CSP no storage	147	102	173	123	244	167	311	236
CSP with storage	177	116	205	139	282	184	352	255
CSP with gas co-firing	106	115	129	137	189	182	251	253

(2) The case for VLS PV system – exploratory considerations

When considering the "New Policies Scenario" of the World Energy Outlook, we can see that the region will still be energy poor in 2040 and that many of the key challenges are yet to be overcome. Energy use per capita remains far below the average of the rest of the world and the GDP per capita is still 1/4 of the average of the rest of the world. Another reserve is the assumptions regarding the LCOE of solar energy. Indeed, looking at for example the Renewable Energy IPP Procurement (REIPPP) Program in South Africa, the average PPA price of the third round in 2013 has already reached the level of 100 USD/MWh (see Table 6.2-2), a level which is either never reach before 2040 or barely reached in 2030 depending on the scenario considered.

It is therefore important to acknowledge the following facts:

- The solar PV technology is still at its beginning and is evolving at a tremendous rate. New material are used for solar panels, efficiency rises every year, BOP improved as the capacity grow, etc. It is therefore extremely difficult to forecast the solar LCOE in 2040, but it doesn't seem impossible to use scenarios where it fells down at few US cents per kWh.

- A national RE program properly managed leads to a drastic decrease of the production costs and generate huge positive externalities, such as employment, local content and the attraction of international banks and investors (see Tables 6.2-2 and 6.2-3, and Fig. 6.2-21).

Table 6.2-2 Summarized results for REIPPP program Windows 1, 2 and 3 – Economic Data[21)]

	Wind	PV
WINDOW 1		
Capacity offered (MW)	1850	1450
Capacity awarded (MW)	634	631.5
Projects awarded	8	18
Average tariff (SAc/kWh)	114	276
Average tariff (USc/kWh) ZAR8/$	14.3	34.5
Total investment (ZAR mill)	13312	23115
Total investment (USD mill) ZAR8/$	1664	2889
WINDOW 2		
Capacity offered (MW)	650	450
Capacity awarded (MW)	562.5	417.1
Projects awarded	7	9
Average tariff (SAc/kWh)	90	165
Average tariff (USc/kWh) ZAR7.94/$	11.3	20.8
Total investment (ZAR mill)	10897	12048
Total investment (USD mill) ZAR7.94/$	1372	1517
WINDOW 3		
Capacity offered (MW)	654	401
Capacity awarded (MW)	787	435
Projects awarded	7	6
Average tariff (SAc/kWh)	74	99
Average tariff (USc/kWh) ZAR9.86/R	7.5	10
Total investment (ZAR mill)	16969	8145
Total investment (USD mill) ZAR9.86/R	1721	826

Table 6.2-3 Summarized results for REIPPP program Windows 1, 2 and 3 – Local Content[21)]

Technology	Round 1	Round 2	Round 3
Solar PV			
Local content %	38.4	53.4	53.8
Local construction jobs	2381	2270	2119
Local operations jobs	6117	3809	7513
Wind energy			
Local content %	27.4	48.1	46.9
Local construction jobs	1810	1787	2612
Local operations jobs	2461	2238	8506
Concentrated solar power			
Local content %	34.6	43.8	44.3
Local construction jobs	1883	1164	3082
Local operations jobs	1382	1180	1730

Fig. 6.2-21 Share of debt financing in REIPPP program: Rounds 1, 2 & 3[21)]

It is therefore worth exploring a scenario based on the development of VLS-PV systems across West Africa. This scenario would rely on a specific development of the power infrastructures at regional and national levels (see Fig. 6.2-22, for the regional potential of renewable energy in West Africa), since a high penetration rate of intermittent technology puts at risk the balance of the grid, increasing the risks of black out. It requires also to pay attention to the relationship between solar and the other technologies. Indeed, in this scenario gas fired plants and hydro plants would also have the role of back-up systems during day time, and therefore a portion of their capacity would be used to support the development of solar, which will impact the average kWh price. The relevancy of such scenario would be assessed not only by calculating the resulting kWh price but also by assessing the growth of the region in terms of GDP per capita and employment (see Table 6.2-4). Indeed, the solar sector is by far the sector sectors which produces the biggest number of jobs. Although it would be necessary to determine which are the segments where Africa can have a competitive advantage, it is clear that various segments have a strong local content, such as environmental studies, yield assessment, construction, maintenance and operation.

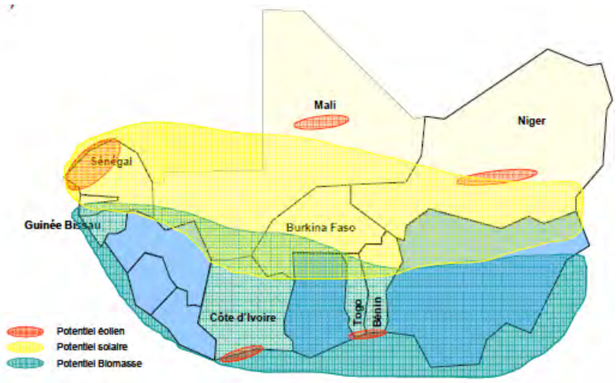

Fig. 6.2-22 Renewable energy potential in West Africa[14)]

Table 6.2-4 Job creation and income per MW installed for different technologies in the energy sector[22)]

Direct workforce income attributable to a single average-sized plant of given generation technology

Technology	Jobs/ MWe	Average Size (MWe)	Direct Local Jobs	Average Salary ($/hour)	Workforce Income ($/year)
Nuclear	0.5038	1,000	504	$31	$32,485,024
Coal	0.1866	1,000	187	$28	$10,987,904
Hydro > 500 MW	0.1137	1,375	156	$33	$10,792,791
Hydro Pumped Storage	0.0954	890	85	$38	$6,696,842
Hydro > 20 MW	0.19	450	86	$33	$5,790,470
CSP	0.47	100	47	$27	$2,618,990
Combined Cycle	0.0544	630	34	$28	$2,018,100
PV	1.06	10	11	$15	$334,468
Micro Hydro < 20 MW	0.45	10	5	$35	$326,196
Wind	0.049	75	4	$35	$291,200

6.2.3 Deployment of VLS PV systems: institutional and financial challenges

(1) Institutional challenges

The first challenge to overcome concerning the development of VLS PV systems is the implementation of an appropriate institutional environment that will enforce the strategic vision of an energy mix with a high penetration rate of PV. The fact that almost none of the recent Energy Master Plan in West Africa includes solar technologies as a viable option, when many West Africa countries have lauchned ambitious solar programs, is an important signal of the lack of coherency in the management of the energy sector, both at regional and national level. As an example, we can mention the case of Senegal, where the recommended energy mix in the Master Plan does not include solar whereas close to 200 MW of PPA were signed in 2013 based on the solar PV technology, representing 10 % of the total capacity to be installed before 2030 (see Table 6.2-5).

Table 6.2-25 Investment program – Least cost option of the Energy Master Plan of Senegal (2010 – 2030)[23)]

Année	Demande de pointe (MW)	Addition								Puissance installée (MW)	Réserve totale (%)	Puissance nette à la pointe (MW)	Réserve nette à la pointe (%)	LOLP (h/an)	Investissements	
		Type et taille des unités (MW)							Sous-total (MW)							
		STCO	GTG	Biomasse	Vent	Hydro	Diesel	CCG							M$US	MFCFA
2010	442									511	16%	511	16%	193	0	0
2011	480		110				1x50		160	671	40%	671	40%	62	120	56,224
2012	528									671	27%	671	27%	65	80	37,483
2013	542			1x30	125	15		3x50	320	941	74%	816	51%	42	68	31,771
2014	557	1x125							125	1,048	88%	923	66%	7	170	79,472
2015	629				50	96+42			188	1,180	88%	1,005	60%	64	158	74,162
2016	724	1x125	1x32			50			207	1,337	85%	1,162	61%	58	166	77,553
2017	761	1x125							125	1,404	85%	1,229	62%	43	121	56,759
2018	801							2x50	100	1,504	88%	1,329	66%	15	102	47,701
2019	844								0	1,474	75%	1,299	54%	52	57	26,505
2020	891	1x125							125	1,599	79%	1,424	60%	20	0	0
2021	944								0	1,599	69%	1,424	51%	49	68	31,771
2022	996		3x32						96	1,677	68%	1,502	51%	31	189	88,396
2023	1,051								0	1,677	60%	1,502	43%	71	137	63,988
2024	1,110	1x125							125	1,802	62%	1,627	47%	35	121	56,759
2025	1,172							2x50	100	1,902	62%	1,727	47%	19	102	47,701
2026	1,246								0	1,902	53%	1,727	39%	58	125	58,276
2027	1,315	1x125							125	2,027	54%	1,852	41%	33	102	47,701
2028	1,390		2x32						64	2,061	48%	1,886	36%	58	115	53,636
2029	1,469	1x125							125	2,186	49%	2,011	37%	39	0	0
2030	1,552		2x32						64	2,250	45%	2,075	34%	50	58	27,130
									2,049						2,058	962,988

Many detailed studies are first required in order to set realistic objectives concerning the capacity to be installed, their location and the adequate grid infrastructures. These objectives should take into account, as measurement of the efficiency of any energy policy, their impacts on GDP growth, job creation and on the development of all sectors of the economy (agriculture, service and industry). Indeed, the kWh price, which is today the main driver of the energy policies in West Africa, may not be the only factor policy makers should take into account when considering.

Once these studies are done and properly analyzed, their transformation into a political agenda with clear quantity and quality figures is one of the key factors of success, together with a monitoring tool to assess their performance. West Africa already presents adequate institutional bodies at the regional level, represented by ECOWAS and ECREEE (see Fig. 6.2-23), but they still lack the capacity to generate the necessary commitments at the national levels. Indeed, West Africa still lacks experience in the promotion of IPP projects and there is a strong need in the region to upgrade the capacity of the government to design an appropriate regulation framework, manage the design of the national energy master plan and put in place the overall public guarantee framework necessary to attract both public and private investments.

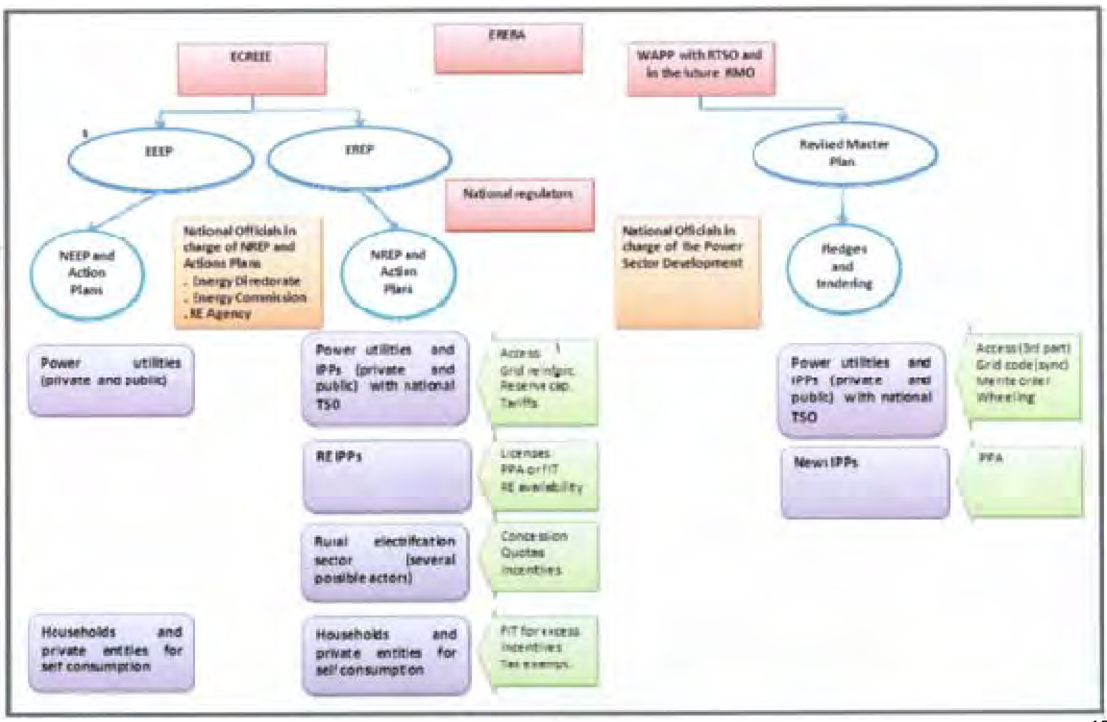

Fig. 6.2-23 Organization chart for the development of the ECOWAS Renewable Energy Policy[19)]

(2) Financial challenges

Whatever the energy mix scenario prescribed, the investments in the power sector required for the next 30 years are tremendous, in the order of several billion per years, half of it being in the transmission system and the other half in the production system. The challenges that it represents can be highlighted by the historical data: between 1995 and 2005, only 1 billion USD were invested by private sources in the power sector in West Africa. Several years even show no private investment at all (see Fig. 6.2-24).

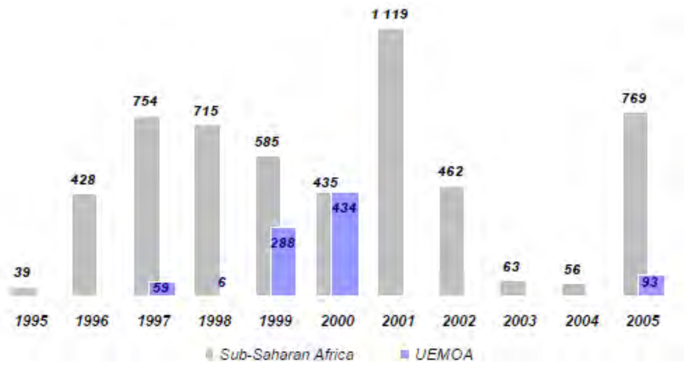

Fig. 6.2-24 Private investment in the West African energy sector (1995 – 2005) – 1 000 USD[14)]

The requirements to attract the necessary private and public investments in West Africa are far to being in place, and in any case the level of the institutional reforms and of local expertise required to do so is at a level which not be fully comprehended today. In particular, such level of investments will require both a strong international guarantee system, such as a PRI mechanism and strong national and regional guarantee systems, in place, which today does not really exist. In this respect, the example of Nigeria (see Fig. 6.2-25) and South Africa (see Fig. 6.2-26) could be interesting examples to be studied, although the Nigerian case may need to be improved in the next years in order to be able to perform as expected – Nigeria itself requires an average investment of 10 billion USD per year to reach a targeted capacity of 77 GW in 2040.

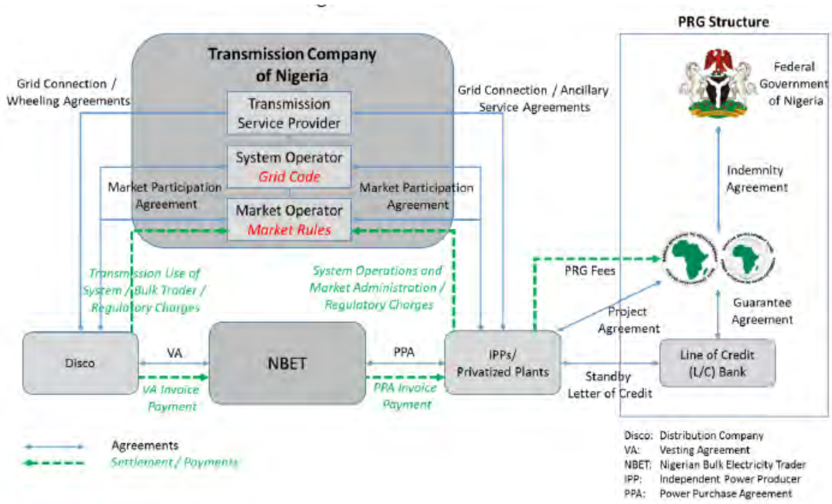

Fig. 6.2-25 Partial Risk Guarantee Framework in Nigeria proposed by the African Development Fund[24)]

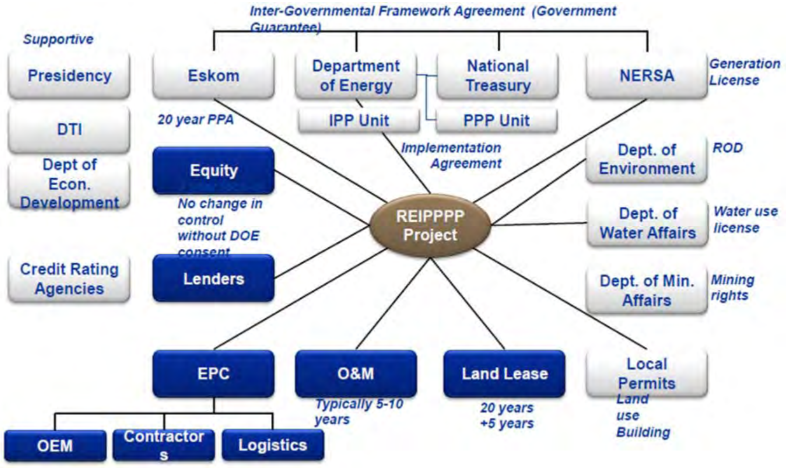

Fig. 6.2-26 Overview of the REIPPP (Renewable Energy IPP Procurement)[25)]

6.2.3 Conclusion: Role of DFIs and International Institutions

Whereas VLS PV systems may be a viable energy option for West Africa, there is no study study available today to demonstrate it. The current scenarios rely mostly on a conventional approach where the solar sector does not play a major role. However, these scenarios show that West Africa, despite its strong annual forecasted growth of more than 6 % per year – the highest of all other regions of sub Saharan Africa – remains poor both at energy and economic levels. It is therefore worth trying to bring new energy and development approaches. The lives of hundred millions of people is at stake, and time is passing at a tremendous speed given the demographic growth of this region, among the highest of the planet.

In order to raise the required financing to support the growth of the energy sector in West Africa, a strong implication of the Development Institutions is necessary. Whereas today most of them have their own agenda, a coordination and a coherency of their actions would have a major impact on the results of their policies. In this respect, our recommendations would be to start with the following actions:

- Set up a task force of experts from both the private and the public sectors, that cover the whole range of expertise required to implement an efficient energy strategy
- Launch a regional study managed by this task force to identify innovative scenarios, where VLS PV should be considered. The study would cover all matters related to technical (production, transportation, distribution, grid design, etc.), legal, insurance, social, economic, macro-economic, commercial and environmental issues.
- Train the regional institutions and the national bodies in managing IPP programs
- Disseminate the vision elaborated by the task force among the countries using ECREEE
- Design financing schemes able to absorb the huge investments required in the next years
- Design a coherent strategy adopted by all the DFIs in line with the vision of the task force

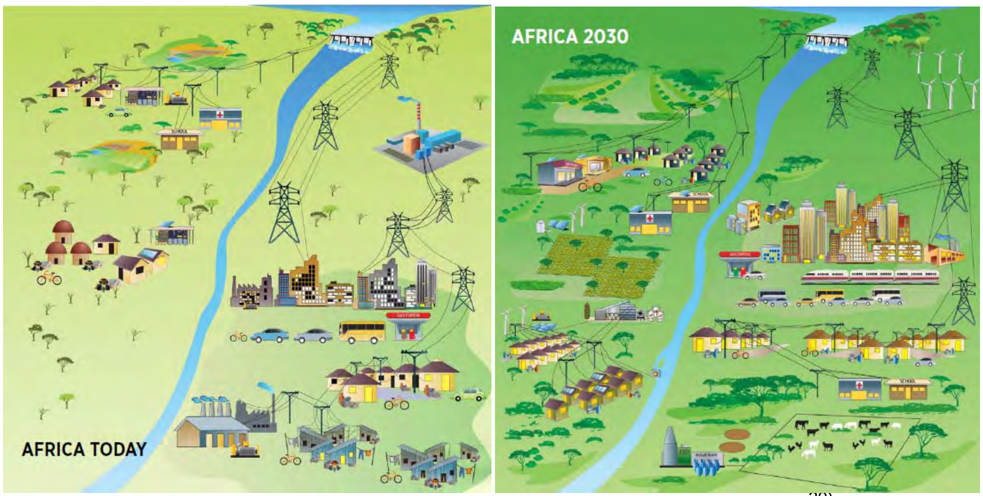

Fig. 6.2-27 Representation of Africa in 2014 and in 2030[20)]

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Chapter 7 Concept of VLS-PV Supergrid in the Northeast Asia

7.1 Introduction

The protection of global climate and conservation of the valuable resources and achieving sustainable global development-these are the key challenges that world is facing today. As a demand for energy is increasing rapidly, the many countries of the world faces not only energy security challenges, but also faces serious environmental problems such as global warming and depletion of traditional fossil fuels. One of the principal solutions to overcome these problems is to increase significantly the share of renewable energy among total primary energy supply of the world. Fortunately, the increased use of renewable energy can solve not only the problem of increasing demand of energy supply, but also can address environmental protection through reducing CO_2 emissions and the exhaustion of finite fossil fuel reserves[1)].

Theoretically, it can be considered that an energy system is sustainable for long term period if more than 2/3 of the energy demand covered by renewable energy sources[1)]. Therefore, it is expected that renewable energy will play dominating part of the future energy supply. Renewable energy sources are, by definition, inexhaustible. However, some renewable energy sources may fluctuate dramatically over the different time periods. For some of the renewable energy sources, the fluctuations are quite predictable but for others such as solar and wind power sources the fluctuations are non-controllable and non-predictable since it is difficult to predict their intensities. In the other hand, apart from biomass and hydropower, renewable energy sources are not possible to be stored naturally. Therefore in order to avoid intermittency of solar and wind power sources, artificial energy stores have to be made as required.

The variability of the power generation caused by the use of renewable energy sources such as solar and wind power systems are going to be bigger challenges as the contribution of renewables to transmission grid rises to a substantial level. One of the most efficient ways to overcome these challenges is an integration of renewable energy power sources into high capacity transmission grid called “Supergrid”. The supergrid can be defined as a system of high capacity transmission grid designed to transfer large amounts of electricity over the long distances. The High Voltage Direct Current (HVDC) transmission is now becoming a key technology to transfer massive amounts of energy over long distances while integrating an increasing amount of renewable energy into the regional energy system.

7.2 Renewable energy development and HVDC supergrid technology

Global wind and solar energy capacity has tripled since 2009, and renewable energy now provides more than one-fifth of the world’s electricity supply[2)]. Renewable energy has added about half of the world’s new generating capacity each year since 2008 and every second megawatt of new electricity that is added globally is renewable energy, implying that the share of renewable energy could reach 50 % in 2030. According to the Ecofys scenario, fossil fuels, nuclear power and traditional biomass are almost entirely phased out by 2050[2)]. The renewable energy technologies are available and economically feasible already and with millions of people lacking access to reliable power, the emergence of renewable sources is a lifesaver. Currently, many countries of the world have set the ambitious targets to increase the share of renewable energies in the total energy mix by 2020, 2030 and 2050.

There are large number of studies have been carried out on investigating the possibilities to achieve a higher share of renewables in the total energy supply mix[2-10)]. These studies clearly show that renewable energy will play more dominant role in electricity supply in the future. These investigations also have demonstrated that the main barriers to the large scale deployment of renewable energy supply are not technological or economical issue, but rather are more social and political issue. In terms of technological solution, the key preconditions to achieve the above listed ambitious targets of increasing significantly the share of renewable energies in the total energy supply are to have high capacity transmission grid to facilitate an efficient integration of large scale renewable energy sources in the current system and renewal of the existing transmission system to reliably satisfy the increasing energy demand.

Modern electricity transmission grids commonly use alternating current (AC) to transport energy from large, centralized power plants (mainly by coal, oil, gas, and nuclear power plants) to the load centers. However existing AC grids are not adequate to efficiently transport high capacity electricity over long distances and not powerful enough to handle the transmission of the high capacity electricity generated at the level of Megawatt and Gigawatt scale[1,11-13)]. In other words, if the higher value of AC is to be transferred over longer distances, more reactive power is required for that transmission. A key solution to handle the reactive power issue is the use of direct current (DC) transmission line where large amount of energy need to be transferred over long distances. In addition, transmission loss of the AC system is one of the major concerns when transferring large amount of electricity over long distances[1,11-13)]. For this principal reason alone, HVDC transmission is now becoming a key technology to transfer massive amounts of energy over long distances. The fundamental process that has been used in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting point and from DC to AC (inverter) at the receiving end.

HVDC is a proven technology which efficiently transfers electricity from production centers to large industrial regions. HVDC transmission has typically 30-50 % less transmission loss when compared to AC overhead lines (for comparison: given 2 500 MW transmitted power on 800 km of overhead line, the loss of a conventional 400kV AC line is 9,4 % whereas with HVDC transmission line at 500 kV, it is only 6 %, and at 800 kV, it is just 2,6 %)[14)]. Over distance of about 600 km or more, overhead lines using HVDC transmission technology are more cost-effective than AC technology[1,11-13)]. HVDC transmission link using submarine cable, at 600 kV and 2 200 MW, there will be an energy loss of less than 3% of the total electricity (including cable and converter losses [14)].

Recent advances in DC transmission technology made possible to transmit DC at higher voltages, especially voltages above 600 kV. The use of Ultra High Voltage Direct Current (UHVDC), the voltage above 600 kV, has been found to be economically attractive for power blocks up to 6 000 MW over distances above 1 000 km[13-14)]. Currently, a long distance 800kV UHVDC line loses just 3,5 % per 1 000 km and is capable to transmit several gigawatt of power[15)]. At transmission capacity of 5000 MW, UHVDC transmission losses are as low as around 2 % per 1 000 km, plus less than 1,5 % loss per converter stations at the sending and receiving end of the transmission line[16-17)]. The main disadvantage of the UHVDC is complexity of the transmission system and necessity for the converter stations that are quite costly at present. Because of its stability and low losses, HVDC supergrids could balance out the natural fluctuations in renewable energy in a way that AC never could. Therefore, further development of HVDC supergrids can dramatically reduce the need for the constant base-load power of large coal or nuclear power plants.

Currently, a supergrid is becoming as the indispensable platform to enable high penetration of renewable energy sources practically and it also enables sharing of all other energy sources as well. A supergrid not only enables wide range of all energy sources but also reduces the total generation capacity needed to fulfill energy needs.

Currently, the HVDC long distance supergrids are used mainly for integrating local grids into national network. The need for reliable interconnections among neighboring networks is boosting the development of HVDC supergrid transmission. The development of renewable energy sources, especially development of Very Large Scale Solar Power Systems (VLS-PV) and **o**ffshore wind farms has meant an increasing demand for the HVDC supergrid[18)].

The experts are predicting that potential role of HVDC as an important basis for establishing of the international trans-national supergrids[11-13)].

There are, currently, the number of cross-border transmission links is in operation in Europe, North America, Southeast Asia and Africa[19-20)]. The existing electricity exchange through grid interconnection routes has been developed mainly for the improvement of energy system security in emergency situations. There are many initiatives on the development of local and regional supergrids in Europe, Asia and other parts of the world in order to meet the increasing need to transfer large amount of renewable energy over long distances from a place where there is an surplus to places where there are shortages[10-12,19-21)].

7.3 Overview of the HVDC supergrid development around the world

The first commercial HVDC transmission system was linked the Swedish mainland to the Island of Gotland in the mid-1950s[22)]. Since introduction the first commercial HVDC transmission line in 1954, a large number of HVDC transmission systems have been built. Table 7.3-1 shows the overview of the HVDC systems implemented in the past around the world[23)].

At present, there is continues a dramatic expansion of HVDC projects all over the world. According to Navigant Research, all announced projects that is to be in built between now and 2020 are actually end up being built, the cumulative capital required for HVDC systems is around 217 billion USD[24-25)]. Table 7.3-2 shows the overview of the HVDC systems planned for commissioning around the world between 2012 and 2020 by region.

In the last 40 years, HVDC transmission links with a total capacity of over 100 GW were installed. Another 250 GW will be added in this decade alone[11)].

In 1992, a Swedish company named ABB has developed a vision of an HVDC supergrid first time. Their vision could enable Europe to be supplied solely by renewable energy consisting of hydropower in the north, wind power in the Atlantic coast and solar in the south part of the Europe[26)].

Table 7.3-1 List of HVDC projects[23)]

Name	Country	Cable (km)	OHL (km)	Volt (kV)	Power (MW)	Year	Supplier
Hellsjon-Grangesberg	Sweden	0,2	10	±10	3	1997	ABB. The first HVDC VSC pilot system in the world
Gotland Visby-Nas	Sweden	70		±80	70	1999	ABB. The first HVDC VSC commercial system in the world
Terranora (Directlink)	Australia	65		±80	180	2000	ABB. Land cable
Eagle Pass, Texas B2B	USA			±16	36	2000	ABB.
Tjffireborg	Denmark	4,4		±9	7	2000	ABB. Interconnection to wind generating stations
Cross Sound Cable	USA	40		±150	330	2002	ABB. Buried underwater cable
Murraylink	Australia	180		±150	220	2002	ABB. Underground XLPE cable
HVDC Troll 1-2	Norway	67		±60	2x41	2005	ABB. The world's first offshore platform HVDC
Estlink	Estonia - Finland	105		±150	350	2006	ABB.
BORWIN 1	Germany	203		±150	400	2009	ABB.
Valhall	Norway	292		150	78	2010	ABB.
Trans Bay Cable	USA	85		±200	400	2010	Siemens & Pirelli; Siemens first VSC installation.
Caprivi Link	Namibia		950	350	300	2010	ABB. The first commercial HVDC VSC OHL
East West Interconnector	Ireland – UK	250		±200	500	2012	ABB.
BorWin2	Germany	200		±300	800	2013	Siemens.
DolWin1	Germany	165		±320	800	2013	ABB.
HelWin1	Germany	130		±250	576	2013	Siemens.
Dalian City Infeed	China	43		±320	1000	2013	CEPRI
SylWin1	Germany	205		±320	864	2014	Siemens.
Skagerak 4	Norway - Denmark	240		500	700	2014	ABB. The first 500 kV IGBT
Mackinac B2B	USA			±71	200	2014	ABB.
SydVastlanken	Sweden	200	80	±300	2x720	2014	Alstom Grid (VSC) ABB Cable
INELFE France - Spain	France - Baixas	60		±320	2x1000	2014	Siemens
Troll 3&4	Norway	67		±60	2x50	2015	ABB.
DolWin2	Germany	135		±320	900	2015	ABB
NordBalt	Sweden - Lithuania	450		±300	700	2015	ABB.
Aland	Finland-Aland	150		±80	100	2015	ABB
HelWin2	Germany	130		±320	690	2015	Siemens.
Zhoushan Multi-terminal	China	134		±200	400	-	CEPRI 400/300/100/100/100
DolWin3	Germany	162		±320	900	2017	Alstom Grid

Table 7.3-2 HVDC systems planned for commissioning for period 2012-2020[24-25)]

Region	Number	Lengths DC lines (km)	Total capacity (MW)
North America	29	26 992	75 150
Europe	23	5 772	20 220
China & India	33	60 561	266 700
Rest of World	12	25 120	37 110
Total	97	118 445	399 180

As it was stated earlier, a number of HVDC transmission links has been increasing rapidly every year. There are already in operation several HVDC transmission lines in Europe, Asia, North America, South America, Australia, and Africa, but the vast majority of new construction is now occurring in Europe, North America, and Asia (India and China)[25)]. In Europe and North America, demand for construction of the HVDC transmission is driven by renewable energy integration, while in China the demand is driven by a rapidly expanding power generation sector all over the country[25)]. Currently, HVDC was emerged as the preferred transmission technology over long-distance bulk power supply. The world's five longest operational HVDC transmission lines are listed below[14)]:

<Rio Madeira transmission line, Brazil>

The Rio Madeira HVDC transmission line in Brazil with an overhead length of 2 385 km is the world's longest power transmission line. The 600 kV HVDC bipolar line was brought into commercial operation in November 2013. It is capable to transmit 7,1 GW of power.

<Jinping-Sunan transmission line, China>

China's 2 090 km Jinping-Sunan 800 kV UHVDC transmission line is the world's second longest power transmission line. The 7,2 GW transmission line is owned by State Grid Corporation of China (SGCC) and was put into operation in December 2012. The line passes through eight Chinese provinces to transmit power generated from Guandi, Jinping and Sichuan hydroelectric plants located in Yalong River in Sichuan province to the industrialized coastal area of Jiangsu province in eastern China. The project investment amounts approximately 22 billion CNY (3,5 billion USD). ABB supplied the key components of the project, including the 800 kV UHVDC transformers for both converter stations.

<Xiangjiaba-Shanghai transmission line, China>

The Xiangjiaba-Shanghai 1 980 km, ±800 kV UHVDC transmission line (with a rated power of 6400 MW) represents a major breakthrough in the technology of electric power transmission. It has the capacity to transmit up to 7,2 GW. The line is owned by SGCC, and it was the world's first largest-capacity HVDC system when it was completed in July 2010. The operation of the line has started in July 2010. Then it was overtaken by the 7 200 MW Jinping–Sunan HVDC line, which was put into operation in December 2012. The Xiangjiaba-Shanghai line transmits power from the Xiangjiaba hydropower plant located in south-west China to Shanghai which is the country's major industrial and commercial hub.

<Inga-Kolwezi transmission line, Congo>

Congo's 1 700 km-long Inga-Kolwezi HVDC line is 500 kV transmission line with a rated capacity of 560 MW. The Inga-Kolwezi HVDC line carries power from the Inga Falls hydropower station on the Congo River to Katanga in south-eastern Congo. The line has started commercial operation in 1982 and was the longest transmission line in the world at that time. Later in 2009, ABB did refurbishment of the line by replacing some of the key components for the project, including the converter stations supplied by new thyristor valves, new high-voltage apparatus and a new control as well as protection system to enhance the efficiency and reliability.

<Talcher-kolar transmission line, India>

India's 1 450 km Talcher-Kolar HVDC line is one of the world's longest transmission lines. The 500 kV HVDC transmission line has a rated capacity of 2 500 MW. It was the world's second longest transmission line at the time of commissioning in February 2003. The Talcher-kolar HVDC transmission line had the capacity to transmit 2 000 MW of power when it first started operation. But later the line was upgraded to 2 500 MW in 2007. Siemens built the converter stations for the Talcher-kolar HVDC line. Power Grid Corporation of India is also building India's first UHVDC transmission line over the 1 728 km distance. The North-East Agra UHVDC line is capable of transmitting 8 000 MW of power. The project is being delivered by ABB and is scheduled for commissioning in 2015. It will be the longest power transmission line in the country when completed. Integration of renewable energy is also driving HVDC development in India. India is working towards a single national transmission network with a cumulative capacity of about 250 GW, with the southern grid merging with the already synchronized grids of the northern, eastern, western and north-eastern regions grid by early 2014[25).]

In addition to the above stated HVDC transmission lines, China is developing a very sophisticated grid system for number of reasons: its main coal deposits are in the north and its main solar and wind potential are in the west and northwest. A number of HVDC supergrid projects have been completed successfully and many ambitious projects are under development now. The State Grid Corporation of China (SGCC) is a leading transmission company and it has recently pushed for approval of a massive 250 billion USD upgrade plan which connects regional grids via 20 HVDC power corridors by 2020[27)]. By 2015, SGCC is planning to invest 500 billion CNY (75,5 billion USD) to extend the UHVDC grid over 40 000 km. By 2020, the capacity of the UHV network is expected to be some 300-400 GW, which will function as the backbone of the whole grid system. The network will have 400 GW of renewable energy sources connected out of which hydropower will account for 78 GW[28)].

In China, most of renewable energy resources are based mostly in the western, north-western and northern part of the country, which are over 2 000 km away from the main power network load centers in the eastern and central regions. Therefore China has been developing intensively the construction of the UHVDC transmission lines in order to transmit the electricity from the energy-rich western and northern part to the central and eastern regions of the count. Fig. 7.3-1 shows a map of the both HVAC and HVDC transmission supergrids in China which are under operation and to be built in coming years[29-30)].

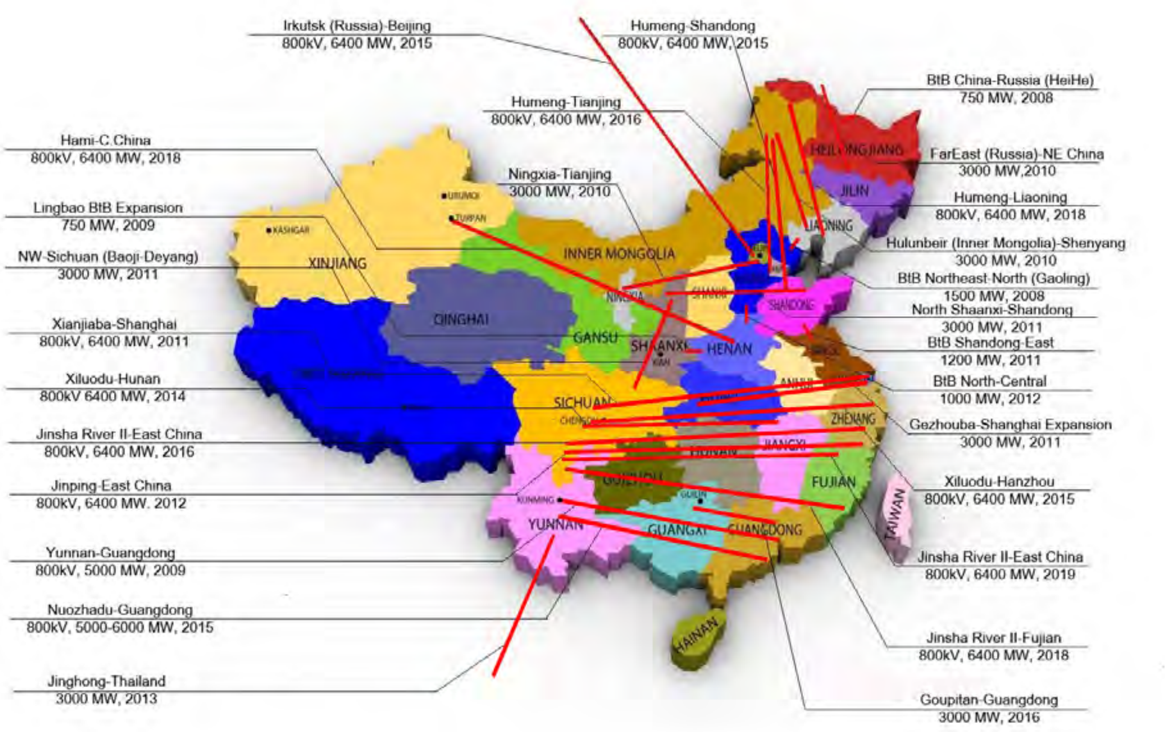

Fig. 7.3-1 China UHVDC Planning Map[31)]

First 800 kV HVDC line is now fully operation in China. Siemens and China Southern Power Grid have put into operation the world record HVDC system, which is capable of transporting huge amounts of hydro power from several hydro power plants in the Yunnan Province to Guangdong Province. The transmission capacity has now been doubled to 5 000 MW[15,16,32)].

Siemens together with its Chinese partners has designed and developed the HVDC system for the Yunnan-Guangdong 800 kV UHVDC transmission line which covers a transmission distance close to 1 500 km[15,16,32)]. A distance of 3 000 km and even more is feasible now with this kind of UHVDC technology[33)]. High-voltage DC transmission lines carry electricity from China's massive Three Gorges dam, the largest power plant in the world[33)].

Recently, in 2014 China began construction on a west-to-east HVDC transmission project to transport about 40 billion kWh per year from the Xiluodu hydropower plant in southwest China 1 700 km to the eastern province of Zhejiang. The project follows SGCC's Xiangjiaba-Shanghai and Jinping-Sunan transmission lines, which were completed in 2010 and 2012 respectively. The three transmission lines combined will have 21,6 GW of capacity[25)].

China is not only constructing the longest HVDC in the world, it is becoming a manufacturing base all kinds of HVDC supergrid system components. China is now biggest HVDC investor due to its favorable Government policy to support both renewable energy and development HVDC transmission network[34)]. SGCC of China is already one of the world largest HVDC grid operators by far, however, there are no projects have yet been built outside China by SGCC. China is setting the world standards, and looking for the opportunities to develop HVDC projects outside China[35)].

In Europe and North America, demand in construction of HVDC transmission supergrid is driven by renewable energy integration, while in China it is also being driven by a rapidly expanding generation sector as whole. The global HVDC market is expected to reach 9,62 billion USD by 2018, and grow at a CAGR of 16,97 % during the next five years (2013-2018)[21)]. The major driving factors for HVDC market are the growth offshore wind farms as well as large scale solar power plants in the areas far from industrial load centers.

From the short review of the existing experiences for the construction long distance HVDC supergrid in the worldwide, it can be concluded that a technology of HVDC supergrid transmission line as well as construction of VLS-PV plants and wind farm are now becoming cost effective, technically proven commercial technology capable to be applied for any regional infrastructure projects such as implementation of the transnational supergrid in Northeast Asia.

7.4 Potential of renewable energy of the Northeast Asia

In Northeast Asia, including Far East Siberia are rich in both fossil fuel and renewable energy sources. Mongolia and northern China, including Inner Mongolia has high level of solar radiation, dry and cooler weather conditions which are ideally suited for Photovoltaic and Concentrated solar power.

Geographically, the Gobi Desert is located in the boundaries of Mongolia and China. Gobi desert area of Mongolia and China has tremendous amounts of renewable resources, especially solar and wind energy. The theoretical potential of solar energy of the Gobi desert is enormous - far beyond what the world could ever require. With today's solar cell efficiencies at 18-23 %, electricity which can be obtained from Gobi desert alone can capture enough solar energy to supply the world’s electricity demand and much more. According to the IEA PVPS Task 8 study 40 % Gobi deserts landmass is suitable for construction of the VLS-PV[18)]

Since 1990, a number of researches have been carried out for studying of renewable energy resources Gobi desert[20,36)]. According to these studies the wind energy potential of Mongolia is about minimum 1,1 TW and solar potential is about 1.5TW. The total potential of renewable energy of Mongolia, including wind, solar, geothermal and hydro resources can be as great as 2,6 TW capacity[21)]. The average wind energy density is 7 MW/km^2 and solar energy density is 66 MW/km^2. For example, the wind energy density of class I area in the Gobi Desert is higher than 0,4~0,6 kW/m^2 based on average wind speed 7,1~8,1 m/s at 30 m height[36)]. This is the equivalent density of 400~600 MW/km^2. Average solar electricity generation potential is estimated 3,6-5,4 kWh/m^2/day.

Although Northeast Asia mostly consists of major energy importing countries, as indicated above, Northeast Asia has large amount of renewable energy resources ranging from solar and wind resources in Gobi desert of Mongolia/China, very high wind potential in coastal area of East China Sea. There are also huge potential of hydropower resources within the region (eastern Siberia, Russian Far East, Central and south China, as well as some part of Japan and Korea). In addition to Gobi desert area, northwestern Jilin province of China, and coastal area of the East China Sea are named as key locations for aggressive development large scale wind farms. The East China sea have very high potential of wind resources best suited for off-shore wind farm development same as North sea in Europe

Solar and wind resources of the Gobi desert is most promising renewable energy resources, which are sufficient to power all Northeast Asia several times.

7.5 Needs of cooperation for supergrid in the Northeast Asia

The Asia in general and Northeast Asia in particular have experienced highest rate of economic growth in the past. Northeast Asia is becoming one of the fast growing world leading economies. Due to high economic growth, the Northeast Asia has been one of the fastest growing energy markets over the past 30 years. It is expected that this trend will persist in the foreseeable future at a higher rate of energy consumption than in other parts of the world. Therefore, the energy supply infrastructure in the Northeast Asian sub-region have to be changed continuously in response to issues such as increasing demand, resource availability, environmental concerns, changing technology and the need for regulatory reform, and sector restructuring.

On the other hand, Northeast Asian countries, namely Korea, Japan are highly dependent on external energy supplies, especially oil and gas. Korea imports 96 % of primary energy from abroad, 82 % of its oil imports are purchased from the Middle East[37)]. Currently Japan’s energy self-sufficiency, excluding nuclear power, is about 4,9 %[37)]. Therefore, it can be concluded that compared to other Northeast Asia countries, South Korea, Japan are more vulnerable in terms of energy security as they have almost no natural resources both countries are highly energy dependent. China and Mongolia can be added to the category of vulnerability in terms of shortage of energy supply. Therefore, all Northeast Asian countries are vulnerable not only to the energy security but also quite vulnerable to climate change impact too. To narrow the gap between rising energy demand and deficit of energy supply, it is necessary to deepen energy cooperation between Northeast Asian countries to satisfy their increasing electricity demands with a safe and clean renewable energy than that provided by the conventional or nuclear power plants.

Thirdly, the distribution of and demand for the fuel resources for electricity production in Northeast Asia do not coincide geographically. At the same time each country encounters the different problems of energy shortage and even energy security. These factors clearly show that there is an urgent need for developing of transnational electricity exchange in this sub-region. In the past, there are have been proposed a number of conceptual studies on potential need for transnational electricity exchange infrastructure in Northeast Asia (Russia, Japan, China, Republic of Korea, North Korea and Mongolia), with neighboring countries. All these studies form a basis to initiate a proposal for energy integration and energy cooperation between Northeast Asian countries.

Energy cooperation itself not only economic cooperation, it is also more political and environmental cooperation. Therefore energy integration in Northeast Asia is critical factor in order to keep fast economic growth in the sub-region continuously. To maximize the benefit from energy integration to the economies for each country, a strong high level multilateral political cooperation is needed. One of the key cooperation agenda can be development of joint energy infrastructure in Northeast Asia. Energy integration among Northeast Asian countries can create a large market and expansion of economic potential for all participating nations and may contribute in political peace and security.

In the past, there are in Northeast Asia a number of bilateral and multilateral regional energy cooperation agreements have been established in various areas of energy sector development. Some vision and initiatives including Long-term vision of natural gas infrastructure designed by Northeast Asia Gas and Pipeline Forum (NAGPF), Northeast Asia Regional Electrical System Ties project (NEAREST), Greater Tumen River Initiative (GTI), recently Gobitec and Asian Super Grid initiatives were initiated as an institutional framework to facilitate energy cooperation in Northeast Asia.

As regards further development of renewable energy in the sub-region, in order to tap the full potential of renewables, a regional transnational supergrid is necessary to accelerate further deployment of distributed renewable generation and to offset intermittency issues of renewables. This will also reduce transmission losses offering lower cost electricity in the sub-region, leading to increased industrial competitiveness. The development of the sub-regional HVDC supergrid network will be one of the key components of the Gobitec and Asian Super Grid initiatives and it will be instrumental in our vision toward to a renewable energy based society in Northeast Asia.

It can be concluded that all countries of Northeast Asia have recognized that there are real need and bright opportunities for developing large scale transnational energy projects based on the utilization of abundant renewable energy resources through long distance HVDC supergrid, such as the Gobitec and Asian Super Grid initiatives.

The Gobitec and Asian Super Grid initiatives are very ambitious project proposals and it has the full potential to meet the challenges of the energy supply for Northeast Asia and shift to renewable energy supply at larger scale. In realization of the Gobitec and Asian Super Grid initiatives, the governments of the participating countries political institutions should take a pioneering role. Therefore, in order to harness the full potential of renewable energy sources from the Gobi desert, it needs to have at first high level Government commitment for long term cooperation between participating countries, a better policy and regulatory framework, as well as regional and national transmission planning need to be developed and agreed between all stakeholders.

Energy integration with introduction of transnational supergrid will require:

- To have a joint energy cooperation strategy in which the participating countries can align their targets and harmonize them with national renewable energy strategies.
- To have an agreement in eliminating physical, trade and regulatory barriers to ensure beneficial electricity market in Northeast Asia.
- To have legal certainty for the participating countries, investors and other stakeholders.
- To develop a harmonized set of trade and transit rules to reduce investment risks and create a joint platform of electricity exchange.
- To have an agreement that benefits from the cross-border electricity exchange are concentrated not only for a few countries but are distributed among all participants.

Observing emerging great efforts that Northeast Asian countries having now for the development a renewable energy it can be concluded that the all countries of Northeast Asia are in the way to shift for a renewable energy future, but actual movements are in different stages of development. Actually, shift for a renewable energy is happening in China already, renewable energy applications at large scale are booming in China, where from about 100GW of newly added capacity, 58 % came from renewable (hydro, wind, solar PV) sources and development rate of renewables even much faster than any other parts of the world[35)].

As the debate triggered by the Fukushima disaster, Japan is currently also dramatically scaling up their solar rooftop applications as well as mega-scale projects. An important impact was provided due to introduction of the new feed-in tariffs that promote greater renewables integration into the grid. The Japanese government's efforts to reform the nation's electricity sector present significant opportunities for the companies heavily involved in renewable energy businesses, such as SoftBank, who has already launched a retail electricity business in anticipation of the liberalization of the market[38]. The company SoftBank has started aggressively installation of the solar power installations in Japan and is involved in the government's efforts to upgrade the national grid.

7.6 China's role for future supergrid integration in the Northeast Asia

The supergrid approach has been successfully used at a regional level for the past 40 years in USA, Europe and China since HVAC and HVDC lines was used for connecting big hydropower plants to industrial regions[26]. Currently, the supergrid approach gets more and more attention because of necessity for integration of large amount renewable energy power generation into electricity grid[12,15-16,23,26].

Because of reverse distribution of renewable energy resources and load consumption density in China was need to construct long-distance transmission grid integration in order to absorb of large amount renewable energy power generation into high capacity electricity grid. Supergrid is main pre-requisite to integrate the large amount renewable energy power generation as supergrid enables to lower intermittency challenge of renewable energy sources.

There are 6 big GW-scale solar power sites: Gansu (4 317 GWp), Qinghai (3 103 GWp), Xinjiang (2570 GWp), Ningxia (1 614 GWp), Inner Mongolia (1 405 GWp) and Jiangsu(1 049 GWp). Each has built over 1GW. There are 8 big wind farm sites: Hami, Jiuquan, Western Inner Mongolia, Eastern Inner Mongolia, Hebei, Sandong, Jilin and Jiangsu. Each is planned to be over 10 GW. Capacity installed PV capacity in 2013 was 12,9 GW reaching cumulative capacity through 19,7 GW by the end of 2013[39]. The installed wind power capacity in China was 16,1 GW in 2013 and cumulative installed wind energy capacity reached to 91 424 MW at the end of 2013[9,40]. Future plan of China for wind will be 150 GW (5 GW Offshore) by 2015; 200 GW by 2020 (30 GW Offshore), and 300 GW by 2030[12,41].

With dramatic increases of wind and solar capacity, China faced a big challenge of transmitting large bulk wind and solar power to the main industrial load centers in east and north of China. China is not just increasing building of large scale renewable energy capacities but is also investing a huge amount in updating the electric power grid and constructing a new very high capacity long-distance power lines utilizing advanced HVDC technology, which are able to accommodate a variety of decentralized renewable energy sources[41,42]. In the past, China has built several long distance HVDC lines already in order to connect large scale hydro, and newly introduced wind and solar power Giga-plants built in north-west and northern part of China to industrialized centers in the south (see Fig. 7.6-1). In doing so, China has accumulated huge experience for constructing the long distance HVDC lines. These experiences of China are very important for development of supergrids at regional level in Northeast Asia in the future. In other words, China can serve as model for further development transnational supergrids in Northeast Asia in the future.

By observing great efforts by Northeast Asian countries to develop a renewable energy, it can be concluded that all countries of NEA are in different stages of development to shift to renewable energy in the future. In recent Chinese renewable energy policies, we can find the most important and flexible industrial policies to support and promote renewable energy industries.

China not only has an effective and favorable government policy to support the development of new industrial sectors such as renewables and HVDC grid, but also their experience of building large scale renewable energy projects, constructing high capacity long-distance HVDC power lines, and utilizing advanced HVDC technology are very useful and important for the Northeast Asian countries. These can serve as energy integration model for the region in the future.

Fig. 7.6-1 Directions of the electricity transmissions from Large Scale Renewable energy power plants in China[12)]

7.7 The Gobitec initiative and supergrid for the Northeast Asia

The main goal of the Gobitec initiative and supergrid for Northeast Asia proposal is to build sustainable energy infrastructure based on renewable energy sources, where electricity produced by the vast potential of renewable energy in Gobi desert and Siberia will be transmitted through HVDC supergrid to all countries in the Northeast Asia.

As it was noted in the previous part of this paper, China has already developed several long distance HVDC and UHVDC transmission supergrids inside the country. China has accumulated a huge experience in this field, and it is now also becoming biggest manufacturing base for all kinds of HVDC supergrid system components. The experiences of China to develop long distance HVDC transmission supergrids are providing an important foundations and capabilities to develop regional transnational supergrids which can lead to greater level of energy integration and energy trading in the Asian region.

For the regional supergrid project such as Asian Super Grid (ASG), it is considered that Gobi desert can serve as a major regional solar and wind power hub to deliver electricity to the Northeast Asian countries through the UHVDC transmission supergrid. Fig. 7.7-1 shows the one of the proposed topology of the ASG, which describes the main direction of the supergrid between Russia and China across Mongolia (Gobi desert) and further connection within China before leading to Japan and Korea.

Fig. 7.7-1 Proposed topology of the Northeast Asian Supergrid[20)]

According to the Masayoshi Son, CEO of Softbank, founder of the "Japan Renewable Energy Foundation" an implementation of the "Asian Super Grid" project may have 3 stages: The first stage is deployment of a HVDC transmission inside of Japan to interconnect all of Japan from south to north. The next stage is expanding transmission grid to Russia, Korea and China. And the third stage is establishing transnational supergrid which can cover all Asia[38)]. However, he was noted that main goal of the Asian Super Grid is deployment large-scale renewable energy generated from the Gobi desert for the Asian region[38)].

The other alternative option which is described Fig. 7.7-1 suggests in the first step to establish HVDC supergrid connecting Far East Russia, Mongolia and China as first pilot stage. In our opinion, this option can be realized within short period of time as there are already exists cross-border 220 kV AC transmission line connecting Russia with Mongolia. Recently, China is also building 220 kV cross-border AC transmission line between south of Mongolia (Gobi desert) and China. This AC transmission line can be expanded to HVDC transmission line if electricity flow between countries will increase significantly. The other reason why we propose to start ASG project from the interconnection between Russia, Mongolia and China is the fact that China is the biggest market to purchase electricity generated from the Gobi desert and is located right next to the Gobi desert. Secondly, China has accumulated huge experience in constructing and implementing the long distance HVDC lines, which can be applied to establish HVDC supergrid connecting Far East Russia, Mongolia and China as first pilot stage.

Bringing such regional project, such as Gobitec and ASG into practices will require a high level government commitment and intergovernmental negotiations to eliminate physical, trade and regulatory barriers in order to ensure beneficial electricity market in Northeast Asia. High level intergovernmental agreement would be an important first step towards to meeting goals of the ASG – to build regional electricity network for Northeast Asia. As the countries have different target/policy structures and different economic structures, the processes involved in the implementation of the project may encounter some obstacles. Therefore it may be appropriate to create a joint development districts at first (for example in the Gobi desert of Mongolia close to Mongolia and China border) for the first pilot stage of the ASG project. The first stage may allow assessing the legal framework and potential possibility before implementing actual project at regional level. From this point of view, an option to start construction HVDC supergrid from Mongolia (Gobi desert) to China is the most important part of the implementation ASG project. In parallel, it would be important to carry out comprehensive research which focuses on the development an integrated energy regional policy and assessment of the legal framework and potential possibility before implementing actual project at regional level with the projections of regional energy supply and demand in the future.

It would be important to carry out comprehensive research which focuses on the development an integrated energy regional policy and assessment of the legal framework and potential possibility of the ASG project that can be undertaken in parallel with the implementation first pilot stage of the ASG project.

The next step can be expanding HVDC transmission grid into regional supergrid in order to supply energy to other countries of Northeast Asia. In the long run Northeast Asian regional supergrid can be connected to other countries of Asia.

A regional HVDC supergrid connecting Northeast Asian countries can offer following opportunities:

- It could enable mutual economic benefit through renewable energy resource development and infrastructure construction and cost-effective energy supply in the participating countries in Northeast Asia.
- It could strengthen energy supply security through diversification of energy supply through renewable energy resource development.
- It could build the basis to increase the use of renewable energy in the sub-region and help Northeast Asian countries to contribute significantly in greenhouse gas emission reductions
- It will help Northeast Asian countries to meet their increasing electricity demand with a safe and clean renewable energy power sources than that can be provided by the conventional or nuclear power.
- It will build investor’s confidence in increasing investment in renewable energy, which can lead to shifting investment to renewable energy development.

After review of the existing experiences for the construction HVDC supergrid project in the world, specifically in China, the following recommendations can be drawn in relation to the implementation of Gobitec and ASG in Northeast Asia:

- The technology of HVDC supergrid transmission line, as well as technology and construction of the VLS-PV plant and wind farms are now becoming very cost effective and mature commercial technology. Therefore, it can be concluded that the implementation of the Gobitec and ASG project is feasible from the technological point of view.
- Construction of the regional HVDC supergrid transmission line, as well as increasing share of renewable energy in the region will lead to further decrease a cost of electricity as because renewable energy potential is large especially in the Gobi Desert and cost of PV, wind technology is decreasing significantly.
- The governments in the region need to demonstrate their high level government commitment risk reduction for the development of the Gobitec and ASG project, which is key factor to gain the confidence of the private sector and international financing community to support major investment decisions for the actual implementation Gobitec and ASG project.
- As because the implementation of the Gobitec and ASG project is capital intensive, an improved investment climate is necessary.
- As because the Gobitec and ASG project is transnational international project a clear, transparent, stable legal framework for long-term energy cooperation based on mutual benefits for energy-producing, energy-consuming as well as transit countries have to be developed.

- As because of Gobitec and ASG project is regional transnational project which uses high capacity transmission lines passing several countries, regional stability in the region have to be secured.
- As because the Gobitec and ASG project may deliver a number of economic, social and environmental benefits to participating countries, such as transfer of high technology, job creation, poverty alleviation and a reduction of carbon dioxide (CO_2) emissions, strong political and financial support from all countries is needed to support implementation of this project.
- As because the implementation of the Gobitec and ASG project will apply the latest achievement of high technology the intellectual property rights have to be insured accordingly.
- As Northeast Asian countries have different times of peak electricity demand due to time difference and seasonal variation of meteorological conditions (in Mongolia and China demand peaks appears during winter times, while in Japan, Korea the demand peak occurs in the summer) regional HVDC supergrid transmission line may help in power balancing of the supply and can smooth energy balance, which may enable all countries to share effectively generated power and storage facilities, allowing for more economic operation of the power sector in each countries as whole.
- As because the Gobitec and ASG project can contribute to regional development of renewable energy strong support of international organizations and financial institutions, including APEC, ESCAP, IRENA, EC and ADB is needed.

7.8 Conclusions

One of the key solutions to overcome the problem of increasing demand of energy, protection of global climate and conservation of the valuable finite resources is significant increase the share of renewable energy among total primary energy supply. Renewable energy now provides around one-fifth of the world's electricity and it is becoming an important part of today's energy supply. Observing emerging great efforts that some countries having during the last years for the development a renewable energy it can be concluded that world is moving forward to the shift for a renewable energy future, although actual movements are in different stages of development.

The variability of the power generation caused by the use of renewable energy sources such as solar and wind power systems can become big challenges when the contribution of renewables to transmission grid rises to a substantial level. One of the most efficient ways to overcome these challenges is an integration of renewable energy power sources into high capacity HVDC transmission grid called a "Supergrid" for transferring massive amounts of energy over long distances.

The supergrid, in combination with HVDC grid technology will provide an effective solution to emerging problems associated with renewable energy integration. The supergrid is becoming a global trend now and the technology of HVDC and UHVDC as well as technology of the VLS-PV plants and wind farm is now becoming cost effective, technically proven commercial technologies capable to be applied for any regional energy infrastructure projects such as the ASG in Northeast Asia.

One of the key drivers for the HVDC development in worldwide is necessity of integration of high capacity renewable energy power sources. The development of renewable energy integration fosters HVDC applications in countries and regions like China, East Europe, and South America, etc. China has already developed several long distance HVDC transmission lines successfully and currently it is accelerating UHVDC construction and becoming biggest manufacturing base of all kinds of HVDC supergrid system components.

Due to high economic growth in the past, the Northeast Asia is becoming one of the fastest growing energy markets and it is expected that this trend will persist in the foreseeable future at a higher rate of energy consumption than in other parts of the world. To narrow the gap between rising energy demand and deficit of energy supply, it is necessary to deepen energy cooperation between Northeast Asian countries to satisfy their increasing electricity demands with a safe and clean renewable energy than that provided by the conventional or nuclear power plants. The energy integration in Northeast Asia is critical factor in order to keep fast economic growth in the region continuously.

The abundant solar, wind resources of the Gobi desert in combination with environment-friendly natural gas and hydropower reserves of the Russian Far East could become the key source of energy for the countries in the Northeast Asian region, and would lessen the region's heavy dependence on fossil fuel import.

Energy cooperation itself not only economic cooperation, it is also more political and environmental cooperation. One of the key cooperation agenda can be development of joint energy infrastructure in Northeast Asia, such as the Gobitec and ASG initiatives, which can enable to increase share of renewable energies. Successful implementation Gobitec and ASG into practices will require a high level government commitment and intergovernmental negotiations to eliminate physical, trade and regulatory barriers in order to ensure beneficial electricity market in Northeast Asia. High level intergovernmental agreement would be an important first step towards to meeting goals of the ASG – to build regional electricity network for Northeast Asia.

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Chapter 8 Renewable Energy Mix and Economics of Supergrid in the Northeast Asia

8.1 Introduction

Besides ongoing climate changes[1,2], pollution provoked by human activity including the conventional energy sector[3,4], increasing variability and an expected rise of fossil fuels cost[5-7], the idea of building a new, renewables-based energy system becomes more and more feasible[8-11]. In recent years there have been projects aimed at increasing utilization of renewables in renewable energy (RE) rich regions and delivering this energy to electricity demand centers[12-16]. This, obviously, cannot be done without utilization of high voltage current (HVDC) transmission grids[17]. The idea of a global supergrid for power supply was already discussed some years ago[14], but attracted new attention by the Gobitec and Northeast Asian Super Grid initiative[14-16,18-20] influenced by the EU-MENA Desertec[12,16] even though it was originally initiated already in 2003[19]. A sustainable energy supply in Northeast Asia needs to be based on renewable energy sources to overcome the constraints of diminishing fossil resources, climate change impacts, health issues and security. The Mongolian Gobi desert is known for its excellent resource availability[15,20]. Great wind and solar resources in Tibet, large installed hydro power capacities in Japan, Central China, South-East China, and good potential of hydro power in North Korea and Tibet, all make it possible to build a renewable resources-based energy system interconnected by HVDC transmission lines forming the North-East Asian supergrid. Fig. 8.1-1 indicates a possible Super Grid design in Northeast Asia and the location of renewable energy sources[19-20].

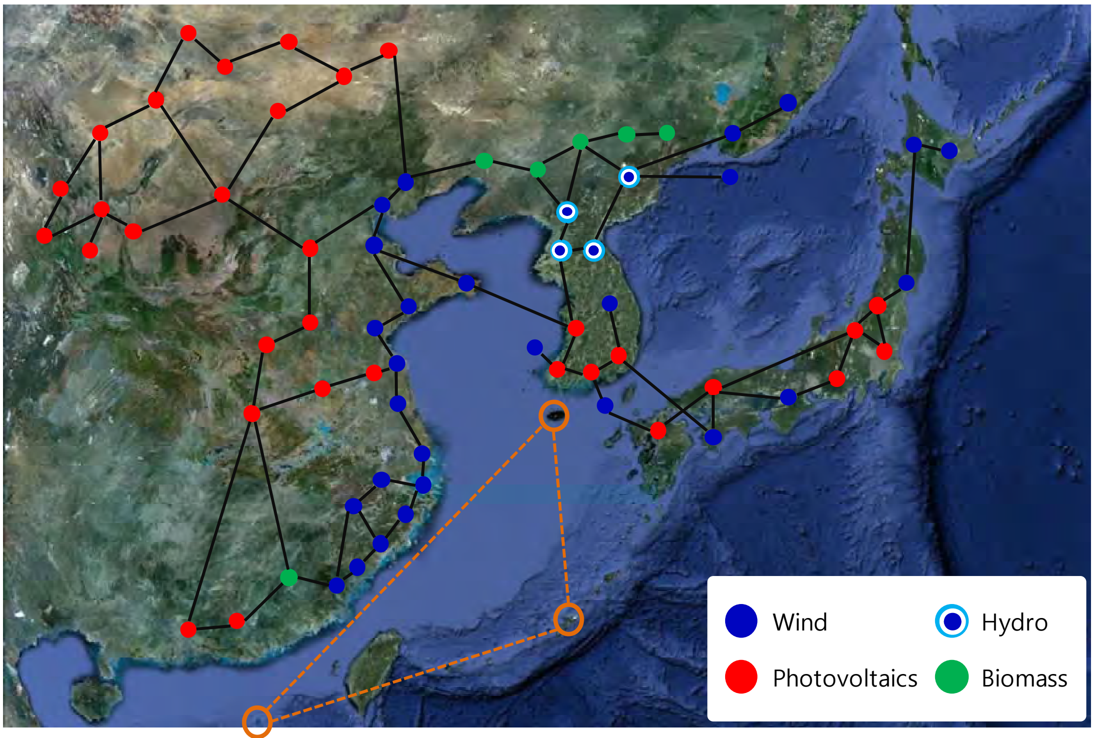

Fig. 8.1-1 Example of supergrid design in Northeast Asia[19-20]

A key objective of this research work is the definition of an optimally structured energy system based on 100 % RE supply:

- optimal set of technologies, best adapted to the availability of the regions' resources,
- optimal mix of capacities for all technologies and every sub-region of Northeast Asia,
- optimal operation modes for every element of the energy system,
- least cost energy supply for the given constraints.

8.2 Methodology

The energy system optimization model is based on linear optimization of perfect foresight conditions under applied constraints. A multi-node approach enables us to describe any desired configuration of sub-regions and power transmission interconnections, i.e. not all the sub-regions have to be interconnected, but a grid configuration can be defined in scenario assumptions or can be chosen close to an existing grid configuration. Hourly resolution of the model guarantees that for every hour of the year total generation within a sub-region and electricity import cover electricity demand (load and electricity export).

8.2.1 Input data

The generic model is built by several types of different input data and constraints. These are, first, historical weather data for direct and diffuse solar irradiation, wind speed and precipitation amounts; second, synthetic load data; third, power yield of technologies; fourth, efficiency of energy conversion processes; fifth, capital expenditures, operational expenditures and ramping costs for all technologies; sixth, limits for minimum and maximum installed capacity for all energy technologies; seventh, configuration of regions and interconnections.

Data for solar irradiation, wind speed and precipitation are taken from NASA databases[21)] and partly reprocessed by the German Aerospace Center[22-23)]. The spatial resolution of the data is $0{,}45 \times 0{,}45$. Time resolution is hourly for wind speed and solar irradiation, and monthly for precipitation. The feed-in time series for fixed optimally-tilted solar photovoltaic (PV) systems is computed in accordance to Gerlach et al.[22)]. The feed-in time series for wind power plants is computed in accordance to Gerlach et al.[22)] for standard 3 MW wind turbines (E-101 from Enercon) for hub height conditions of 150 m.

8.2.2 Applied technologies

The technologies taken into account for the modeling of optimal energy systems based on 100 % RE supply for Northeast Asia can be divided into three main categories: conversion of RE resources into electricity, energy storages, and electricity transmission.

The technologies for converting RE resources into electricity applied in the model are ground-mounted and rooftop solar photovoltaic (PV) systems, onshore wind turbines, hydro run-of-river (RoR) plants and hydro dams. Hydro dams in this model embody a power generation and storage function. Ground-mounted and rooftop PV systems are unified in the model into one entity with averaged parameters.

The electricity transmission grids are represented on two levels: power distribution and transmission within the sub-regions are assumed to be based on standard alternating current (AC) grids and inter-regional transmission grids are modeled on high voltage direct current (HVDC) technology. For the work presented in this paper, grid losses are not included in the model.

The electricity storage technologies used in the model are battery storage, pumped hydro storage and power-to-gas technology. Power-to-gas storage includes synthetic natural gas (SNG) synthesis technologies: water electrolysis, methanation, CO_2 scrubbing from air, gas storage, and both combined and open cycle gas turbines (CCGT, OCGT). SNG synthesis process technologies have to be operated in synchronization because of hydrogen and CO_2 storage absence. The full model block diagram is depicted in Fig. 8.2-1.

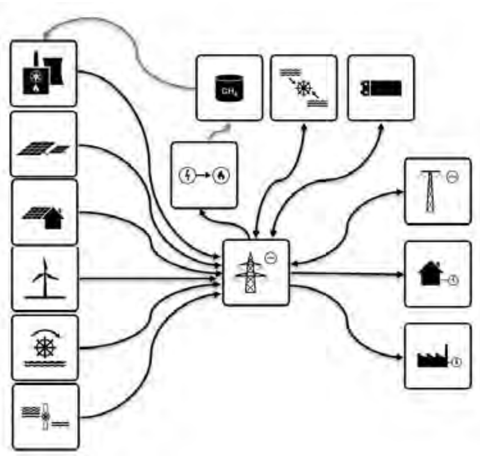

Fig. 8.2-1 Block diagram of the energy system model for Northeast Asia

The elements on the left are power generation (CCGT, OCGT, PV ground-mounted, PV rooftop, wind onshore, hydro run-of-river, hydro dams), at the top storage (power-to-gas, gas storage, pumped hydro storage, battery) in the center the sub-region's AC distribution and transmission grid and on the right power load and inter-regional HVDC power transmission.

8.3 Scenario assumptions

8.3.1 Nodes and grid structure

Northeast Asia is divided into 14 sub-regions. West and East Japan (territory divided by 50/60 Hz distribution grid border), South Korea, North Korea, China divided into eight sub-regions by State Grid Corporation of China: Northeast, North, East, Central, South, Northwest China, Tibet and Uygur regions, West and East Mongolia.

For the energy system analysis of Northeast Asia, we have applied three scenarios: firstly, a region-wide open trade scenario, in which all the regions are independent (no HVDC grid interconnections) and the electricity demand has to be covered by the respective region's own generation; secondly, country-wide open trade, in which all sub-regions of the same country are connected (no interconnections between countries); thirdly, area-wide open trade (Fig. 8.3-1), in which the different country-wide HVDC grids are interconnected and there are no limitations on international power exchange. The Chinese HVDC grid configuration is based on the existing Chinese Grid operated by State Grid Corporation of China and its development plans. Additional interconnections in the area-wide open trade scenario are: West Japan to South Korea, South Korea to North Korea, South Korea to North China, North Korea to Northwest China, and North China to East Mongolia.

For the country-wide open trade scenario the following connections are assumed to be not existent: East Mongolia – North China, Northeast China – North Korea, North China – South Korea, North Korea – South Korea and South Korea – West Japan.

Fig. 8.3-1 Grid configuration of area-wide open trade scenario

8.3.2 Financial and technical assumptions

The model optimization is carried out on an assumed cost basis and technological status for the year 2020 and the overnight building approach. PV costs are assumed as an average of ground-mounted and rooftop PV systems. The capex and opex numbers refer in general to kW of electrical power, in case of water electrolysis to kW of hydrogen combustion thermal energy, and for CO_2 scrubbing, methanation and gas storage to kW of methane combustion thermal energy. Efficiencies of water electrolysis, CO_2 scrubbing and methanation refer to the lower heating value of hydrogen and methane, respectively.

Table 8.3-1 Financial assumptions for energy system components for the 2020 and 2030 reference years

Technology	Capex [EUR/kW]	Opex fix [EUR/kW]	Opex var [EUR/kWh]	Lifetime [year]
PV	1 008 / 731	15 / 11	0	30 / 35
Wind onshore	1 179 / 1 000	24 / 20	0	20 / 25
Hydro run-of-river	2 000	40	0	50
Hydro dam	2 000	40	0	50
Water electrolysis	685 / 380	24 / 13	0,001 2	30
Methanation	421 / 234	18 / 5	0,001 5	30
CO_2 scrubbing	641 / 356	25 / 14	0,001 3	30
CCGT	750	15	0,001	30
OCGT	380	7.6	0,001	30
	Capex [EUR/kWh]	Opex fix [EUR/kWh]	Opex var [EUR/kWh]	Lifetime [year]
Battery	300 / 150	10 / 10	0,000 2	10 / 15
PHS	70	1,4	0,000 2	50
Gas storage	0,05	0,001	0	50
	Capex [EUR/(kW_{NTC}*km)]	Opex fix [EUR/(kW_{NTC}*km)]	Opex var [EUR/kWh_{NTC}]	Lifetime [year]
HVDC line on ground	0,612	0,007 5	0	50
HVDC line submarine	0,992	0,001 0	0	50
	Capex [EUR/kW_{NTC}]	Opex fix [EUR/kW_{NTC}]	Opex var [EUR/kWh_{NTC}]	Lifetime [year]
HVDC converter pair	180	1,8	0	50

(The numbers for 2020 and 2030 are identical unless a second number indicates a change for 2030 assumptions. The financial assumptions for storage systems refer to kWh of electricity, and gas storage refers to one thermal kWh of methane at the lower heating value. Financial numbers for HVDC transmission lines and converter stations are given for the net transmission capacity (NTC). Assumptions are mainly taken from Pleßmann et al.[8] but also other sources[12,24-27].)

Table 8.3-2. Energy to power ratio of storage technologies (left) and efficiency assumptions for energy system components for the 2020 and 2030 reference years (right)

Technology	Energy/Power Ratio [h]
Battery	6
PHS	8
Gas storage	80

	Efficiency [%]
Battery	85
PHS	78
Gas storage	100
Water electrolysis	84
Methanation	77
CO_2 scrubbing	78
CCGT	58
OCGT	38

(Assumptions are mainly taken from Pleßmann et al.[8])

8.3.3 Applied data

(1) Feed-in for solar PV and wind energy

The derived values for full load hours and levelized cost of electricity (LCOE) for optimally tilted PV systems and onshore wind energy generation in Northeast Asia are presented in Fig. 8.3-2.

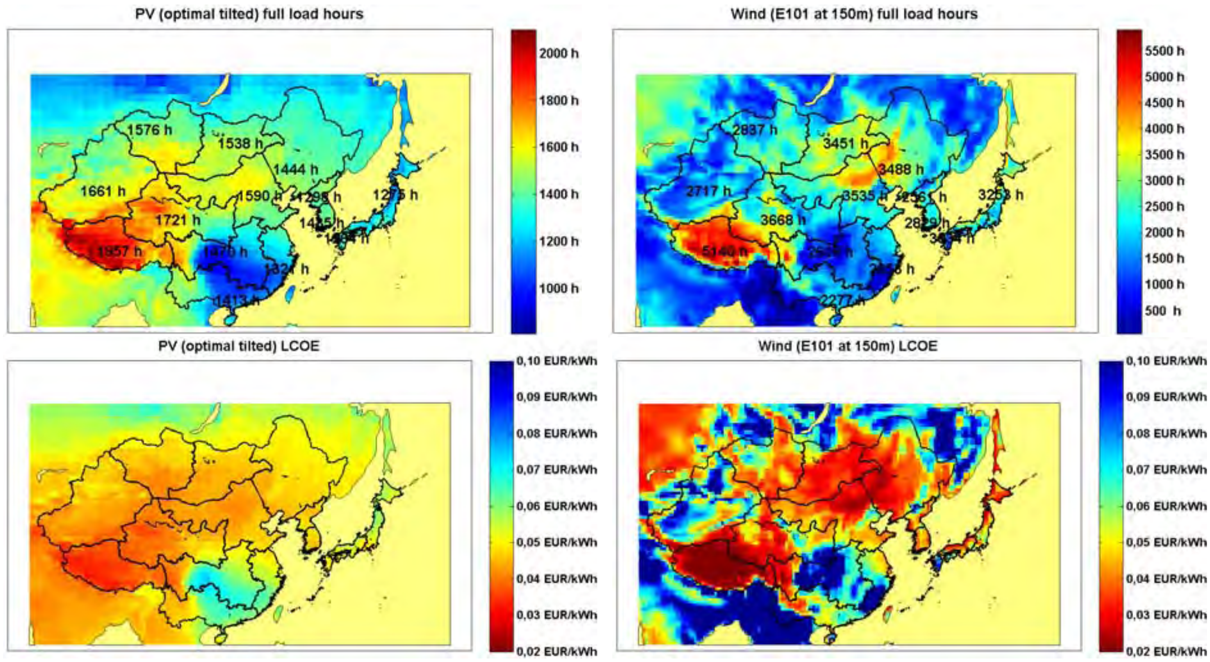

Fig. 8.3-2 Full load hours (FLH, top) and levelized cost of electricity (LCOE) of solar PV systems and wind energy in Northeast Asia for the reference year 2030 (bottom)

(FLH diagrams are for optimally tilted PV systems (top, left) and wind power plants (top, right). Please notice the different LCOE scaling for the reference years 2020 and 2030. The assumed wind power plants consist of 3 MW wind turbines at 150 m hub height. Dataset is used in a 0,45 x 0,45 spatial and hourly temporal resolution for the real weather conditions of the year 2005. The LCOE numbers are calculated by applying cost numbers in Table 8.3-1. Resource data are based on Gerlach et al.[22] using NASA data[21] reprocessed by the German Aerospace Center[23].)

Feed-in full load hours for sub-regions are computed on the basis of the 0,45 x 0,45 spatially resolved single sub-areas' data using a weighted average formula. The sub-regions' numbers are calculated using the rule: 0-10 % best sub-areas of a region are weighted by 0,3, 10-20 % best sub-areas of a region are weighted by 0,3, 20-30 % best sub-areas of a region are weighted by 0,2, 30-40 % best sub-areas of a region are weighted by 0,1 and 40-50 % best sub-areas of a region are weighted by 0,1.

The feed-in values for hydro power are computed based on the monthly resolved precipitation data for the year 2005 as a normalized sum of precipitation in the regions. Such an estimate leads to a good approximation of the annual generation of hydro power plants (deviation of computed data for all Northeast Asian regions to public data is less than 5 %).

(2) Upper and lower limitations on installed capacities

Lower and upper limits applied to renewable energy sources (optimally tilted PV, wind turbines, and hydro energy) and pumped hydro storage. For gas turbines, battery and gas storage, and units of the power-to-gas process, the lower limit is set to zero.

Upper limits for optimally tilted PV systems and wind power plants are based on land use limitations and the density of capacity. The maximum area covered by PV systems is set to 6 % of the total sub-regions' territory and for wind power plants to 4 %, respectively. The capacity densities for optimally tilted PV systems is 75 MW/km^2 and for onshore wind power plants 8,4 MW/km^2, respectively.

For hydro power plants and PHS storage, upper limits are set to 150 % and 200 % of already installed capacities by the end of 2013. For North Korea the PHS upper limit is set equal to South Korea because of no installed PHS capacity and obviously high potential in North Korea. All upper limits of installable capacities in Northeast Asian sub-regions are summarized in Table 8.3-3.

Table 8.3-3 Upper limits on installable capacities in Northeast Asian regions

Region	area [1 000 km^2]	Limits [GW] Solar	Wind	Run-of-River	Hydro Dam	PHS
Total area	11 499	111 287	8 314	162	162	105
East Japan	195	876	65	7,1	7,1	19
West Japan	179	807	60	8,0	8,0	32
South Korea	99	444	33	1,2	1,2	8,8
North Korea	116	524	39	4,8	4,8	8,8
Northeast China	1 308	14 718	1 100	5,1	5,1	1,2
North China	1 154	12 979	970	24	24	6,4
East China	479	863	64	7,4	7,4	12
Central China	1 279	14 391	1 075	51	51	7,7
South China	1 013	1 824	136	38	38	10
Tibet	1 127	12 682	948	0,2	0,2	0,2
Northwest China	1 380	15 528	1 160	13	13	0
Uygur	1 618	18 202	1 360	1,2	1,2	0
West Mongolia	788	8 870	663	0	0	0
East Mongolia	763	8 579	641	0	0	0

For gas turbines, battery, gas storages and power-to-gas technologies, upper limits are not specified. The demand profiles for sub-regions are computed as a fraction of the total country demand based on synthetic hourly resolved load data weighted by the sub-regions' population.

8.4 Results

For all three scenarios (Fig. 8.3-1) optimized electrical energy system configurations are derived and characterized by optimized installed capacities of RE electricity generation, storage and transmission for every modelled technology, leading to respective hourly electricity generation, storage charging and discharging, electricity export, import and curtailment. In Table 8.4-1 the average financial results of the different scenarios are presented for levelized cost of electricity (LCOE), levelized cost of electricity for primary generation (LCOE primary), levelized cost of curtailment (LCOC), levelized cost of storage (LCOS), levelized cost of transmission (LCOT), total annualized cost, total capital expenditures, total renewables capacity and total primary generation. Weighted average cost of capital (WACC) is set to 7 % for all scenarios.

Table 8.4-1 Financial results for the three scenarios and the year 2020 (top) and 2030 (bottom) applied in Northeast Asia regions

2020 Scenarios	Total LCOE	LCOE primary	LCOC	LCOS	LCOT	Total ann. cost	Total CAPEX	RE capacities	Generated electricity
	[EUR/kWh]					[billion EUR]		[GW]	[TWh]
Region-wide	0,115	0,068	0,008	0,040	0	696	6 113	3 888	7 918
Country-wide	0,090	0,059	0,005	0,021	0,005	539	4 949	3 017	7 434
Area-wide	0,077	0,054	0,005	0,011	0,007	459	4 368	2 593	7 305
2030 Scenarios	**Total LCOE**	**LCOE primary**	**LCOC**	**LCOS**	**LCOT**	**Total ann. cost**	**Total CAPEX**	**RE capacities**	**Generated electricity**
	[EUR/kWh]					[billion EUR]		[GW]	[TWh]
Region-wide	0,081	0,052	0,005	0,025	0	490	4 555	3 810	7 669
Country-wide	0,070	0,048	0,004	0,015	0,003	419	4 041	3 158	7 319
Area-wide	0,064	0,046	0,003	0,010	0,004	383	3 796	2 819	7 181

(The scenarios are defined by Fig. 8.3-1, and Tables 8.3-1 and 8.3-2)

From Table 8.4-1 it can be easily seen for the 2020 assumptions a considerable decrease of electricity cost of the entire system in case of area-wide open trade power transmission compared to the country-wide and region-wide scenarios of about 15 % and 37 %, respectively. Grid utilization decreases the primary energy conversion capacities and generation by 25 % and 35 % in terms of installed capacities and by 7 % and 9 % in terms of generated electricity in reference to country-wide and region-wide scenarios, respectively. Grid utilization leads to a significant decrease of storage utilization (Table 8.4-2), whereas cost of transmission is relatively small in comparison to the decrease in primary generation and storage costs. Decrease of curtailment cost in case of open trade between regions is significant, however, the impact of energy excess on total cost is rather low.

For the 2030 assumptions the structure of the 2020 results can be confirmed; however, the simulated energy systems are more shaped by the relatively improved PV LCOE and in particular by the significant cost reduction of storage. The most prominent result is that the region-wide scenario of 2030 (0,081 EUR/kWh) costs more or less the same as the area-wide scenario of 2020 (0,077 EUR/kWh). The spread in LCOE of the scenarios is reduced from 0,038 EUR/kWh (2020) to 0,017 EUR/kWh (2030). Both numbers will further decrease in an updated version of our results since no loss of the HVDC transmission is taken into account in this work. In the 2030 results the RE capacities increase mainly in the country-wide and area-wide scenario whereas the generated electricity is reduced. This is a consequence of an increased proportion of PV in the 2030 scenarios. In turn, this is a consequence of faster cost reduction of PV versus wind energy and of the reduced storage cost. The result is a better competitive edge to the HVDC transmission. This effect will be even stronger in an updated version including HVDC transmission losses.

Table 8.4-2 Overview on installed RE technologies and storage capacities for the three scenarios and the year 2020 (top) and 2030 (bottom) applied in Northeast Asia regions

2020 Scenarios	Wind [GW]	PV [GW]	Hydro RoR [GW]	Hydro dams [GW]	Battery [GWh]	PHS [GWh]	PtG electrolyzers [GW_{el}]	CCGT [GW]	OCGT [GW]
Region-wide	1 403	2 169	156	160	2 702	102	372	299	167
Country-wide	1 758	944	154	160	1 131	102	232	233	180
Area-wide	1 961	308	162	162	59	105	196	216	225
2030 Scenarios	**Wind [GW]**	**PV [GW]**	**Hydro RoR [GW]**	**Hydro dams [GW]**	**Battery [GWh]**	**PHS [GWh]**	**PtG electrolyzers [GW_{el}]**	**CCGT [GW]**	**OCGT [GW]**
Region-wide	1 310	2 200	140	160	3 326	100	346	236	180
Country-wide	1 722	1 135	141	160	1 653	99	239	177	198
Area-wide	1 895	620	142	162	637	105	224	161	226

(The scenarios are defined by Fig. 8.3-1, and Tables 8.3-1 and 8.3-2)

In the case of the region-wide open trade scenario, all sub-regions of Northeast Asia need to match their demand using only their own renewable energy resources. In the case of the country-wide and area-wide open trade scenarios, a division of regions into net exporters and net importers can be observed. Net exporters are sub-regions with the best renewable resources and net importers are sub-regions with moderate ones. Annual import and export diagrams for country-wide and area-wide open trade scenarios are presented in Fig. 8.4-1.

Fig. 8.4-1 (bottom) reveals the net exporter regions Tibet, Central, North and Northeast China, and North Korea. Net importers are East, South China, South Korea and Japan. Surprisingly, electricity export from Mongolia is negligible, which can be explained by the fact that wind potential in Chinese Inner Mongolia is better and North China's generation is slightly lower in cost (Fig. 8.3-2). In the case of the country-wide open trade scenario, generation in Japan and South Korea exceeds demand because of wide utilization of storage, and energy losses during charge and discharge.

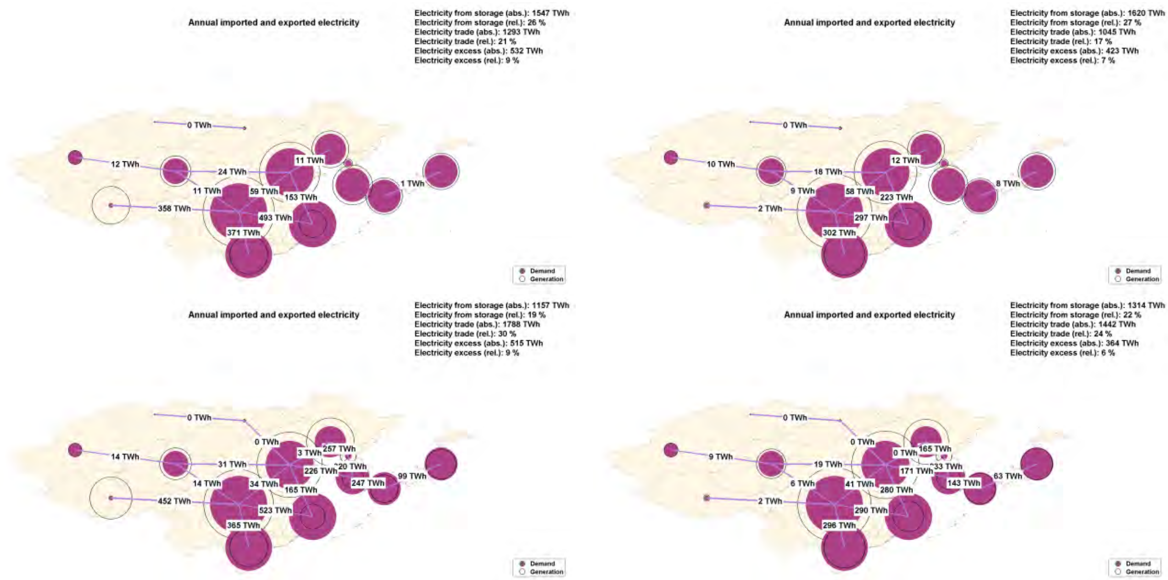

Fig. 8.4-1 Annual generation and demand diagrams for country-wide (top) and area-wide (bottom) open trade scenarios for Northeast Asia and the reference year 2020 (left) and 2030 (right) (Differences in generation and demand are mainly due to export and import, but in a minor quantity also due to storage losses.)

The main differences of the results for the 2020 and 2030 assumptions are the reduced role of inter-regional trade, increased role of storage, less curtailed energy and a dramatic change of the function of Tibet. The importing regions tend to import less electricity due to improved economics of local RE generation, in particular PV, but also substantially improved storage economics. The major exporting regions are all located in China (North, Northeast and Central). The remote location of Tibet leads to an entire loss of competitiveness compared to the three major exporting regions in China.

For sub-regional energy system structures, an overview on installed capacities is presented for the three different scenarios in Fig. 8.4-2.

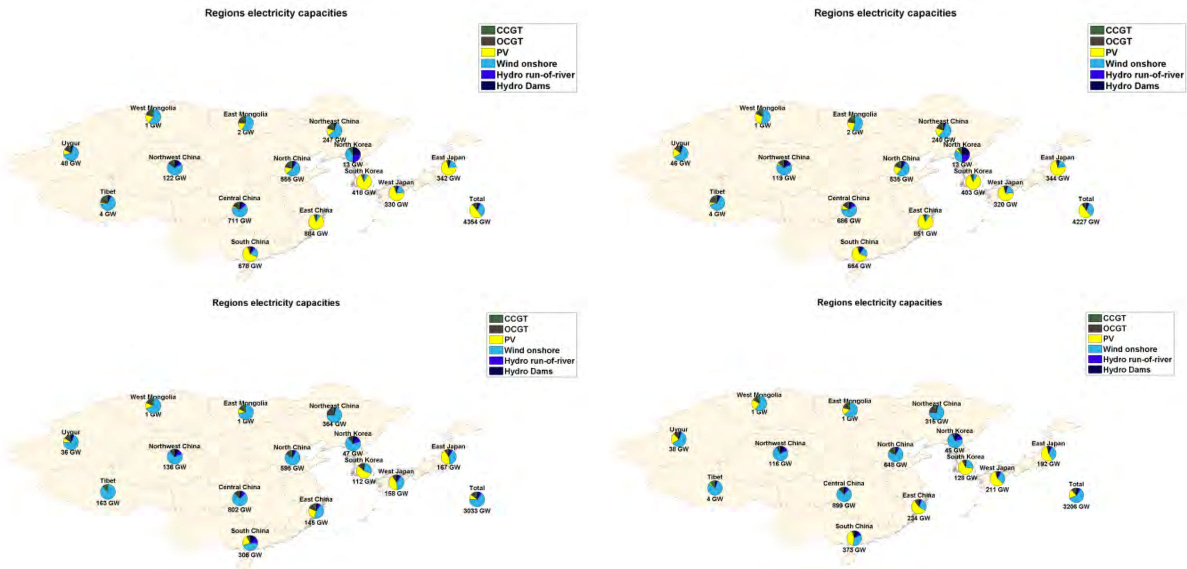

Fig. 8.4-2 Installed capacities for region-wide (top) and area-wide (bottom) open trade scenario for Northeast Asia and reference year 2020 (left) and 2030 (right).

As can be seen from Fig. 8.4-2, in the case of region-wide open trade in the sub-regions of Japan, South Korea, East and South China, solar PV capacities exceed 50 % of all installed power capacities despite the fact that wind power FLH in these regions is better or comparable to PV FLH. That happens due to the upper limit of installable wind power capacity being much lower than the upper limit of PV capacity because of the lower area limit and considerably lower power density of wind technology. Due to reaching the maximum capacity of the least cost component (wind power plants), the second least cost energy component (PV systems) is installed to cover demand. The interconnected HVDC transmission grid significantly decreases total installed capacities (Fig. 8.4-2 and Table 8.4-1) and especially solar PV capacities whereas installed capacities are increased in wind resource rich regions, such as Tibet and North China.

The main difference for the 2030 results are increase PV capacities in the net importing regions, such as Japan, South Korea, East China and South China, and a respective shift of wind power capacities from Tibet to North China, Northwest China and Central China. The differences in the region-wide scenario are rather small.

The structure of HVDC power lines and utilized RE resources strongly influence the total storage capacity needed but also the composition of different storage technologies for the energy system in the same area. Diagrams of storages discharge capacities are presented in Fig. 8.4-3 and further results for storage capacities, annual energy throughput and full cycles per year are summarized in Table 8.4-3.

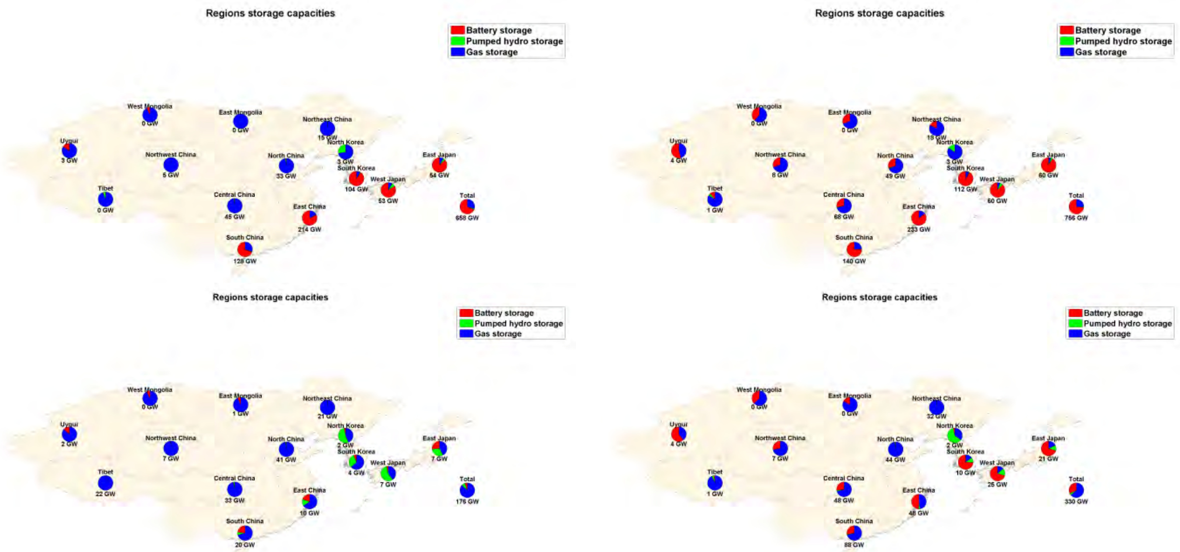

Fig. 8.4-3 Storages discharge capacities for region-wide (top) and area-wide (bottom) open trade scenarios for Northeast Asia and the reference year 2020 (left) and 2030 (right)

Table 8.4-3 Overview on storage capacities, throughput and full cycles per year for the three scenarios and reference year 2020 (top) and 2030 (bottom) applied in Northeast Asia regions

	Storage capacities			Throughput of storages			Full cycles per year		
Scenario	Battery [TWh_{el}]	PHS [TWh_{el}]	Gas [TWh_{th}]	Battery [TWh_{el}]	PHS [TWh_{el}]	Gas [TWh_{th}]	Battery [-]	PHS [-]	Gas [-]
Region-wide	2,7	0,1	373,8	803	24	814	297,3	233,0	2,2
Country-wide	1,1	0,1	313,8	360	27	594	318,5	269,5	1,9
Area-wide	0,1	0,1	294,6	28	33	553	469,2	312,4	1,9
	Storage capacities			Throughput of storages			Full cycles per year		
Scenario	Battery [TWh_{el}]	PHS [TWh_{el}]	Gas [TWh_{th}]	Battery [TWh_{el}]	PHS [TWh_{el}]	Gas [TWh_{th}]	Battery [-]	PHS [-]	Gas [-]
Region-wide	3,3	0,1	364,1	997	22	722	299,7	218,2	2,0
Country-wide	1,7	0,1	305,4	545	24	561	329,5	239,0	1,8
Area-wide	0,6	0,1	404,0	223	23	546	350,2	215,6	1,4

(The scenarios are defined by Fig. 8.3-1, and Tables 8.3-1 and 8.3-2)

The decrease of the PV generation fraction goes hand in hand with the decrease of short-term storages (batteries and PHS). At the same time the increase of the wind generation fraction leads to an increase of long-term storage (gas storage). Consequently, power transmission and decrease of PV generation share leads to a reduced share of battery and PHS storage (in Japanese sub-regions and Korea PHS installed capacities reached the lower limits and cannot be decreased further). The HVDC transmission grid interconnection dramatically decreases total storage requirements since capacities for energy storage, discharge and storage throughput decrease from 190 $TWh_{el,eq}$, 658 GW and 1 234 $TWh_{el,eq}$ in the region-wide open trade scenario (reference year 2020), respectively, to 147 $TWh_{el,eq}$, 176 GW and 337 $TWh_{el,eq}$ (reference year 2020) in the area-wide open trade scenario, respectively, where the thermal energy units are converted to electrical energy units by applying the average efficiency of gas turbines. Finally, it can be stated that interconnected HVDC power lines substitute in particular for short-term storage, i.e. transfer of energy in time (storage) is substituted by transfer of energy in space (transmission) by reducing overall generation and storage capacities and increasing transmission capacities to reach a lower total energy system cost.

Table 8.4-4 Total LCOE components in all sub-regions for two scenarios for the reference year 2030

Region-wide	LCOE primary	LCOC	LCOS	LCOT	LCOE total	
	[EUR/kWh]	[EUR/kWh]	[EUR/kWh]	[EUR/kWh]	[EUR/kWh]	
Area average	0,052	0,005	0,025	0,000	0,081	
East Japan	0,048	0,013	0,027	0,000	0,088	
West Japan	0,055	0,003	0,026	0,000	0,084	
South Korea	0,055	0,005	0,046	0,000	0,106	
North Korea	0,073	0,015	0,016	0,000	0,104	
Northeast China	0,046	0,005	0,017	0,000	0,068	
North China	0,045	0,004	0,017	0,000	0,066	
East China	0,061	0,005	0,047	0,000	0,113	
Central China	0,049	0,002	0,011	0,000	0,062	
South China	0,060	0,003	0,027	0,000	0,091	
Tibet	0,030	0,003	0,012	0,000	0,045	
Northwest China	0,042	0,004	0,009	0,000	0,056	
Uygur	0,049	0,003	0,014	0,000	0,066	
West Mongolia	0,051	0,007	0,024	0,000	0,082	
East Mongolia	0,045	0,006	0,023	0,000	0,074	
Area-wide	**LCOE primary**	**LCOC**	**LCOS**	**LCOT**	**LCOE total**	**export (-)/ import (+)**
	[EUR/kWh]	[EUR/kWh]	[EUR/kWh]	[EUR/kWh]	[EUR/kWh]	[%]
Area average	0,046	0,003	0,010	0,004	0,064	0,0
East Japan	0,044	0,001	0,010	0,003	0,057	14,5
West Japan	0,050	0,001	0,012	0,003	0,067	18,8
South Korea	0,047	0,002	0,010	0,013	0,072	57,5
North Korea	0,052	0,007	0,004	0,008	0,071	-78,4
Northeast China	0,042	0,005	0,016	0,004	0,067	-30,1
North China	0,040	0,003	0,010	0,004	0,057	-34,2
East China	0,058	0,001	0,020	0,017	0,096	64,5
Central China	0,046	0,003	0,006	0,003	0,059	-29,2
South China	0,062	0,002	0,014	0,005	0,083	34,3
Tibet	0,027	0,005	0,007	0,002	0,042	-16,2
Northwest China	0,040	0,004	0,006	0,002	0,051	-11,5
Uygur	0,048	0,002	0,012	0,002	0,064	11,7
West Mongolia	0,049	0,005	0,020	0,003	0,077	9,1
East Mongolia	0,043	0,006	0,019	0,003	0,071	1,1

(The share of export is defined as the ratio of net exported electricity to generated primary electricity of a sub-region and the share of import is defined as the ratio of imported electricity to electricity demand. The area average is composed of sub-regions' values weighted by electricity demand. (The scenarios are defined by Fig. 8.3-1, and Tables 8.3-1 and 8.3-2.)

The findings of this section can be summarized for the aggregated area in an energy flow diagram comprising the primary RE resources converters (wind power, solar PV, hydro run-of-river, hydro dam), the energy storage (PHS, battery, power-to-gas, CCGT, OCGT) and the HVDC transmission grid. The difference of primary power generation and final electricity demand is subdivided into potentially usable heat and the ultimate system loss, both are constituted by curtailed electricity, ~~by~~ heat of transforming power-to-hydrogen in the electrolyzers, hydrogen-to-methane in the methanation and methane-to-power in the gas turbines, efficiency loss in PHS and battery storage, as well as by HVDC transmission grid (not yet accounted in this article). This energy flow characteristic is visualized in Fig. 8.4-4 for two selected scenarios.

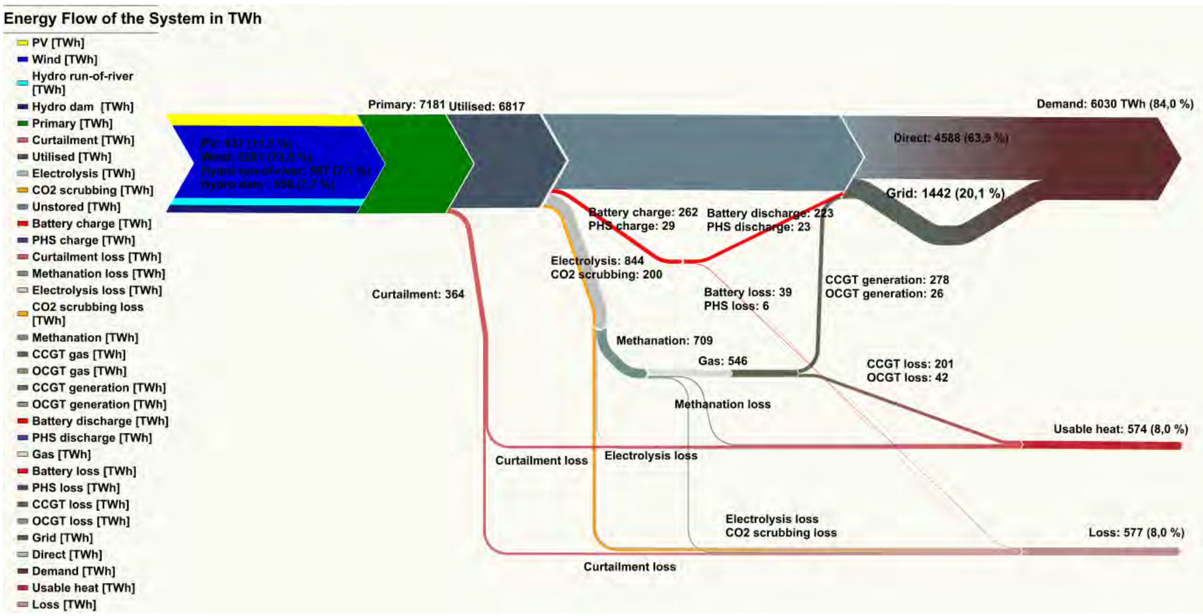

Fig. 8.4-4 Energy flow of the system for the scenarios area-wide open trade for the reference year 2030
(Please note the 'usable heat' is accounted as loss in this work, however it could be used in the heat sector in case of temporal and spatial match of demand and supply.)

The area-wide open trade scenario for the reference year 2020 costs 0,077 EUR/kWh whereas the cost of the region-wide open trade scenario for the reference year 2030 is calculated at 0,081 EUR/kWh. Due to the different reference years, the total LCOE of the energy system cannot directly be compared, but roughly the same absolute costs have to be raised to cover the same electricity demand. However, the two energy systems differ structurally since in the area-wide scenario 24 % of the generated energy is traded inter-regionally, 1 % is stored and contribution shares of solar PV and wind energy are about 6 % and about 79 %. In the region-wide scenario the same final electricity demand is covered by 0 % inter-regional trade, 33 % storage contribution, 39 % solar PV generation and 47 % wind energy generation. The ultimate system loss and the potentially usable heat differ slightly in the two scenarios with 9 % and 9 % (area-wide) and 12 % and 10 % (region-wide), respectively. The potentially usable heat is accumulated closer to the energy demand centers in the region-wide open trade scenario, leading to a higher probability of actual usage, providing a higher value to that heat. However, this potentially usable heat can only be beneficial in case of temporal and spatial match of demand and availability. Future research which also integrates the heat sector can derive an economic value for the potentially useful heat being lost. This represents a constraint of the work presented in this article.

8.5 Conclusions

The 100 % renewable energy system in Northeast Asia is no wishful thinking; it is a real policy option, in particular due to rapidly decreasing RE technology LCOE and improving storage economics. The HVDC transmission grid plays a key role since the established supergrid enables a substantial cost decrease of the renewable resources-based energy system, as the total system LCOE decreases from

0,115 EUR/kWh to 0,077 EUR/kWh for the reference year of 2020 and from 0,081 EUR/kWh to 0,064 EUR/kWh for the reference year of 2030 for the region-wide and area-wide open trade scenarios, respectively. The major LCOE decrease is caused by cut-off of storages utilization and significantly reduced primary generation capacities. However, the LCOE spread of the scenarios is reduced significantly from 0,038 EUR/kWh (2020) to 0,017 EUR/kWh (2030), which may indicate that a very large scale RE integration could provide a too small economic benefit for its realization. Such results have already been found for the case of Germany[28-28)], but one has to have in mind that the area of Northeast Asia and Germany cannot easily be compared; nevertheless, the structure of results needs to be investigated in more detail.

In parallel the total capex requirements are reduced substantially from about 6 100 billion EUR to about 4 400 billion EUR for the reference year 2020 by taking the HVDC transmission grid into account. The total capex requirements for 2030 assumptions are reduced from about 4 600 billion EUR to about 3 800 billion EUR. The total capex requirements reflect the LCOE results.

The very good economics of wind energy heavily influences the optimized energy system design. However, some intended improvements of the model will partly reduce the dominance of wind energy, such as transmission losses of HVDC power lines, 1-axis tracking PV systems and PV self-consumption of prosumers.

The trade-off between grids and storage is well known. The found LCOE difference of 0,038 EUR/kWh (2020) and 0,017 EUR/kWh (2030) between the area-wide and region-wide open trade scenarios clearly documents the assumed increasing competitiveness of storage solutions. The attractiveness of a strongly interconnected transmission grid over a large area is dependent on the spread of the centralized and decentralized system option. The smaller the LCOE difference of a highly centralized to a highly decentralized energy system becomes the less attractive will be a centralized approach finally. More decentralized approaches might be also in the long-run the cheaper option since very large scale energy infrastructure projects are often characterized by cost and time overruns and local support of the population is typically higher for more regional approaches. However, for some regions a more centralized energy system in Northeast Asia is very relevant due to rather unattractive RE resource availability (e.g. East China) or limited area for RE utilization (e.g. South Korea).

The findings for the Northeast Asian 100 % renewable resources-based energy system can be compared to most recent insights in Europe about non-renewable options, such as nuclear energy, natural gas and coal carbon capture and storage (CCS) alternatives[30)]. These alternatives lead also to a decarbonized energy system, which is of utmost relevance for a climate change mitigation strategy. The LCOE of the alternatives are as follows: 11,2 EUR/kWh for new nuclear (assumed for 2023 in the UK and Czech Republic), 11,2 EUR/kWh for gas CCS (assumed for 2019 in the UK) and 12,6 EUR/kWh for coal CCS (assumed for 2019 in the UK). However, a recent report published by the European Commission[31)] concludes that CCS technology is not likely to be commercially available before the year 2030. The findings for Europe are assumed to be also valid for Northeast Asia in the mid-term. The 100 % renewable resources-based energy system options for Northeast Asia presented in this work are considerably lower in cost (about 30-40 %) than the higher risk options, which have still further disadvantages, such as nuclear melt-down risk, nuclear terrorism risk, unsolved nuclear waste disposal, remaining CO_2 emissions of power plants with CCS technology, diminishing conventional energy resources base and high health cost due to heavy metal emissions of coal fired power plants.

More research is needed for a better understanding of a fully optimized renewable energy system in North-East Asia, however, this research work clearly indicates that a 100 % renewable resources-based energy system is a real policy option.

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Annex

Task8 participants

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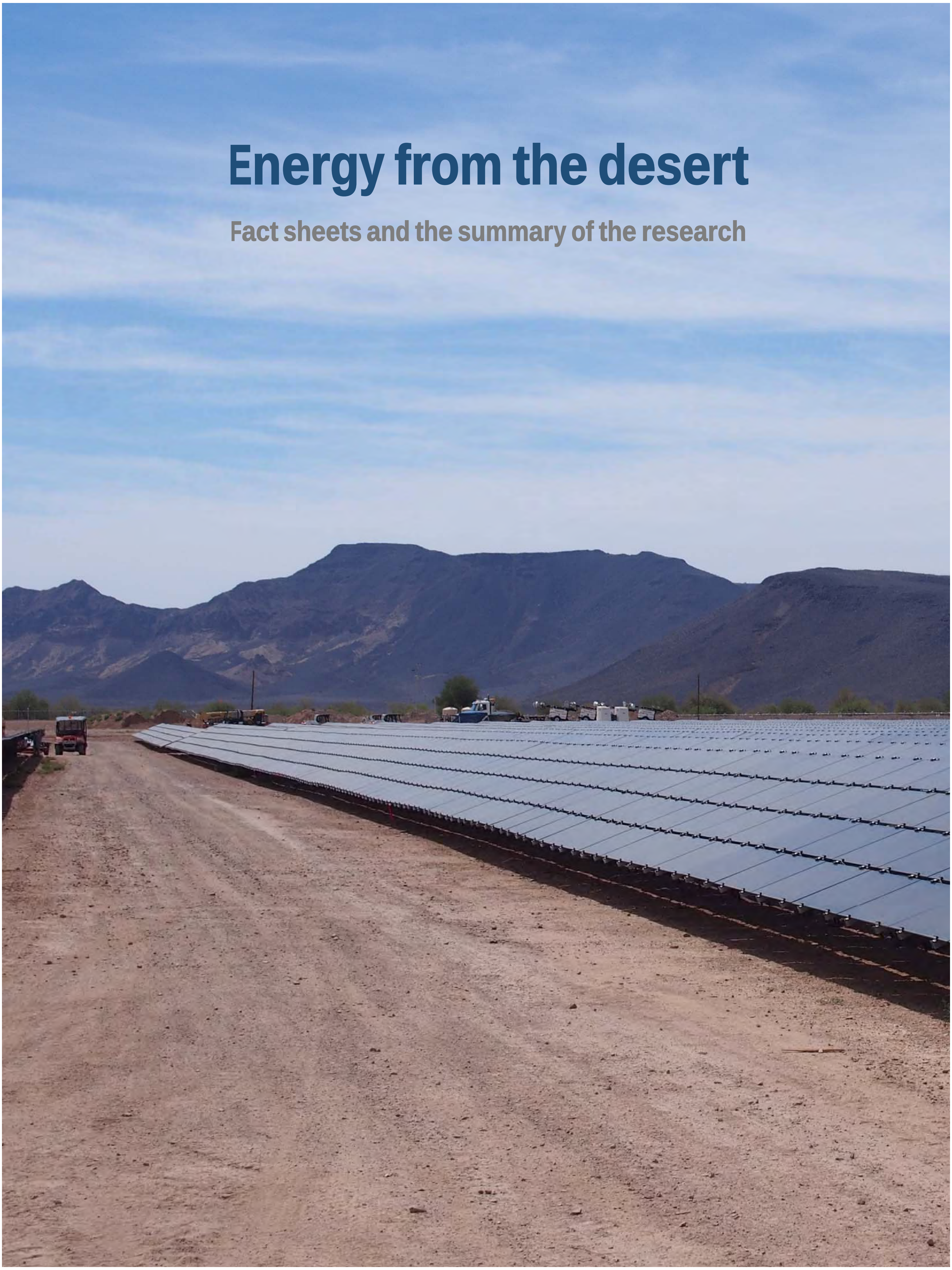
Energy from the desert

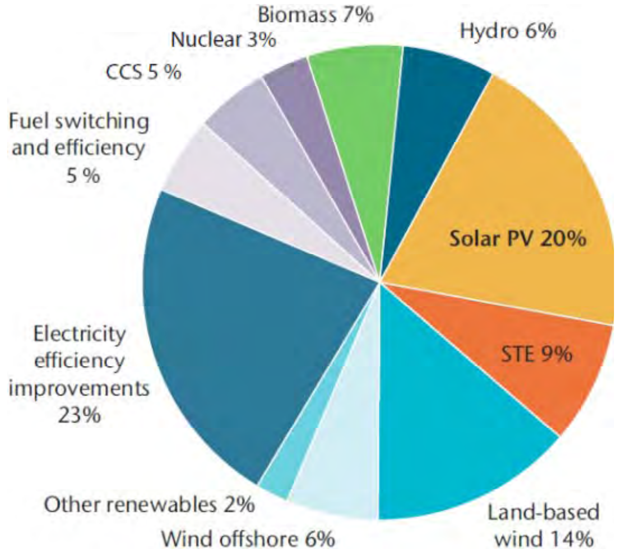
Fact sheets and the summary of the research



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

(©OECD/IEA 2014, Technology Roadmap: Solar Photovoltaic Energy, fig.6, p. 19, IEA Publishing. Licence: www.iea.org/t&c/termsandconditions)

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

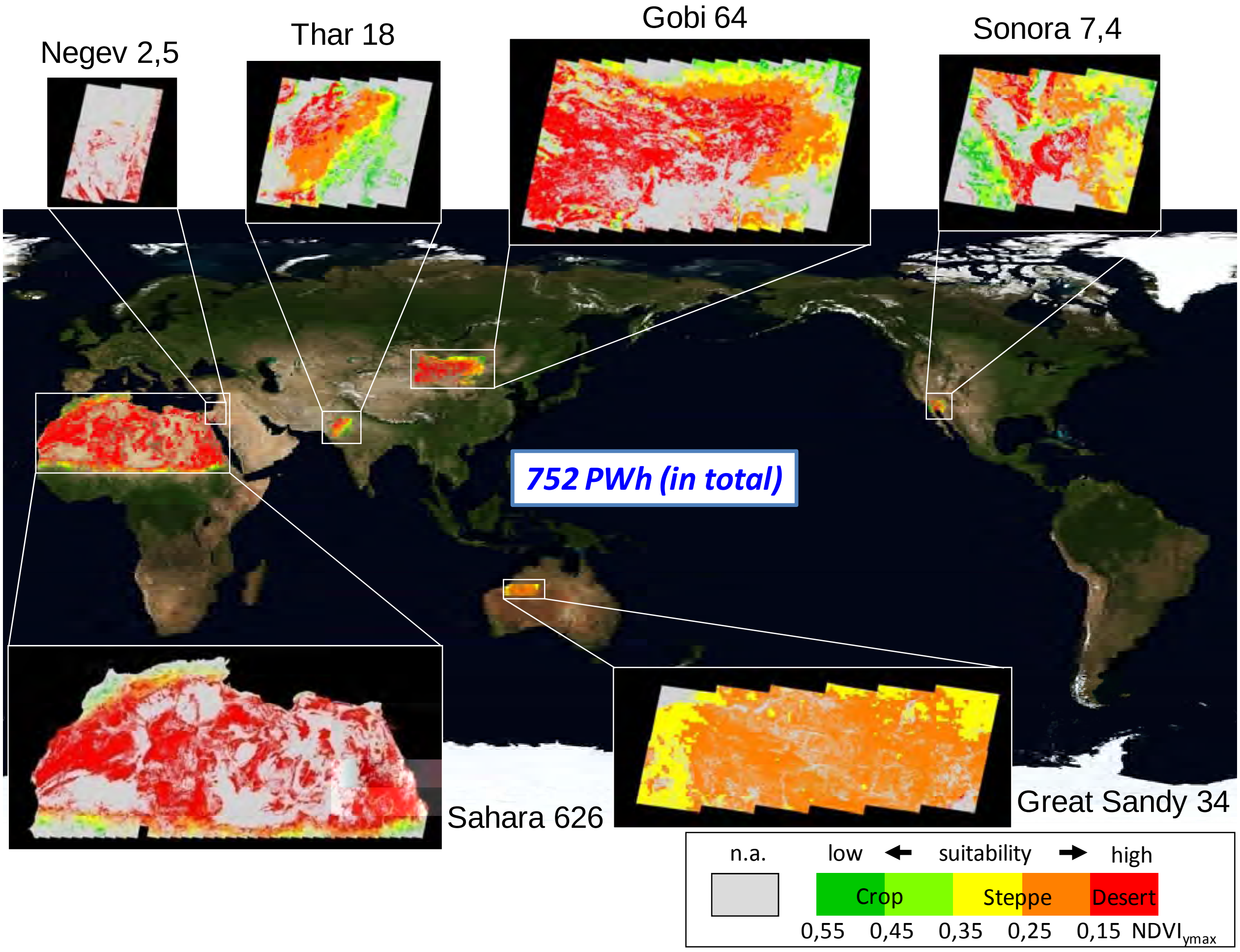
5 times

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.

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.

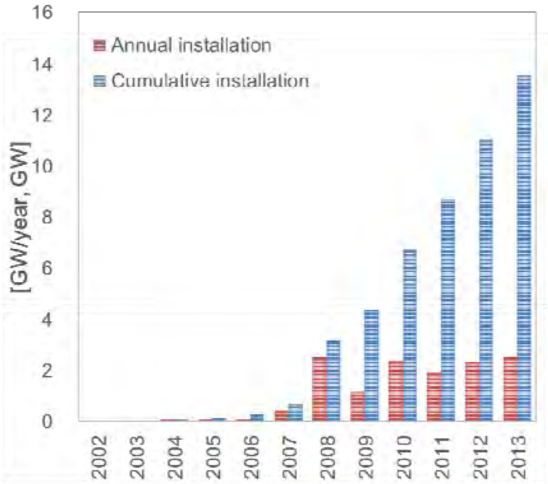


Expected annual electricity generation at the PV power plants in world 6 deserts

VLS-PV market expands drastically

VLS-PV market expands in a stable manner

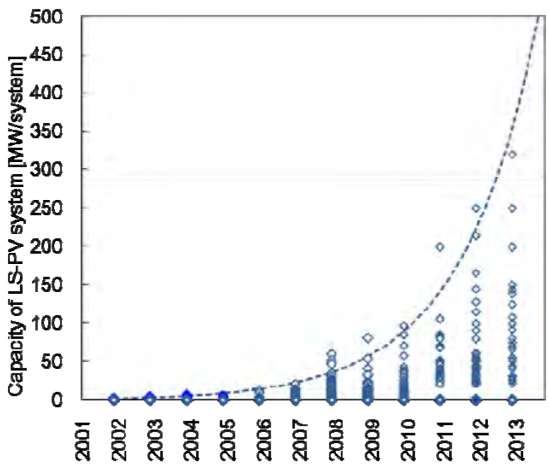
Large scale PV power plants came on the market first in the latter half of 2000s, and many large scale PV power plants over 20 MW were installed in Europe, under the Feed-in-Tariff scheme. After that, large scale PV power plant market expanded to other regions such as in USA and China. Today, PV power 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.)

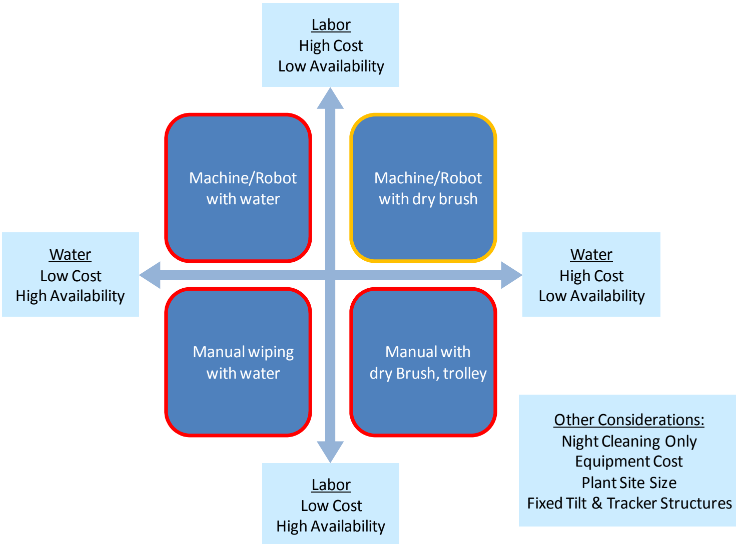
Longyangxia, Qinghai, China (520MW$_{DC/AC}$, c-Si)
(©Yellow River Hydropower Company)

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

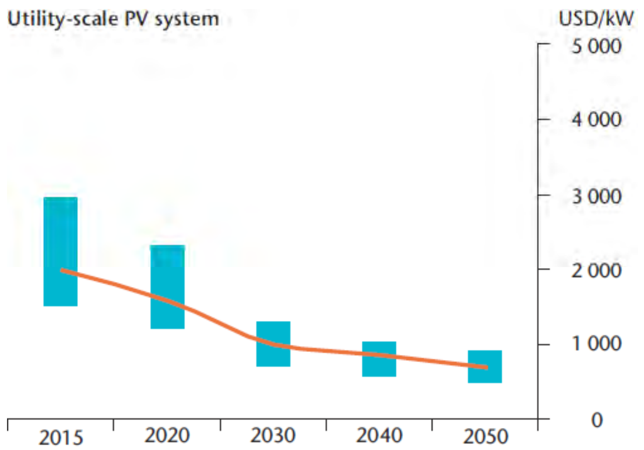
Other technical issues

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.

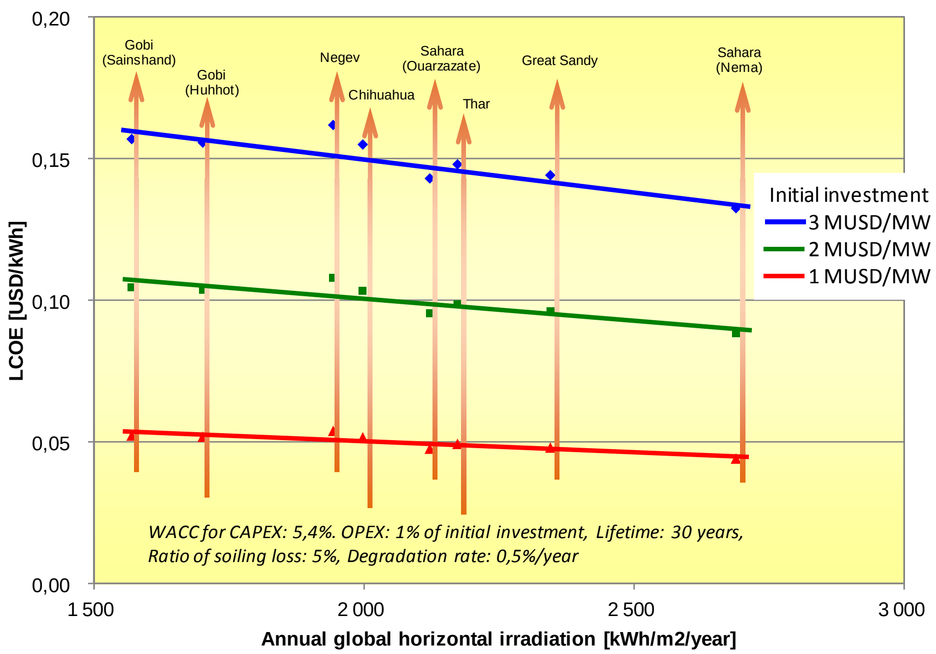


PV investments costs projections in the hi-Ren scenario of Energy Technology Perspective 2014

(©OECD/IEA 2014, Technology Roadmap: Solar Photovoltaic Energy, fig.11, p. 23, IEA Publishing. Licence: www.iea.org/t&c/termsandconditions)

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

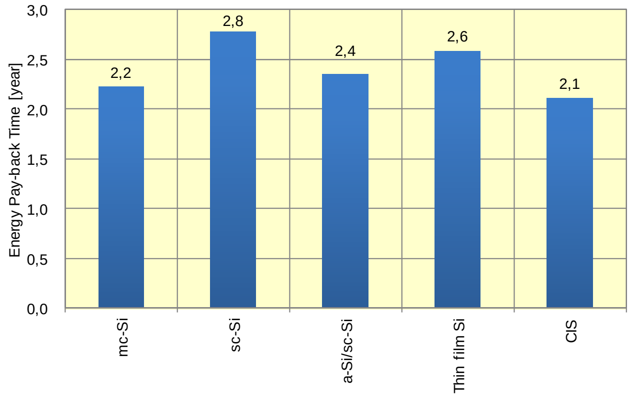
VLS-PV can contribute to sustainable world

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).



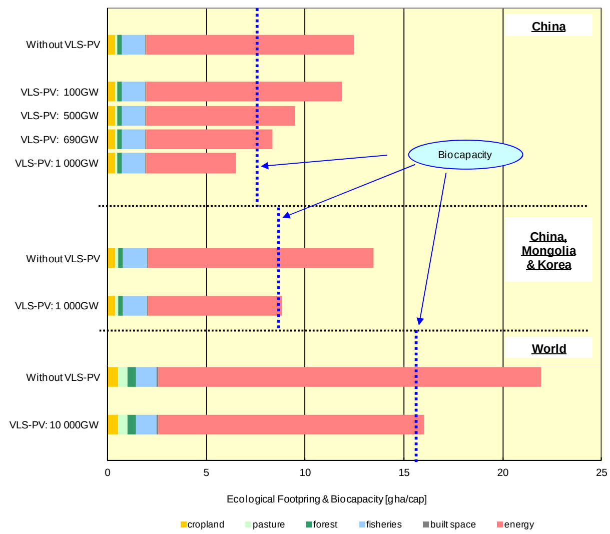
Energy pay back time of 1 GW PV power plant by PV technologies in the Gobi desert, China

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

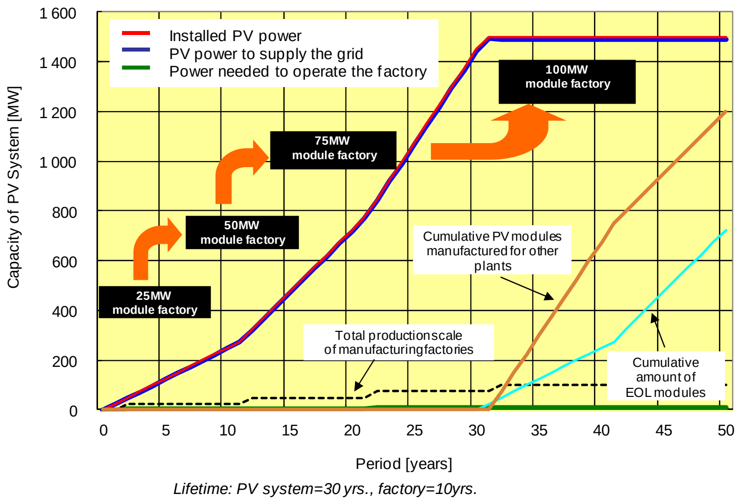
VLS-PV as a tool for social development

VLS-PV development scenario for local employment

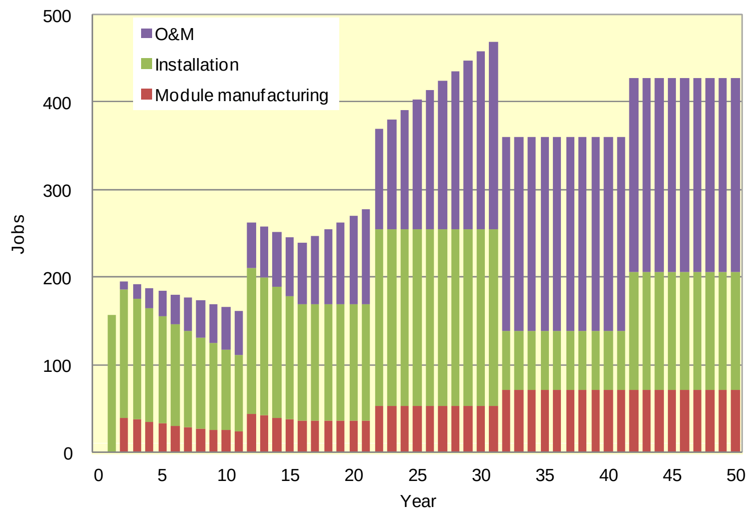
A construction of GW-scale PV power plant will create substantial and stable demand for PV system components as well as employment for construction if the construction is managed in an appropriate manner. Below is one of our scenario proposed for GW-scale PV power plant with sustainable social development. 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.



Sustainable scenario for VLS-PV development



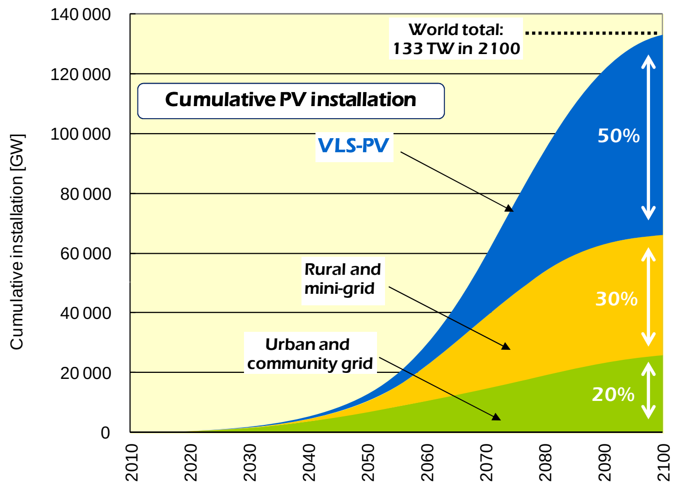
Direct employment by VLS-PV project, with productivity improvement

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.

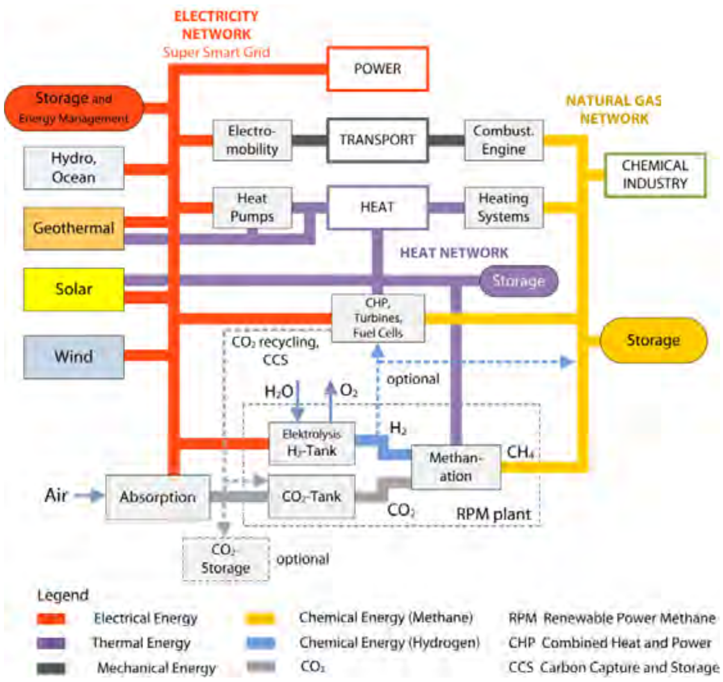
The VLS-PV roadmap is based on assumption; PV electricity will provide one-third of primary energy supply in the world; PV application will be roughly classified rural and mini-grid, urban and community grid, and VLS-PV (PV power plants); VLS-PV will provide a half of PV electricity expected in 2100. 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.

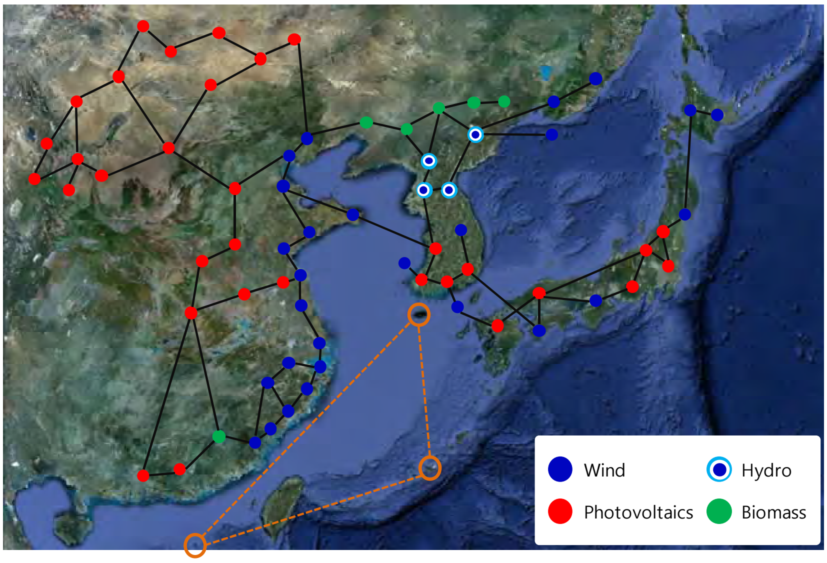


Hybrid PV-Wind-RPM plant as the integral centrepiece of a future sustainable energy supply system

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.

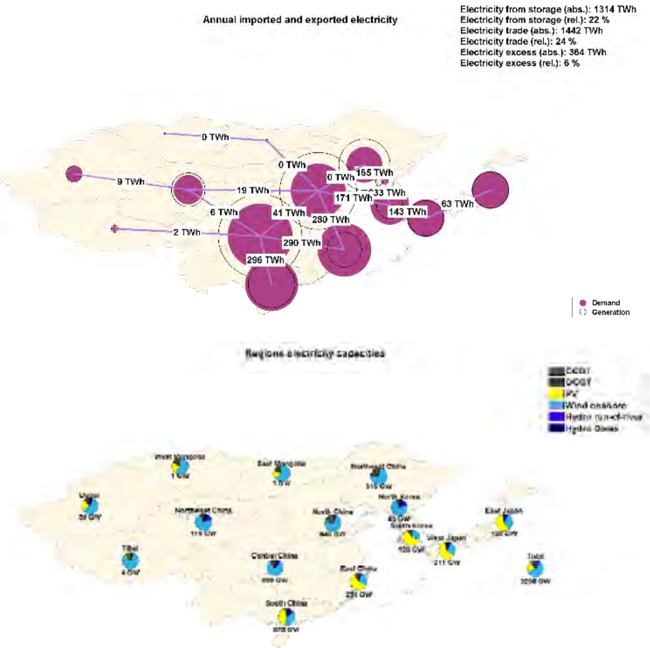
Global deployment of PV power plants will be accelerated by developing an energy supplying system combined with other renewables and energy storage technologies. Our precise study reveals that 100% Renewable Energy system in Northeast Asia is reachable. PV will play an important role although wind energy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

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.



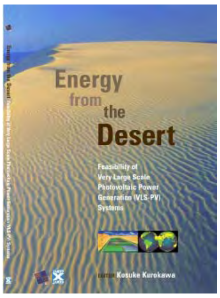
Annual generation and demand (top) and installed capacities (bottom) for area-wide open trade scenario for Northeast Asia and reference year 2030.

For further information

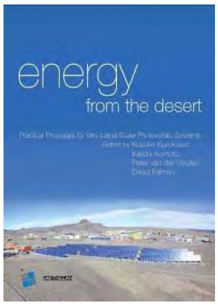
Our publication: Energy from the Desert

Task8 group has published our extensive reports as a series of 'Energy from the Desert', focusing on VLS-PV systems. The books show that the VLS-PV is not a simple dream but is becoming realistic and well-know all over the world.

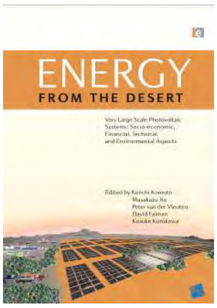
Kosuke Kurokawa, (eds.), 2003. Energy from the Desert - Feasibility of Very Large Scale Power Generation (VLS-PV) Systems, James & James, London



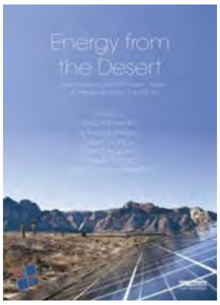
Kosuke Kurokawa, Keiichi Komoto, Peter van der Vleuten, David Faiman, (eds.), 2007. Energy from the Desert - Practical Proposals for Very Large Scale Photovoltaic Systems, Earthscan, London



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



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



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

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