SUMMARY

Energy from the Desert

Very Large Scale Photovoltaic Power – State of the Art and Into the Future

Edited by
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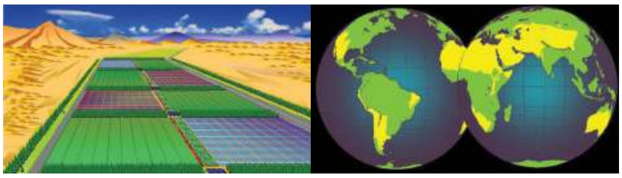

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Routledge
Taylor & Francis Group
LONDON AND NEW YORK
earthscan
from Routledge

First published 2013
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Simultaneously published in the USA and Canada
by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication data
Very large scale PV power : state of the art and into the future / edited by Keiichi Komoto, Christian Breyer, Edwin Cunow, Karim Megherbi, David Faiman, Peter van der Vleuten.
p. cm. – (Energy from the desert ; 4)
1. Photovoltaic power systems. I. Komoto, Keiichi.
TK1087.V47 2013
621.31´244–dc23 2012018942

ISBN13: 978-0-415-63982-8 (hbk)
ISBN13: 978-0-203-08140-2 (ebk)

Typeset in Bembo
by HWA Text and Data Management, London

Contents

Foreword

Looking at recent developments, the role of solar photovoltaic electricity in the future energy supply can be observed to increase constantly in present energy scenarios, policies and, above all, the real markets. Looking at the topic from an International Energy Agency (IEA) perspective, three recent publications mark the increasing role of renewable energy in general and photovoltaics in particular: the *IEA Technology Roadmap Solar Photovoltaic Energy* (2010), the *IEA Energy Technology Perspectives* (2010) and the *IEA Solar Energy Perspectives* (2011). The common message of these publications regarding solar energy and photovoltaics particularly is that this technology *can* provide significant contributions to the future electricity supply. Looking at the greater energy picture, climate change issues, the development of fossils fuels and the Fukushima nuclear accident have increased the perception that renewable energy not only can but will *have to* contribute strongly to the future energy supply. Furthermore, the recent rapid growth of photovoltaic markets all around the world, together with dramatically reduced costs, provides the confidence that photovoltaics *will* be able to play the expected role. These times are thus crucial for the future development of this young energy technology which is facing the challenges of rapid implementation, fast industry growth, increasing market dynamics and fierce global competition.

This new IEA PVPS Task8 book on Very Large Scale Photovoltaic Power Generation Systems comes at a time when photovoltaic solar electricity is about to achieve generation costs close to or at the costs of the retail electricity market. As a result of this development, utility scale photovoltaic applications are observed to be increasing in various countries with high solar irradiation. This trend marks the beginning of a transition from a policy driven to a more business oriented market.

The work of IEA PVPS Task8 is an excellent example of the forward looking nature of international cooperation within the IEA PVPS Implementing Agreement. When the project started in 1999, very large scale photovoltaic power systems were seen as a futuristic, long-term concept which many doubted would ever become reality. Today, only 13 years later, we can see many examples of large and very large scale photovoltaic power systems being planned and realized. The vision of Professor Kosuke Kurokawa who inspired the work of IEA PVPS Task8 has become reality much faster than expected.

This new edition of *Energy from the Desert* provides a very useful update on all critical elements, issues and solutions related to very large scale photovoltaic power systems, with concrete examples of what has been realized so far around the world. Another highlight of this new edition is the comparison with other large scale solar energy concepts such as Concentrated Solar Power (CSP) and Concentrated Photovoltaics (CPV). Finally, the book also serves as a comprehensive compendium of the many publications relevant for large scale photovoltaic power systems.

Therefore, the publication of this book is very timely for the future expected growth of large scale photovoltaic power systems and will help to satisfy the increasing need for information in this growing field. I would like to thank Keiichi Komoto for leading the work of IEA PVPS Task8 and all the experts for their dedication and contributions necessary in making this publication possible. I am sure that this book will have many interested readers who will find the insights provided most inspiring for their future work.

Stefan Nowak
Chairman IEA PVPS Programme
May 2012

Preface

"It might be a dream, however …". This was our motivation when Task8 was established in 1999. Since then, we have published extensive reports as the series 'Energy from the Desert', focusing on very large scale photovoltaic power generation (VLS-PV) systems. The books show that VLS-PV is not a simple dream but is becoming realized and well known all over the world.

During our work, large scale PV systems increasingly count as a realistic energy option and have started to appear around the world; 100 MW scale PV systems are becoming a reality.

Since the nuclear accident in Japan caused by the Great East Japan Earthquake on 11 March 2011, energy policies around the world have been more likely to change direction to less nuclear energy or denuclearization eventually. In parallel, the importance and expectation of renewable energy technologies are increasing drastically as possible energy infrastructure, as well as environmental friendly technology.

Not only as a Japanese, but also as Operating Agent of PVPS Task8, I strongly felt that the direction of this publication and the next step of Task8 activity should be reconsidered. Discussions for preparing this publication within the Task8 group might be the most fruitful discussions since Task8 was established.

Some people are of the opinion that our concept, VLS-PV, is being overtaken by market developments. In a way, this might be correct. However, states/governments all over the world consider solar power plants as a viable option for their energy policy.

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 and that VLS-PV systems must be a promising option for large scale deployment of PV systems and renewable energy technologies.

We believe solar energy can realize our bright future.

Keiichi Komoto
Operating Agent, Task8

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Executive summary

A.1 INTRODUCTION AND OVERVIEW: POTENTIAL OF VLS-PV

Objectives

The purpose of this study is to examine and evaluate the potential and feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) systems, which have capacities ranging from several megawatts to gigawatts, and to develop strategies toward implementing the VLS-PV systems in the future (see Figure A.1).

Our study has comprehensively analysed all major issues involved in such large scale applications, based on the latest scientific and technological developments and by means of close international cooperation with experts from different countries [1, 2, 3].

From the perspective of the global energy situation, global warming, and other environmental issues, it is apparent that VLS-PV systems can:

- contribute substantially to global energy needs;
- become economically and technologically feasible soon;
- contribute significantly to global environment protection;
- contribute significantly to socio-economic development.

Also, it is concluded that desert regions contain an abundant and inexhaustible source of clean energy and 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.

During the past 10 years, MW-scale PV systems have been increasing substantially in the world and 100 MW-scale PV systems are becoming reality. Further realistic discussions and plans of over 100 MW-scale and GW-scale PV systems are going on in some regions. However, to accelerate and implement real VLS-PV projects, decision-makers should be informed about the feasibility of such projects in and around desert regions in an appropriate manner.

VLS-PV basically means generation of electricity by means of solar irradiation at utility scale. In our specific case, we have studied utility scale generation of solar electricity in desert regions. By nature, desert regions are rich in sunshine, water is scarce and they are sparsely populated. Living conditions in deserts are harsh and they are often considered as unproductive land.

Solar electricity generation at utility scale can change this situation substantially. This will not only provide an infinite, sustainable and inexhaustible source of energy, but also offer the possibility for establishing a source for socio-economic growth in the region. Deserts have the potential to become the future powerhouses of the world.

Based on the viewpoints mentioned above, this report will show the overview and potential of VLS-PV, guidelines for VLS-PV systems, technical options and strategic options

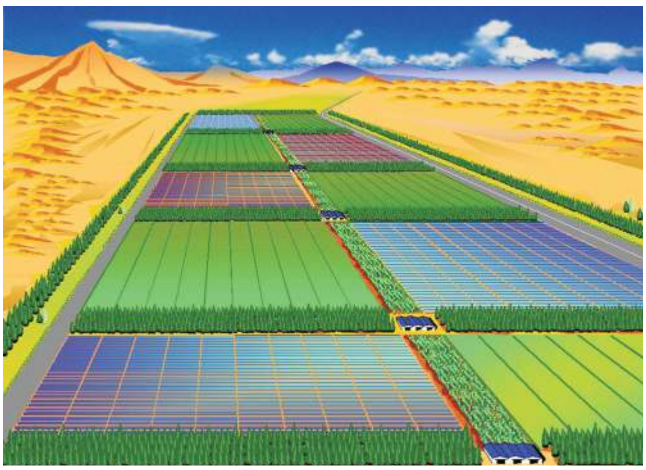

Figure A.1 An image of a VLS-PV system in a desert area for implementing VLS-PV, and will propose our next steps into the future.

Proposed scenarios for solar and renewable energy

It has been repeatedly pointed out by scientists that human beings will face several sustainability issues sooner or later if appropriate measures are not taken promptly, especially from the environmental point of view. It is clear that the anthropogenic environmental burden will be greater than the capacity of the Earth as the global population and its economic activities expand at the current pace.

There are many projections for global energy supply but the roles of PV and other renewable energy vary greatly among the scenarios. Those are heavily dependent on underlying assumptions and projection approaches. In general, PV is expected to increase drastically in most scenarios but it might take a few decades to be a main energy source in the global energy mix without innovations.

PV has already achieved more than some projections presented in the past, for example, *IEA: World Energy Outlook*, and should continuously go over projection in order to become a main energy supply. Achievement of the projection by *IEA: Energy Technology Perspectives* [4] and *PV Roadmap* [5] toward 2050 (see Figs. A.2 and A.3) should be the minimum level, and then the VLS-PV roadmap toward 2100 should be targeted as we proposed in our previous edition [3]. Also, many countries/regions have set ambitious targets for solar and renewable energy.

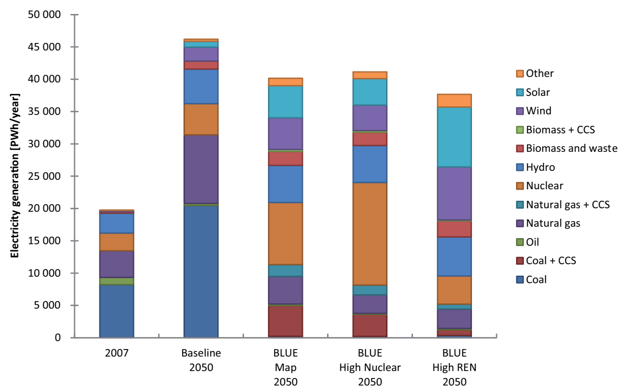

Figure A.2 Projection of electricity generation in different scenarios in ETP [4]

An excellent example of how such a fully renewable powered energy system could work has been analyzed for the Desertec project focused on a cooperation of Europe (EU) and North Africa and Middle East (MENA). The EU-MENA Desertec project gained pace by the Desertec Industrial Initiative (Dii) led by industry giants [6] and might become a blueprint for similar interregional cooperation in other parts of the world reaching a global power grid. As an industrial initiative, Dii assumes the role of a facilitator. It will ensure that development projects come to fruition, but not make any investments itself either by constructing or operating power plants. The focus of the planning phase is to establish the appropriate framework and create a lasting structure for renewable energy which will make long-term commitments to solar energy plants (solar PV and solar thermal) and wind farms, as well as integrated networks, attractive to public and private investors. The Desertec vision has become a real project for a sustainable energy supply within the EU-MENA region and gained a lot of momentum for harvesting the precious and nearly unlimited energy resources of the deserts of the world. Very large scale PV power plants are expected to become a cornerstone of such an energy system based on a real sustainable fundament.

In the Mediterranean region, it is recognized that current trends on energy supply and demand are not sustainable and will strain energy security. The following actions are necessary immediately as alternative countermeasures:

- Increase renewables in power generation and in final use
- Demand-side management policies

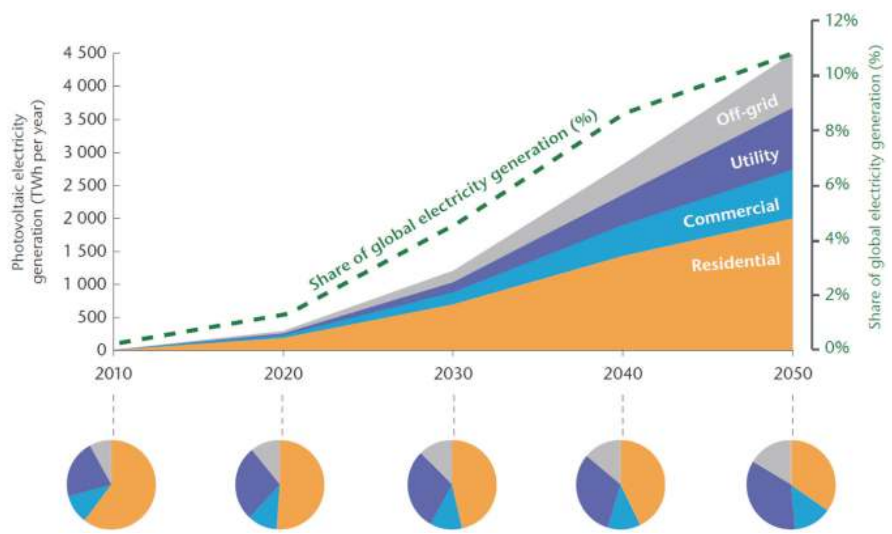

Figure A.3 PV roadmap presented by IEA [5]

- Encourage energy efficiency and energy conservation
- Remove progressively subsidies
- Invest in research, technology and innovation.

In addition to the Dii, the Mediterranean Solar Plan (MSP) and relative initiatives for deploying renewable energy in the Mediterranean region are ongoing. The MSP is one of the key projects proposed within the Union for the Mediterranean, and intends to increase the use of solar energy and other renewable energy sources for power generation, improve energy efficiency and energy savings, develop electricity grid interconnections and foster and encourage the transfer of know-how and technology towards developing countries. The final target is the development, by 2020, of 20 GW of new renewable energy installed capacity in the Southern and Eastern Mediterranean countries.

On the other hand, in the Asian region, the Asian Development Bank (ADB) announced the launch of the Asia Solar Energy Initiative (ASEI) [7], targeted to assist in identifying, developing, and implementing 3 000 MW of solar power in Asia and the Pacific over the next 3 years. The ASEI aims to create a virtuous cycle of solar energy investments in the region, toward achieving grid parity, so that ADB developing member countries optimally benefit from this clean, inexhaustible energy resource. To meet its target, the ASEI will use an integrated, multipronged approach featuring three interlinked components:

- Knowledge management: The Asia Solar Energy Forum
- Project development: 3 000 MW of solar capacity
- Innovative finance: The Asia Accelerated Solar Energy Development Fund.

The ASEI has the potential to not only drive down costs and to usher in innovation in the solar space, but also to demonstrate replicable models to sustain solar capacity additions in Asia and the Pacific. It is also expected to serve as a model for other regions in the world, such as northern Africa, Latin America, and the Caribbean, which are similarly placed. There has been keen support for the ASEI and ADB leadership in this area. Beyond the next 3 years, measures of ASEI's success will be the widespread reach of solar energy generation programs across developing member countries (DMCs) in Asia and the Pacific, and the extent of mainstreaming of solar energy as an option for generating capacity addition in all DMCs with significant potential for solar energy in the region. ADB is committed to seeing this success in the future of Asia and the Pacific.

Global potential of solar energy resource

Energy resource availability is decisive for all power technologies. The basis for all solar energy technologies is the amount and the composition of the global horizontal irradiation (GHI). Different solar system concepts have been developed for optimizing the energy yield. Solar resources adapted to systems' requirements are derived and compared with each other.

Global horizontal irradiation is more or less homogenously distributed on Earth (Figure A.4). Variations of GHI for most populated regions in the world are typically within a range of a factor of two, e.g. Central Europe (~ 1 100 kWh/m²/y) and Arabian Peninsula (~ 2 200 kWh/m²/y). NASA Surface meteorology and Solar Energy (SSE) 6.0 dataset is taken for all calculations [8].

Absolute and relative diffuse irradiation is strongly coupled to regional climatic conditions, in particular to daily and seasonal occurrence of clouds. Most deserts on Earth are located between 15° and 40° N/S. Diffuse irradiation in deserts is quite low and ranges typically between 15 percent and 30 percent. Diffuse irradiation is lost for solar power technologies only capable of converting direct solar irradiation, thus sites of low diffuse irradiation are most appropriate for these technologies. Solar system technologies increasing insolation on active surfaces by tracking the Sun's position are most beneficial for lower diffuse irradiation.

A major advantage of solar PV technology is the need for no moving parts; this is still the case for fixed optimally tilted systems. To give up such a great advantage very good reasons are needed; these might be given for specific tracking systems. 1-axis north-south horizontal continuous tracking systems follow the Sun over the day. 1-axis north-south optimally tilted tracking systems are better adapted to each site latitude. The PV system of highest annual irradiation is the 2-axes non-concentrating tracking system. A large plant area is needed due to two-directional shading effects and a higher mechanical stress and cost is effective due to more moving parts and engines. 2-axes concentrating tracking variation is only needed for high concentrating PV (HCPV) systems and solar thermal electricity generation (STEG).

Summarizing the results, 1-axis horizontal north-south continuous tracking PV systems might be competitive for fixed optimally tilted PV systems. An increase in irradiation of 20–30 percent for sunny and very sunny regions might justify higher capital and operational expenditures, especially for plant operators achieving further advantages by more full load hours of the PV plant [9]. 2-axes non-concentrating and concentrating tracking PV systems further increase the irradiation on the module surface; however the higher complexity of such systems significantly reduces the financial benefits of these approaches. In the case of HCPV systems, significantly higher power conversion efficiencies in reference to non-concentrating PV systems result in about 35 percent higher electricity generation potential per area unit, leading to a beneficial cost potential of HCPV systems.

In total, solar resource is available in all populated regions in the world. Fixed optimally tilted PV systems

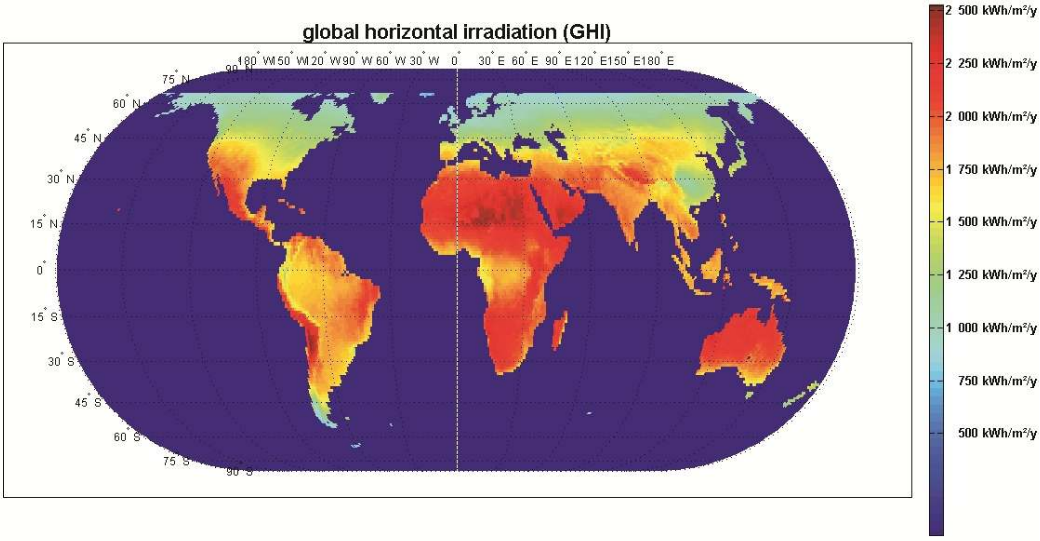

Figure A.4 Annual global horizontal irradiation (GHI)

are the standard PV power plant system types, however depending on local conditions, adapted tracking systems increase the annual yield per installed capacity and lower the power generation cost.

PV market potential for 2020

Photovoltaic energy technology has the potential to contribute to the global energy supply on a large scale. This potential can only be realized if sustainable and highly competitive PV economics are achieved. An integrated economic PV market potential assessment is presented consisting of grid-parity and fuel-parity analyses for the on-grid markets and an amortization analysis for rural off-grid PV markets. All analyses are mainly driven by cost projections based on the experience curve approach and growth rates for PV systems and electricity and fossil fuel prices for the currently used power supply. Finally the outcome of the derived economic PV market potential has been transformed to pessimistic, realistic and optimistic estimates of a cumulated installed PV capacity by the end of 2020. These installed capacity estimates are compared with PV scenarios published by leading organizations in the field of energy and PV scenarios.

The economic PV market potential derived by the grid-parity approach is estimated to about 980 GW up to 3 930 GW and in the most likely case to about 2 070 GW by the year 2020, if an advanced economic storage system for PV electricity is available [10]. The market estimate according to the fuel-parity approach leads to about 900 GW up to 1 500 GW fully economic potential for PV power plants in the year 2020 [10]. The total addressable economic market potential for rural off-grid PV applications is estimated as about 70 GW [10]. An integrated economic PV market potential has been performed to avoid double counting. The integrated assessment leads to an overall sustainable economic PV market potential of about 2 800 GW to 4 300 GW in the year 2020 [10].

The outcome is depicted in Figure A.5 for an integrated sustainable economic market potential estimate for PV systems on the basis of a learning rate of 20 percent for modules and inverters and 15 percent for the other balance of system (BOS) components.

Only a fraction of the market potential will be realized in time, thus PV market expectations are derived resulting in cumulated installed PV capacity for the year 2020 in a pessimistic (600 GW installed capacity in 2020 and an annual growth rate of 20 percent), realistic (1 000 GW in 2020 and growth rate of 30 percent) and optimistic market view (1 600 GW in 2020 and growth rate of 40 percent) [10]. Only EPIA and Greenpeace can imagine such a fast progress in PV development. Other leading organizations like the IEA, WWF and EWG expect about one third or even less compared with the derived pessimistic market expectation.

Due to the complementarity of solar PV and wind power, market expectations for PV need not be lowered. Moreover, being complementary to wind power, PV together with wind power might become the backbone of the global energy supply in the coming decades [11, 12]. However, hybrid PV-Wind systems are very likely to start to strongly influence the global power system in the next decade by sophisticated hybrid concepts, like renewable power methane technology. The fast progress of sustainable energy technologies seems not to be included in current energy scenarios of leading international organizations. Plenty of indications are given that several organizations would make no mistake in revising their scenarios in the field of PV. In conclusion, PV is on its way to become a highly competitive energy technology.

Trends in large-scale PV systems

Installation of large-scale (MW-scale) PV systems has been increasing substantially year by year throughout the world. The starting point and milestones for this development

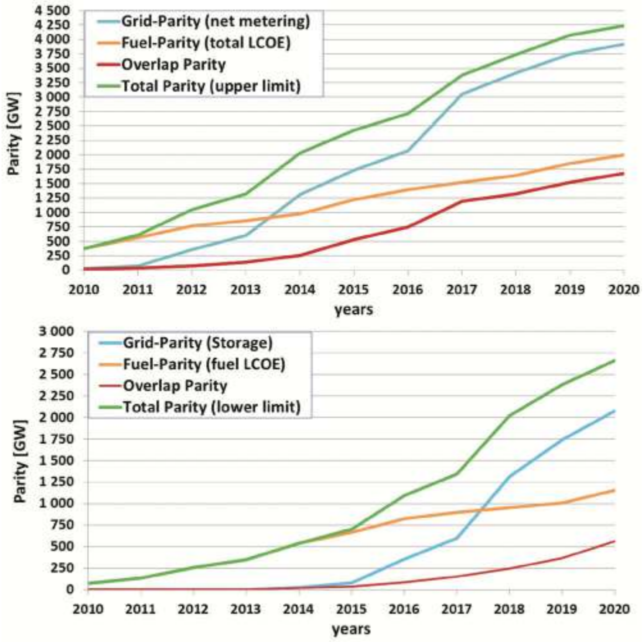

Figure A.5 Total economic market potential for PV systems in the 2010s in the upper (top) and lower limit (bottom)

have been the feed-in-tariff schemes in European countries. These schemes created an attractive market for developers, investors, etc. and a new business model of MW-scale PV systems was established.

In 2011, the number of MW-scale PV systems is over 1 500, and that of PV systems over 20 MW is more than 80. Among these, the largest PV system, Perovo I-V PV power plant in Ukraine is 100 MW, constructed in December 2011. The second largest PV system, Sarnia PV power plant in Ontario, Canada is 97 MW_{AC} (80 MW_{DC}), and the third largest PV system, Montalto di Castro PV power plant in Lazio, Italy is 84 MW.

Summing up MW-scale PV systems installed by 2011, the total capacity of MW-scale PV systems has reached more than 8 GW, and this occupies a significant share of the cumulative installed capacity of all PV applications in the world.

It is obvious that MW-scale PV systems are already a major PV application. As the capacity of the MW-scale PV systems expands year by year, the maximum capacity is achieving 100 MW and some PV plants which have a capacity of hundreds of MW are being prepared. Indeed, a GW-scale PV plant consisting of several 100 MW-scale PV systems is expected to be realized within a few decades. In the near future, VLS-PV systems will become an option for many large remote desert regions in the world where conventional power plants have never been built.

Comprehensive comparison between solar-powered VLS technologies

For utilizing the huge potential of solar energy globally, we can employ a plurality of solar-powered technologies, e.g. not only PV, but also concentrator photovoltaics (CPV), concentrated solar power (CSP) and even wind. It is therefore worthwhile to review the advantages of each from the standpoint of how they can enable solar energy, in all of its manifest varieties, to play a major part in mankind's future.

The developed world has a highly-developed electric power infrastructure that is currently powered mainly by *heat* from either fossil fuel or nuclear sources. CSP, because it too generates heat, fits more smoothly into that infrastructure than does any other renewable energy technology. To this end, another virtue of VLS-CSP is that the heat it generates is easier to store for short periods (i.e. in order to overcome the effect of passing clouds, or for peak load shifting) than electricity. In fact, owing to the relatively large thermal mass of the heat transfer fluid, CSP automatically contains a certain amount of built-in storage. Yet a third virtue of VLS-CSP is that it can power conventional turbines. There are accordingly no problems with the removal of harmonics of the sort that can arise in PV and wind systems when an inverter may function in a less than perfect manner. Last, but by no means least, the fact that the original Luz parabolic trough CSP systems are still operative provides so-called *bankability* to this kind of technology, probably more readily than to any other. Disadvantages of CSP at the present time include the need for cooling water (for efficient operation); an as-yet incomplete knowledge about the efficacy of thermal storage – without which, some form of fossil backup is necessary; and, of course, the need for a "sunny" climate.

For the developing part of the world, VLS-PV is most likely to be the technology of choice because of (a) the increasing local familiarity with PV technology owing to the ever more widespread employment of small stand-alone systems; and related to this (b) its relative simplicity when compared with CSP systems. Inter-connected VLS-PV systems, when strung out across different time zones in the developing world, will go a long way to overcoming the storage problem that is inherent to PV technology. In many regions, such systems will have an advantage over similarly located VLS-CSP systems by virtue of another feature of their simplicity: only the addition of power lines (without the need for additional supply concerns such as cooling water and perhaps backup fuel) being needed to create an electricity grid. The downside of PV, and also of wind, is the intrinsic lack of storage that, in contrast to inter-connected VLS-PV plants, will have to be developed if such plants are to perform as major power sources in isolation.

CPV has the advantage over PV that it requires typically 3 orders of magnitude less PV material. This has economic implications on both system cost and on the size needed for a fabrication plant (also 3 orders of magnitude smaller per MWp); on the continued availability of possibly rare materials; and on the energy payback time of the PV cells. Another advantage is that the actively-cooled variety of CPV plants can provide thermal energy for a variety of associated processes (desalination, air-conditioning, etc.). The prospect of employing the thermal output for additional electricity production is poor at the output temperatures presently allowed by CPV receivers. However, with improved materials, it is possible that VLS-CPV plants might in the future provide both PV and CSP power. The downside of CPV is that, as in the case of PV and wind, appropriate storage systems will have to be developed and, as in the case of CSP, “sunny” climates are necessary.

Wind has the advantage that it is currently the most mature of the VLS technologies. Its disadvantages are (like PV and CPV) the need for storage. An additional disadvantage is the large amount of land area required for very large scale plants unless dual land usage (e.g. for farming) is possible.

We shall therefore eventually have four kinds of very large scale solar technologies, e.g. VLS-PV, CPV, CSP and Wind, with which to be able to replace fossil fuel. These technologies may be regarded as *complementary* to one another rather than in competition. Ultimately, one may envisage a worldwide grid of perhaps ultrahigh voltage DC power lines (or possibly ambient-temperature superconducting cables) fed by the various VLS technologies, each located in climatic regions appropriate to its most favorable economic performance. In summary, at the present stage of their respective developments, all VLS renewable energy technologies look as if they will be complementary rather than competitive with one another.

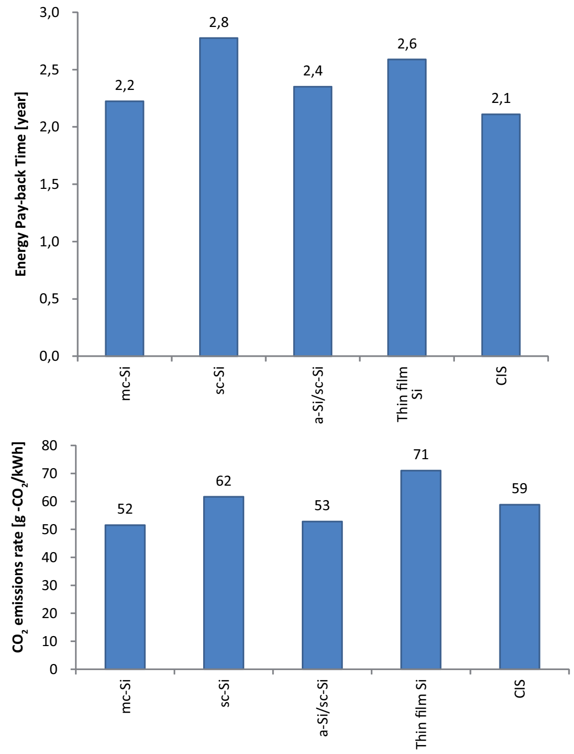

Figure A.6 Energy pay-back time (top) and CO_2 emissions rate (bottom) of the VLS-PV systems

Environmental aspects of VLS-PV

The Life-Cycle Analysis (LCA) methodology is an appropriate measure to evaluate the potential of VLS-PV systems in detail, because the purpose of this methodology is to evaluate its input and output from cradle to grave.

The LCA of VLS-PV systems were carried out by support of IEA PVPS Task12: PV environmental health and safety. Five types of PV modules were evaluated: single crystalline silicon (sc-Si), multi-crystalline silicon (mc-Si), amorphous silicon/single crystalline silicon hetero junction (a-Si/sc-Si), amorphous silicon/micro crystalline thin-film silicon (thin-film Si), and copper indium di-selenide (CIS).

Figure A.6 shows the energy pay-back time and the CO_2 emissions rate. The results of energy pay-back time are 2,1 to 2,8 years. This means that they can recover energy consumption in less than 3 years. CO_2 emissions rates are 52 to 71 g-CO_2/kWh. These results are higher than the estimates published in papers by Fthenakis *et al.* [13] or Mason *et al.* [14]. The reasons for this are the efficiency of PV modules, the assumptions on manufacturing that PV modules and inverters would be produced in Japan, and the inclusion of long transmission lines and heavy mounting hardware, which are based on Japanese standards, produced in China.

(Both figures assume 2 017 kWh·m^{-2}·yr^{-1} irradiation in Hohhot in China. BOS and 100 km transmission lines on Japanese construction standard are produced in China, and PV modules and inverters are produced in Japan. PV modules data are from NEDO. Module efficiencies are 13,9% (mc-Si), 14,3% (sc-Si), 16,6% (a-Si/sc-Si), 8,6% (thin-film Si), 10,1% (CIS).)

In addition, as an indicator of sustainability, Ecological Footprint (EF) analysis was carried out. The EF is a measure of how much biological productive land area humanity uses to produce resources and to absorb waste. On the other hand, the Earth’s available capacity to produce useful biological materials and to absorb the waste is defined as Biocapacity (BC) (see Figure A.7). If the EF exceeds the BC (i.e. the ecological balance (BC – EF) is negative), this ecosystem is not sustainable. If we are able to reduce the EF or increase the BC, we can reduce the negative number of the ecological balance. The method of calculating the EF of PV systems and fossil fuel energy and the BC of the greening to reduce the ecological balance has been developed.

A.2 ENGINEERING AND FINANCIAL GUIDELINES FOR VLS-PV SYSTEMS

Technical and engineering guidelines

From the point of view of engineers, VLS-PV power plants have outstanding advantages, mainly: relatively easy identification of suitable sites, flexibility of planning and engineering, easy energetic integration into local grids and increasing commercial viability. These benefits can

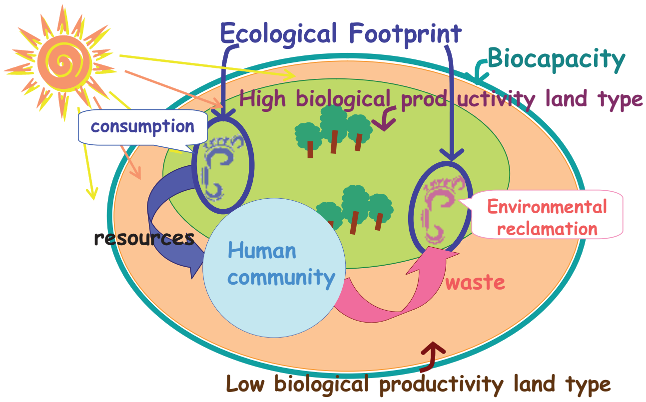

Figure A.7 The Ecological Footprint and Biocapacity

especially be used by emerging economies having very good solar conditions.

Assessment and evaluation of VLS-PV takes place via economic and financial issues, which are always in coherence with a basic understanding of technical issues. The technical engineering guidelines facilitate the access to a basic technical understanding of VLS-PV. They describe the current state-of-the-art for this special power plant technique. They are typically produced by governmental owned utilities and Ministries of Energy as well as Ministries of Environment.

The guidelines introduce and exemplify criteria for selection of appropriate power plant sites. After the identification of a site, discussions with the owner of the local medium or high voltage grid must be established. Issues of discussion are the capacity of the grid in regard to the power from the VLS-PV plant and technical requirements. The desired result is a guarantee of a grid-friendly feed-in operation.

The principle approach to planning and design is shown as Figure A.8.

The design engineer's professional qualification is an essential precondition for securing a high technical quality of engineering. The professional selection of key components and their combination is a fundamental condition. This requires experience and knowledge of the worldwide market prices for several key PV components. During the engineering phase the requirements of the later long-lasting operational phase can be influenced. This is especially valid for the power plant monitoring system. The monitoring system allows recording and visualization of all important operating states, signals and stores them. Individual requirements can be carried out by adequate software adaptation. Dependent on the size of the plant or the intention of the operator, VLS-PV can be remotely controlled and operated or operated by local personnel in a service building. The requirements of the software should also be checked and balanced with the local utility; it sometimes demands a control access to the plant.

Necessary safety conditions of personnel and plant are fulfilled by consideration and realization of set quality criteria and valid local regulations, national and international safety standards.

In an ideal case the country already has its own qualified personnel for planning and engineering VLS-PV. Then the national economy would be independent from services abroad. A domestic content then would contribute to a national value added. Since this is sometimes not the case, a know-how transfer can eliminate this disadvantage. Independent experienced and qualified consultants can teach and train engineers to the necessary technical state-of-the-art level.

Financial guidelines

A project is considered as "successfully developed" once the financial closing stage is reached. Indeed, at that point onward, the investors and the lenders are committed to disburse their funds for financing the plant's construction, which will start shortly after the financial closing.

To reach this stage, the project has to be approved by credit and investment committees, i.e. by both banks and investors. In case of approval, technical and legal due diligences will be conducted by independent auditors mandated by the financers. The result of such audits will

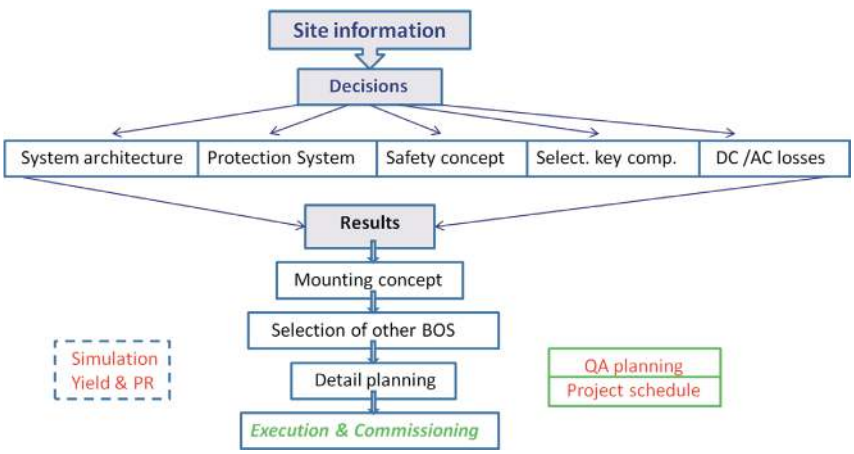

Figure A.8 Structure of planning and designing approach condition the availability of funds for later stages of the project.

The feasibility study should anticipate the requirements of the credit and investment committees and the contents of due diligences. A high quality level, pluri-disciplinary feasibility study is therefore necessary to secure the financing. It should address, together with the technical aspects, all the key financial and legal issues.

Figure A.9 shows the key milestones in the development of a VLS-PV transaction.

In the VLS-PV transaction, the development costs and risks are quite high and the studies are complex. In this respect, the support of governments and development agencies should be as great as possible, directed toward removing the most difficult barriers. Complete studies should point out such barriers and suggest a pluri-disciplinary approach and appropriate management to guide these players.

Unfortunately, such studies are not yet available because, for most national support mechanisms, the value of PV is not at stake. The promoters that develop projects with the greatest value in current markets will not be awarded any extra benefit. On the contrary, as developing such projects is more expensive and time-consuming, promoters will tend to completely avoid developing high value projects, searching only for the cost reduction.

We believe that, given the great cost reduction of the last few years, future markets, based on value, will rapidly emerge and that PV will definitely meet with the conventional energy sector before 2020 in order to take its natural and specific place in the energy mix of all countries.

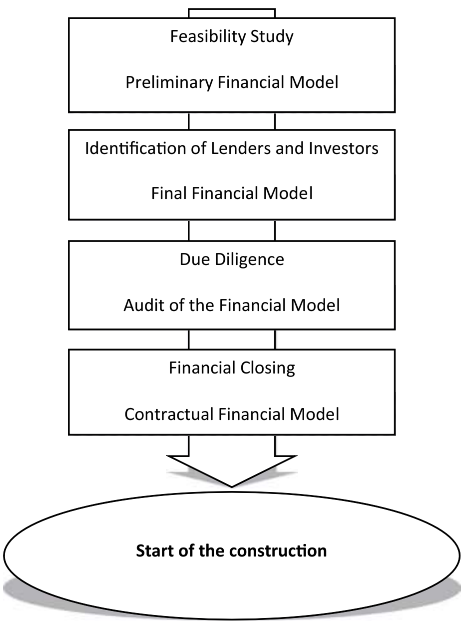

Figure A.9 Key project development milestones – evolution of the business model [15]

A.3 VLS-PV TECHNICAL OPTIONS AND APPLICATIONS

Grid matching issues

The intermittency in output from a VLS-PV plant renders its matching to the requirement of a conventional electricity grid an issue of quite complex proportions. In the first place, the grid has its own intermittency problems, associated with customer requirements. These problems are handled via a combination of economic considerations and the *controlled input* from three basic kinds of power plant: (1) Base-load plants, which have limited ramping capabilities. They operate on a continuous basis for extended periods of time with relatively infrequent shut-downs for maintenance. (2) Intermediate-load plants, which have improved ramping capabilities. They can be started up in the early morning and shut down in the evening. (3) Peak-load plants which are capable of ramping from zero to full power in typically 10 minutes and can undergo smaller ramping steps with extreme rapidity. They are used to follow the moment-to-moment requirements of the grid. Each of these plant types has its own economic considerations based on: fuel cost, frequency of maintenance, age of plant, cost of replacement, and moment-to-moment selling price of the electricity.

When it comes to attempting to input the power from a VLS-PV plant, a number of additional problems arise that result in new grid matching challenges. First, on clear days, a VLS-PV plant performs something like an intermediate-load plant in that it starts up in the morning and shuts down at night. However, unlike fossil-fuelled plants, a VLS-PV plant cannot be ramped up and down at will. Moreover, its peak output, which occurs at noon, will generally not coincide with the time of day at which grid requirements reach their peak. Thus, for example, if a VLS-PV plant is sized to provide the grid's peak load on a given summer day, it will produce more power at noon than can be used. Secondly, even on clear days, the peak output of a VLS-PV plant depends upon the time of year and its specific design. For example, a fixed-tilt plant will typically exhibit its peak output in the spring season, when noontime solar angles are close to normal incidence and ambient temperatures have not yet reached their summer highs. Now a consequence of the relatively benign springtime ambient temperatures is that air-conditioning loads have not yet reached their summer maxima. Therefore, if a VLS-PV plant is sized to meet the peak demand in summer, it will produce more power in spring than can be used. Yet a third challenge is the intermittency of clear days, a solution to which requires a combination of some form of weather forecasting, a facility for storage, and an appropriate grid operation strategy. Otherwise, precisely the same amount of backup conventional generating capacity will have to be maintained for the provision of power when solar input is not available. Finally, the effect of clouds on less than perfectly clear days can lead to grid instabilities unless the output of the VLS-PV plant is suitably smoothed.

A series of papers [16–21] have analyzed the hourly requirements of the Israel electricity grid during the year 2006, and simulated the outputs of various kinds of VLS-PV plant (static, 1-axis, 2-axes and CPV); alone, in combination, in combination with wind energy generation systems (WEGS); localized, and distributed over the Negev Desert.

It was found that very little improvement in grid penetration may be expected by distributing VLS-PV plants around the Negev. It is not clear whether this is a general result, or one that is specific to small geographical regions like the Negev. However, a positive result is that geographical distribution of VLS-PV plants significantly reduces the additional ramping requirements that a single plant would impose upon the grid. This has important implications regarding the lifetime of the non-solar plants in the grid and on their frequency of maintenance. Also, the addition of a suitably sized WEGS plant will be able to increase the rate of annual grid penetration from a pure VLS-PV to approximately 30 percent of the annual requirements. This may appear to be the best that one can do without storage.

The study then analyzed the required properties of storage and appropriate grid operating strategies for increasing grid penetration. It was concluded that up to approximately 90 percent of annual needs could be provided by VLS-PV, storage, and a revised grid operating strategy.

Although these results may not be quantitatively applicable to other regions, many of the results should be approximately correct in other desert areas. Furthermore the overall methodology will certainly be of wide applicability and the various details discussed here all need to be taken into account for optimizing VLS-PV plants wherever they may be.

VLS-PV intermittence and stationary storage

Use of stationary storage for VLS-PV systems will be influenced by the power output intermittence, impacting the grid requirement matching strategy. Photovoltaic power output intermittence prediction encompasses planning, forecasting and nowcasting. Nowcasting anticipates intermittence from the present time up to few hours ahead, forecasting covers up to 10 days, and planning refers to longer time periods. It helps VLS-PV systems to be operated in the same way as conventional power plants.

Regarding planning, yearly to seasonal intermittence is obtained through use of satellite-derived methods or ground-based measurements, and is part of important warranted items in PV project EPC contracts (Engineering, Procurement and Construction). Yet infra-yearly intermittence is not commonly assessed, because it is not commonly mandatory in Power Purchase Agreements (PPA).

Numerical Weather Prediction (NWP) models are used in planning to predict the values of a large parameters range, including solar radiation parameters and temperature, the two main factors impacting PV production. Such models being probabilistic, their use for short-term application is limited.

NWP models cover from the synoptic scale (eastern and central Europe, US and Canada), where they typically provide irradiation forecasts every 3 hours up to 72 hours (3 days) and every 6 hours up to 168 hours (7 days), at the regional and local scale, where they tend to higher spatial resolution, from 4 to 25 km, and at higher temporal resolution, especially for Rapid Update Cycle (RUC) models, allowing hourly predictions.

Model Output Statistics (MOS) techniques, based on statistical methods, use NWP model outputs to obtain solar radiation parameters and temperatures, or to directly predict the PV power output.

Regarding forecasting and nowcasting, daily to very short-term intermittences are linked to the variation of meteorological parameters: temperature, pressure, wind speed and direction aerosols content and water vapor content mainly. They are translated into radiation extinction when dealing with short-term intermittence.

These parameters are taken into consideration to perform classification of solar radiation distribution in typical days, which is important for predicting cloudy days where maintenance operations would be preferred. Classification is usually performed using four classes: clear-sky day, intermittent clear-sky day, intermittent cloudy day and cloudy day.

Nevertheless, such classification is usually performed with a single station, neglecting the smoothing effect when dealing with large PV installations. The smoothing effect is more effective during intermittent regimes, because perturbation does not impact all the plant at the same time.

As an example, a simple calculation technique presented by Hoff and Perez [22] shows that getting a VLS-PV scale will decrease the 1 min expected relative power output variation from 60 percent with a 4,59 MW plant to 10 percent with a 1 GW plant.

Cloud motion models, contrary to NWP ones, are deterministic models, which predict cloud cover and therefore radiation extinction based on cloud advection.

Satellite-based models provide better forecasts than NWP ones under a 5 hours perspective. As they provide estimations for infra-hourly variations, imagery techniques, using generally a Sky Imager, provide better information for very short term and sub-kilometer predictions.

VLS-PV systems power output intermittence and prediction can be performed at various time scales, with the use of databases, and mathematical and statistical tools to predict the power output variations. Persistence models, i.e. forecast equals instantaneous measured parameters with adjustment of solar position, are used in benchmarking the prediction models.

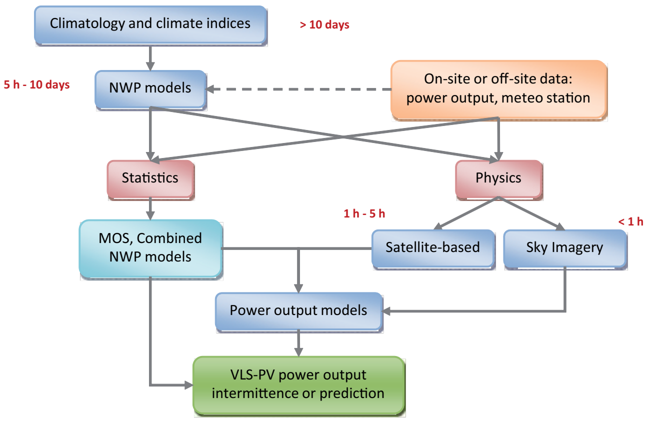

Figure A.10 PV systems power output intermittence and prediction at various time scales

Figure A.10 summarizes the temporal chain of VLS-PV systems power output intermittence and prediction; models are in blue boxes.

Stationary storage is divided into three sectors: chemical, mechanic (including here kinetic, magnetic and electrostatic) and thermal storage.[1] Their grid applications can be of two types: grid services (power quality control through fast delivery of mainly large amount of power and bridging power applications) and energy management (store electricity when the kWh price is low or when unused and inject back when the kWh price is high or to provide guaranteed electricity during identified periods).

Batteries, such as sodium-sulfur (NaS), redox-flow (RFB), nickel-cadmium (NiCd), nickel-metal hybrid (NiMH), zebra ($NaNiCl_2$), valve-regulated lead-acid (VRLA) and lithium-ion (Li-ion) usually considered for grid services applications, tend to be designed for energy management purposes. There are four implementation problems: self-discharge and depth of discharge (DoD), energy density, environmental impacts and maintenance, dismantling and recycling.

Kinetic (flywheel), magnetic (Superconducting Magnetic Energy Storage – SMES) and electrostatic (Supercapacitor Energy Storage – SCES) storage are designed for fast delivery of power, and therefore are used in specific grid services applications, as power quality for crucial applications.

Potential energy storage, Pumped-Hydro Energy Storage (PHES) and Compressed Air Energy Storage (CAES), are the most important installations that can be implemented on one site, and are today reserved for large energy management. Small scales are targeted; for PHES in coastal areas and for CAES through adiabatic operation. It will limit the development times and help get rid of specific sites.

Cost comparison between technologies is hard to achieve because of the variety of pricing regarding the project context. Therefore it is proposed to perform technology cost comparison on the basis of a targeted usable capacity (linked to the yield) and through collection of parameters for Capex and Opex calculation:

For Capex:

- Investment costs:
  - Procurement, assembly and tests
  - Installation and commissioning
- Replacement/refurbishment costs:
  - Replacement numbers over lifetime (depending on the annual operability and the number of cycles)
- Cost proportion compared with initial investment.

For Opex per year:

- Spare parts
- Man-hours
- Consumables.

Predicting intermittence will decrease the need for reserves, progressively bringing PV production from unpredictable to guaranteed. Integrating photovoltaics on grids will require adequacy between available production and demand and participation in grid balance strategies.

Production variation can be performed with coupling to other processes, with energy dumping or with energy storage. Such storage can be implemented by the utility itself or by the operator.

Storage on grid can improve grid stability, by virtually aggregating produced and/or consumed electricity on specific grid spots (homes, small plants, industries, etc.), and then improve flexibility faster than power line creation. Private entities have invested in this sector, bringing a constraint to the storage availability and the associated flexibility. Batteries are the best candidates for this kind of storage, as it remains in MW-scale. Battery limitations must be carefully considered.

Onsite storage refers to the ability of a VLS-PV system to participate in voltage and frequency regulation and to perform load leveling to fit grid requirements and maximize the grid integration. Batteries have specifications that fit with voltage and frequency regulation purposes, but careful attention must be paid to the size of such systems. Large storage capacities will be required for load leveling, and therefore PHES and CAES will be the best candidates.

Onsite storage will therefore not rely on a specific solution, but on a combination of solutions, allowing the VLS-PV system to be considered as a conventional power plant.

Renewable power methane

A 100 percent renewable power supply on a low cost basis is prerequisite for sustainable global development. Solar and wind resources are abundantly available on Earth, enabling the use of PV and wind energy technologies on a large scale in most regions in the world. A global energy supply scenario based on PV and wind power supported by an appropriate energy storage infrastructure is investigated. Results for the degree of complementarity of PV and wind power supply are presented [23] and the need for appropriate energy storage solutions is emphasized.

The renewable power methane (RPM) storage option is presented and discussed for the integration option of hybrid PV-Wind-RPM power plants. Renewable power methane storage enables bidirectional linking of power and gas networks and represents a competitive seasonal storage option. Due to a comparably low efficiency of the full RPM process, the cost of producing RPM is rather high. Therefore, the levelized cost of electricity (LCOE) of the input power needs to be as low as possible. PV and wind power will reach quite competitive LCOE by the end of the 2010s, are abundantly available and show a high degree of complementarity in time. However, both technologies are still fluctuating. Thus combining low cost PV and wind power with the balancing RPM storage to hybrid PV-Wind-RPM power plants represents a new power option for a 100 percent renewable energy supply [24].

Based on the LCOE approach and on cost assumptions for the year 2020, hybrid PV-Wind-RPM power plant economics are derived on a global scale. By the end of the 2010s, the economics of hybrid PV-Wind-RPM power plants are very promising in all regions of good solar and wind resource quality. Hybrid PV-Wind-RPM power plants might represent the fundamental centrepiece of sustainable and low cost power supply in the years to come (Figure A.11).

Estimates for the global energy supply potential of hybrid PV-Wind-RPM power plants show both rapidly increasing competitiveness and low distances between the centres of demand and least cost energy supply, which is complemented by abundant solar and wind resource availability. By the year 2020, about 90 percent of mankind might be supplied by 100 percent renewable power fully competitive to fossil fuel prices of about 150 $USD/barrel_{eq}$

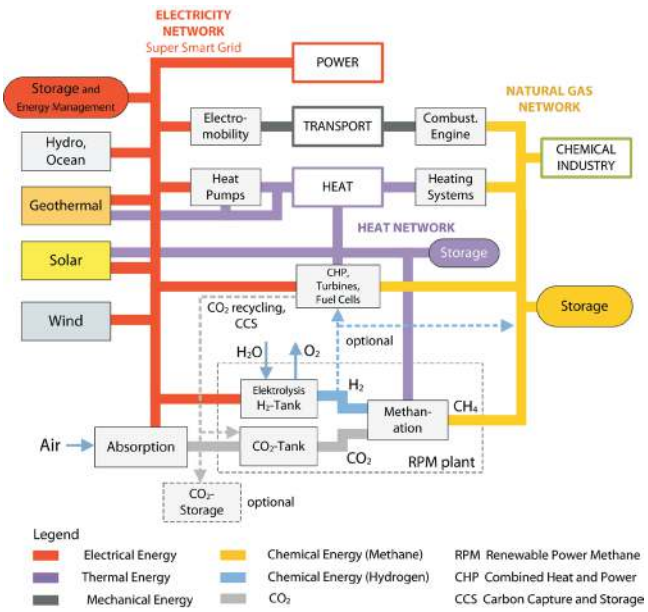

Figure A.11 Hybrid PV-Wind-RPM plant as the integral centrepiece of a future sustainable energy supply system [24]

and with practically unlimited amounts of sustainably provided energy. The RPM approach enables long-term cost stability due to a fully decoupled cost structure from fossil fuels, no net CO_2 emissions and enormous power supply potential offering long-term and sustainable economic growth [24].

This hybrid plant topology might emerge into the role of the key energy supply cornerstone in the world, in particular if mankind intends to economically survive peak oil and physically and economically survive climate change.

A.4 VLS-PV CASE STUDIES

VLS-PV in West Africa

The implementation of VLS-PV systems in West Africa is quite a challenge given the current situation of the power sector in the region. Indeed, the recent development of interconnection systems, the difficult financial situation of the national utilities and the absence of an efficient information management system make it difficult to implement any power transaction in West Africa, let alone new types of transactions such as large scale photovoltaic power plants.

To implement VLS-PV, the strategy should be defined at a regional level, and then spread and managed at a national level, while still being audited and monitored by the regional institutions.

Concretely, these principles could be embodied as shown in Figure A.12.

As an example, a possible approach for Benin was discussed. Benin is an energy-dependent country that relies mainly on expensive imported hydrocarbons for its electricity production. Furthermore, electricity contributes to a very small portion of Beninese primary energy: only 2,2 percent, which represents the third most important source of energy after oil products (38,4 percent) and biomass (59,4 percent).

Given economies of scale in the PV industry, hydrocarbon prices volatility and its upward trends, Benin electricity transport and distribution infrastructure development as well as significant demand growth forecasts and, finally, considerable local solar resource, Benin possesses all assets required for the development of electricity production based on solar technologies.

In this favorable context, we have established a Reference Scenario (see Table A.1) that supposes VLS-PV plants installed capacity representing 10 percent of peak power demand by 2025. According to our experience, the development of such PV capacity in Benin (68 MW) is reasonably achievable from a technical, economic and "project development" perspective.

Helios Energie, a French PV project developing company operating in international markets such as sub-Saharan Africa, has recently conducted a technical and

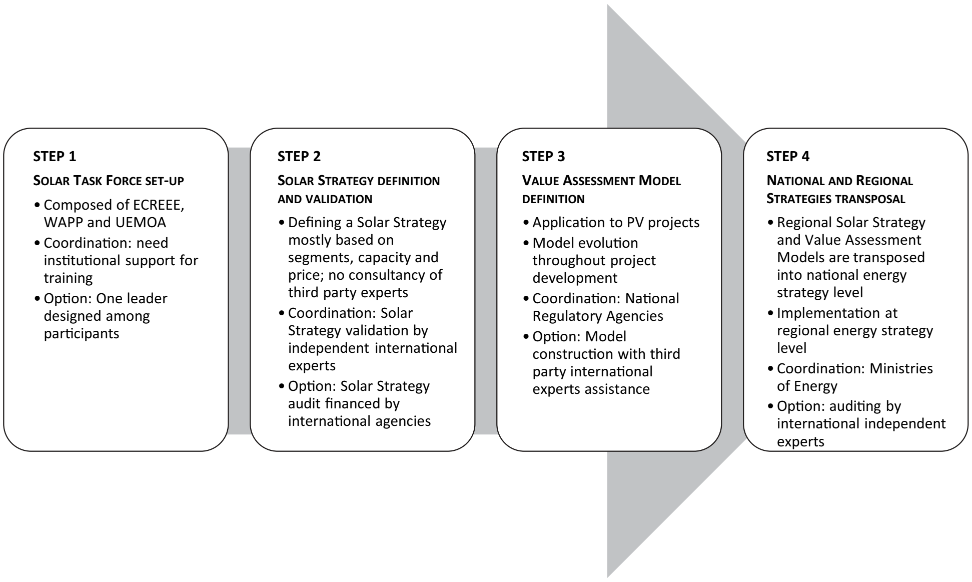

Figure A.12 Steps for implementation strategy

Table A.1 VLS-PV 2025 reference scenario for Benin

Year	2005	2010	2012	2015	2020	2025
Total electricity consumption (GWh)	560	1 002	1 260	1 647	2 484	3 781
Transmission and distribution losses (%)	18	18	17	15	14	14
Total generation (GWh)	661	1 182	1 467	1 894	2 832	4 310
Average annual growth (%)		9	9	8	7	7
Peak power demand (MW)	105	188	233	300	449	683
Average annual growth (%)		9	8	7	7	7
Per capita GDP (×1 000 FCFA)	133	149	168	196	279	408
Average annual growth (%)		2	3.2	5	6	6
VLS-PV installed capacity (MWp)	-	-	6	20	44	68

financial feasibility study for the implementation of a 6 MW photovoltaic plant on the site of Kandi, located in the north of Benin. This study was finalized in April 2011.

The aims of the Kandi project for Benin are: supplying electricity during day time for the northern region of the country, contributing thereafter to the grid stability at this period and off-setting part of the thermal generation that currently supplies the region. Furthermore, this 6 MWp project displays an intrinsic environmental, economic and social value for the region as the first very large scale PV project in the region.

Today, the Kandi project is at an advanced stage of its financial closing process, following the favorable opinion of the French Development Agency (AFD). The selected builder-operator is Siemens Energy France. Construction itself should begin subsequent to the loan agreement by AFD in mid-2012. The electricity produced by this 6 MWp installation, currently expected to be the largest grid connected PV power plant in sub-Saharan Africa, will be amortized over a 25-year period through production sale to SBEE (Société Béninoise d'Energie Électrique).

Once commissioned, this project will represent a significant step forward for the development of VLS-PV power plants in sub-Saharan Africa, showing the feasibility of such a business model in this region of the world.

Figure A.13 Computer image of the 6 MWp PV power plant project in Kandi, north of Benin [25]

VLS-PV in Israel

World electricity production is currently undergoing a quadratic growth with time. This relentless upward trend in electricity production is presumably driven by a combination of population growth and rising industrialization. It is consequently a fact that must be taken into consideration for any long-term planning. For example, by extrapolation through only the coming ten years, electricity generation by 2020 will probably be nearly triple what it was a decade ago in 2000.

On the world energy scale, the state of Israel is of course minuscule, 60 TWh being its estimated 2010 production [26] – i.e. less than 0,3 percent of the world total. However, Israel is a "sunny" country, with the relatively empty Negev desert, and it has the industrial capability of implementing VLS-PV on a relatively massive scale.

In the case of Israel, and its linear electricity growth curve, Figure A.14 indicates that VLS-PV would need to provide 1,92 TWh per year in order to replace the country's present average increase of 366 GW each year of new fossil-fuelled generating capacity. In terms of VLS-PV, taking a nominal annual output of 2 TWh/GWp for a typical desert location [26], this means installing some 960 MW each year.

Naturally, when a bank offers a loan, it expects to be paid back, and there are two classic instruments for paying back the loan on a PV system. One is the so-called feed-in-tariff (FiT) that many governments have adopted. This instrument requires electrical utilities, by law, to purchase PV-generated electricity at a higher rate than it costs them to generate conventional power and a surcharge for all power customers for covering the higher cost. This enables a return on the loan within a time frame that is deemed acceptable to banks. The second method of financing PV is for the government to offer tax incentives to help the purchaser of a PV system cover part of the cost of the initial investment.

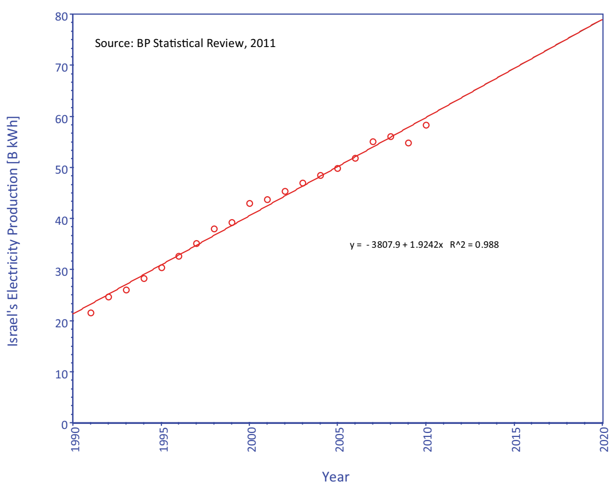

Figure A.14 Israel's electricity production during the past 30 years [27]

In both of the above cases the PV system is treated as an up-front investment that has to return its capital outlay over a period of years. In the case of relatively small PV systems, the amounts of money involved are sufficiently small that many people are prepared to take the risk. But evidently the big lenders – i.e. the banks – have their own ideas about how large the risk may be allowed to become. This may be wisdom on the part of the banks, but if the world is urgently in need of constructing hundreds of GW of VLS-PV plants *each year*, financing of the required investment is unlikely to become available in time to avert catastrophe.

Although there is still some debate in scientific circles as to whether the presently perceived era of global warming is entirely due to anthropogenic causes, there can be little doubt that the increasing use of fossil fuel is definitely a non-negligible contributory factor to this warming. As such, it is in the public good for the world to try and cut down on the burning of fossil fuel. Now many people wrongly assume that this automatically means impeding the development of developing countries. "After all", they argue, "the developed countries are the ones responsible for global warming, so why should the developing countries be made to pay the price of the formers' mistakes?" They clearly have a strong case. However, our claim is that VLS-PV can allow full development of developing countries with a low carbon footprint, while at the same time, enabling the developed countries to clean up their act. The only problem is how to implement VLS-PV on a large enough scale and at a fast enough rate.

Traditionally, the public good is paid for by taxation. In developed societies, such goods as health, education, safer roads, etc. are normally paid for, at least in part, by taxation. Society does not inquire whether a hospital or a school is a good "investment". Neither does it consider how long it will take to return the initial capital cost. It is taken for granted that such capital outlay is for the long-term good of all. And so it should be in the case of "green energy", particularly in a world that is urgently in need in reducing its use of fossil fuel.

In light of the above discussion, we examine the consequences that could emerge if, for example, Israel were to impose an electricity consumption tax (ECT) on all use of electricity in the country. As will be seen, such a tax could not only fund the introduction of VLS-PV on a massive scale, but it would almost certainly lead to a number of additional benefits that could also contribute to lowering the global carbon footprint.

At the present time, the cost of electricity to Israeli consumers is approximately 0,08 EUR/kWh (slightly rounded down for simplicity). Suppose a nominal ECT of 20 percent was to be imposed upon electricity *consumption* (treated here, again for simplicity, as being identical to *production*). From Figure A.14, such a tax during 2010 would have realized 0,96 billion EUR: enough funding – in a single year – for the construction of a 480 MW VLS-PV plant.

Under desert conditions, such a plant would generate, on average, 0,96 TWh of electricity per year. Hence, if no additional fossil-fueled plant were added to the country's existing approximately 10 GW of generating capacity, the production/consumption for 2011 would reach 60,96 TWh. The ECT on this would in turn yield a revenue of 0,975 billion EUR, which could fund a second VLS-PV plant, this one of capacity 488 MW.

A.5 POSSIBLE SCENARIO AND STRATEGY FOR VLS-PV

Expected roles of international cooperation

Significant advances and dramatic cost reductions have been demonstrated in PV technologies over last decade. Further cost reductions of PV are expected due to technological innovations, economies of scale and increased market competition among PV industries worldwide. It is clear that support for high level research and facilitating exchange of information and experiences are crucial if technologies are to be continually expanded, and costs lowered. This can be realized only through the active collaboration of all stakeholders on local, regional and global levels.

Despite the fact that the cost of PV is declining continuously, a VLS-PV system of several hundred MW or GW scale capacity will require increasing amounts of investments. In order to promote VLS-PV systems worldwide, especially in developing countries located in deserts, innovative and favorable financing approaches and active international collaboration are required. Major international collaboration is needed to expand R&D in all areas of VLS-PV systems, especially in policy, regulation, standards and business model development. International cooperation in these areas stimulates the strengthening of international collaboration of existing institutions and activities, as well as the creation of new joint initiatives at regional and global level.

Regional and national programs promoting PV as a mainstream energy source are crucial for further development of large scale PV worldwide. There is an emergence of some of the largest solar promotion programs globally. If such programs are able to achieve the scale envisaged, they have the potential to create a huge wave of demand, which, in turn, will spur increased innovation, efficiency in production, and further cost reduction in PV. The competitiveness of PV against traditional and other alternative energy sources around the world will consequently increase.

In the near future, VLS-PV systems should become an economically viable option to meet the electricity needs of communities in remote desert regions around the world where conventional power plants cannot be built. The rate of deployment of VLS-PV is greatly influenced by the perception of the general public and utilities, local, national and international policies, as well as the availability of suitable standards and codes to govern it. Among a variety of support mechanisms, Feed-in Tariffs (FiTs) would be the main reason behind the strong growth in large scale PV in developed countries.

In the long term, with a solid strategy for implementing of VLS-PV systems, further expansion of large scale PV generation not only can satisfy the increasing energy demand of the region in a sustainable way but also will stimulate the local PV industry and create enough need to justify local manufacturing of PV system components. In addition, diffusion of the various kinds of high-tech knowledge and experience will mean that know-how will be transferred to local renewable energy institutes, utilities and energy companies in order to keep track of worldwide technology developments, technology exchange between universities and scientific institutes.

In January 2012, the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) signed a partnership agreement which will strengthen cooperation between the two organizations. There will also be increased collaboration between the two agencies at the Secretariat level, and in energy technology networks. Some themes for international cooperation have been identified. In addition to regional and national programs, this agreement will further advance international collaboration to stimulate the global deployment of large scale PV power generation systems.

Possible contribution of VLS-PV to sustainability

According to the United Nations, the global population will reach 9,3 billion (i.e. approximately 35 percent increase from today's figure) in 2050 and continues to increase until 2100 [28]. Asian Development Bank (ADB) estimates that global GDP will expand to 292 trillion USD in 2050 from 63 trillion USD today [29].

To what extent can PV/VLS-PV contribute to sustainable issues?

In order to answer this question, a simplified model as shown in Figure A.15 was developed. The model looked carefully into the relations between various sustainability factors to retain the consistency among the factors.

Four scenarios were developed, as shown in Table A.2, namely the base scenario, SC-1, SC-2 and SC-3. For all the three SC scenarios, a boost in VLS-PV was assumed. The installation scenario of VLS-PV was identical to the VLS-PV roadmap presented in the previous edition of this book [3] (see Figure A.16).

SC-1 and SC-2 scenarios in comparison with base scenario

With the increase in PV/VLS-PV, consumption of other energy resources decreases considerably. As is shown in

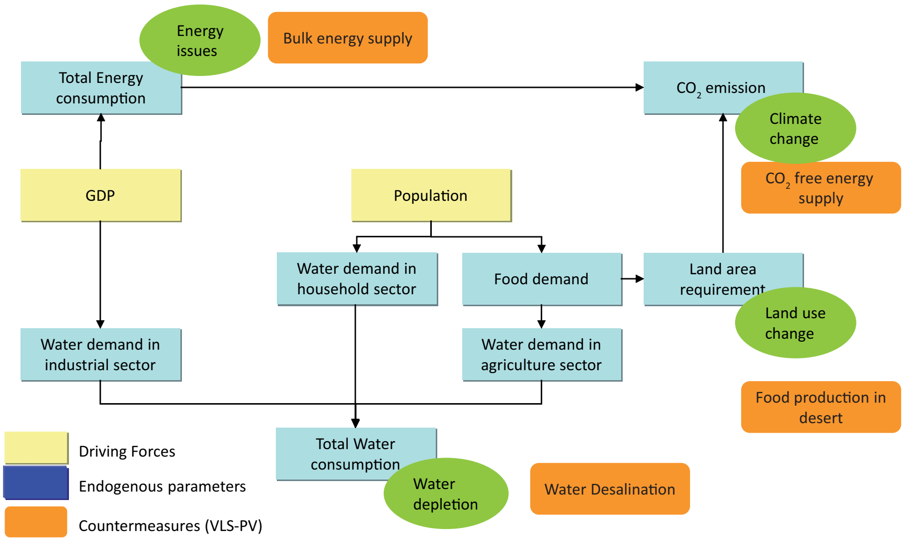

Figure A.15 Model structure

Table A.2 Summary of the scenario descriptions

VLS-PV scenario	Description
BaU	Business as usual. It is assumed that the current trend continues until 2100.
SC–1	Power generated from PV/VLS-PV is used directly in the energy mix. All kinds of energy are replaced by VLS-PV.
SC–2	Power generated from PV is used directly in the energy mix. Only fossil fuels are replaced by PV/VLS-PV power generation.
SC–3	Power generated from PV is used for water production (reverse osmosis). The remaining energy is used for power supply.

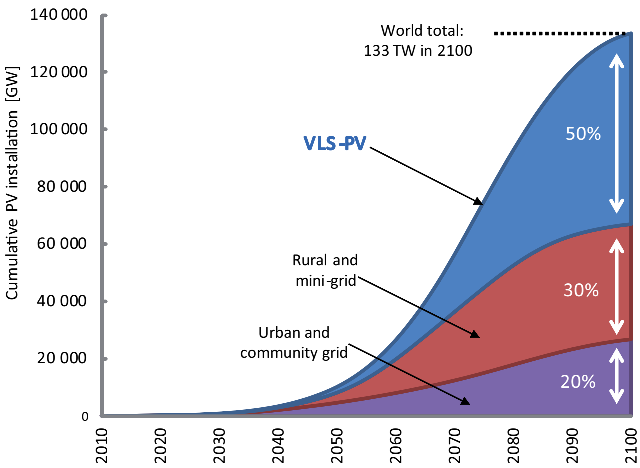

Figure A.16 VLS-PV roadmap: cumulative installation by PV application [3]

Figure A.17, PV/VLS-PV can provide 25 percent of primary energy in 2100. The contributions of PV/VLS-PV in energy saving for coal, oil and natural gas are approximately 2 600 Mtoe, 450 Mtoe, and 2 900 Mtoe in 2100 respectively.

Cumulative CO_2 emission reductions in the projected period reach 531 Gt CO_2-eq in 2100, which is equivalent to 19,5 times today's annual emissions (Figs. A.18 and A.19).

Figure A.20 is the projected temperature increase corresponding to the GHG concentration on the atmosphere. Although the PV/VLS-PV may not be a single and perfect solution for climate change issues, it is clearly shown that the potential contribution is considerable. Combining with other renewable energy technologies or energy efficient measures would be necessary for a sustainable future.

Base scenario versus SC-3 scenario

The SC-3 scenario, on the other hand, is unique. Under this scenario, the power generated from VLS-PV is used for water production. Reverse Osmosis (RO) technologies would be used in order to fulfil the increasing global and water demand. The overall concept of the scenario is to produce water in the most arid and solar resource rich areas, the deserts. The remaining energy is used for power supply. Only VLS-PV in the desert regions are used for desalination applications. Other applications such as roof top PV in urban areas or PV for rural electrification are for conventional electricity use.

Figure A.21 illustrates the additional water demand projected in the base scenario and water production potentials from VLS-PV. Water supply potential from VLS-PV will be enough to fulfil the additional global water demand in 2060 and will be much higher thereafter. The potential will be more than 3,4 times in 2100.

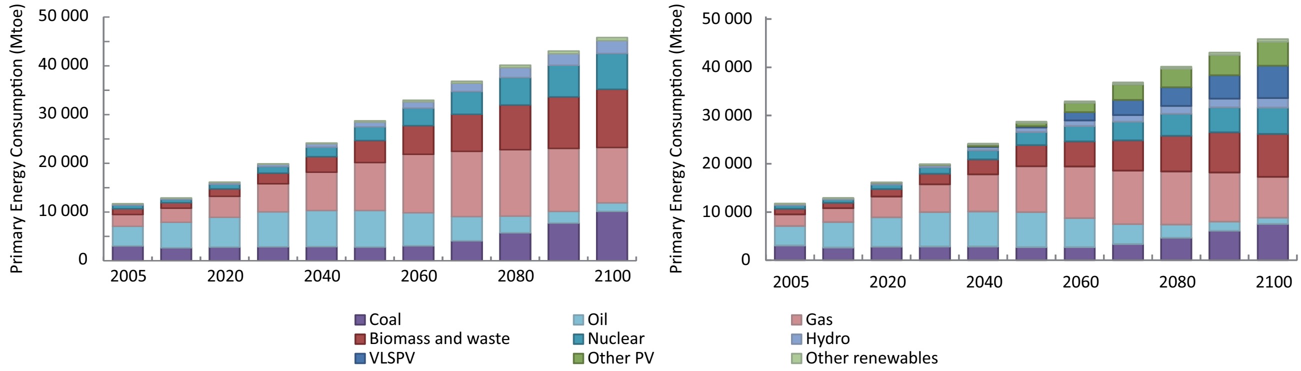

Figure A.17 Primary energy consumption of base scenario (left) and SC-1 scenario (right) [Mtoe]

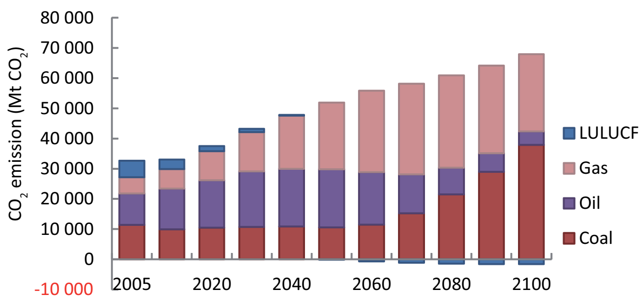

Figure A.18 GHG emissions of base scenario [Mt-CO_2eq]

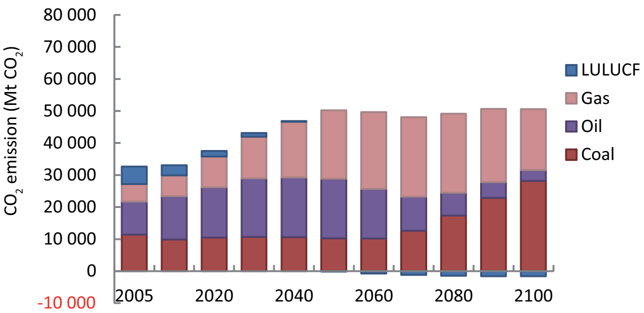

Figure A.19 GHG emissions of SC-1 scenario [Mt-CO_2eq]

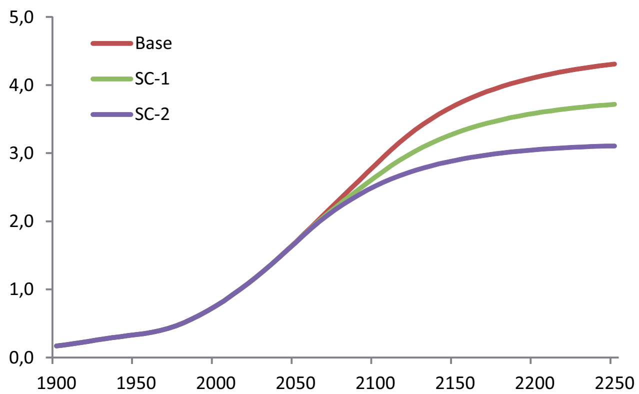

Figure A.20 Temperature change caused in the three scenarios

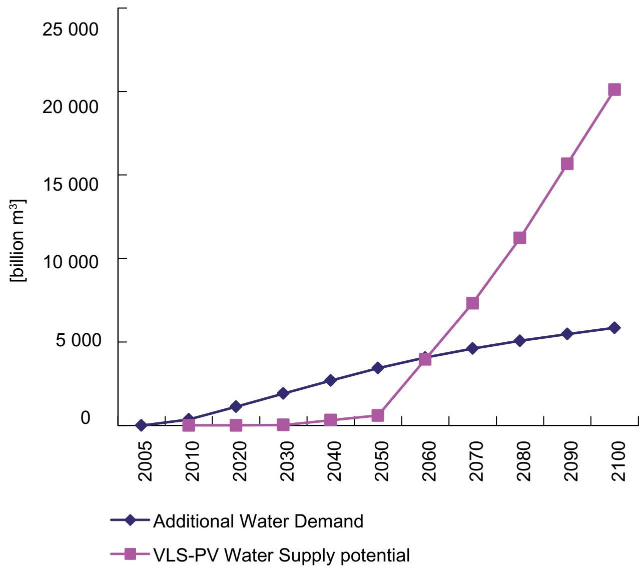

Figure A.21 Water demand and supply capacity (billion m^3)

Strategies for solar power plants in desert regions

Solar power plants in desert regions increasingly count as a realistic energy option. Very large scale ("utility scale") solar power plants have started to appear around the world. From the perspective of the existing global energy system, however, large scale solar power plants remain a promising yet very small niche. They still require financial and political support, entrepreneurs still search for viable business models, and acclaimed benefits such as relieving energy scarcity, job creation, poverty alleviation, and climate change mitigation are still to materialize. Accordingly practitioners and researchers increasingly focus on the challenges of socio-economic feasibility and market implementation to turn desert solar power plants into the "powerhouses of the world".

So far, most studies of socio-economic VLS-PV implementation have taken an informed practitioner's perspective. To tap into the social sciences and the innovation sciences in particular, to suggest ways of systematically thinking about VLS-PV implementation and aggregate existing insights it is necessary to go beyond conventional socioeconomic assessment tools. These normally chart and weigh the pros and cons of a given technological option, and can work well for stable technologies in equally stable societal contexts. However, they fit poorly with the case of solar power plants in deserts. Radical innovations (as opposed to incremental innovations) such as solar power plants in desert regions tend to develop so fast that evaluations at a fixed point in time tend to be instantly outdated and lack serious predictive value. In addition these conventional assessment tools fail to appreciate the intimate relationship between innovation and its societal context. In the case of solar power plants in desert regions this context is in constant flux. For instance, the current financial crises and the political turmoil in a number of North African states (which count as promising solar power plant sites) may greatly affect the odds, forms, implementation trajectory, and benefits of desert solar power plants. Clearly we need to search the innovation sciences for ways to think about VLS-PV implementation concepts that are more dynamic and take changing contexts into consideration. In the following we take our cue from the booming field of sustainability transition studies. This particular field within the innovation sciences asks questions that solar power plants face today: Why do some radical innovations transform from technical possibilities into viable market niches and eventually become part of (or even displace) the dominant technological system, while others do not? What lessons can we draw for the management and implementation of sustainable technologies in uncertain contexts? [30, 31]. We here discuss three such approaches.

Strategic Niche Management (SNM)

SNM is an analysis, policy and practitioner tool that seeks to study and strengthen the dynamics of emergent sustainable technology niches and their transition to full-blown technological systems or "regimes". The SNM approach focuses on the overall level of the niche, in our case solar power plants in desert regions, where individual projects are aggregated. The point of departure is that such radical innovations may be desirable in the future from a sustainability perspective, but face grave competitive disadvantages today. These disadvantages partly stem from the technological and economic uncertainties that accompany most new technology. Other, and arguably more fundamental, disadvantages follow from the fact that radical technologies may not fit well with existing dominant technological practices – precisely because they represent a break with conventional ways of thinking and doing. Consider how national employment, industrialization, and energy security policies support conventional energy players and technologies. So do existing technological capabilities in most countries. Even such mundane matters as insurance rules, planning and construction procedures, energy cost calculation methods (how to account for externalities such as climate change or nuclear risk?), energy user behavior, and so on have been tailored over many years to suit conventional energy stakeholders and technologies. Through these mechanisms and others, existing energy regimes tend to lock-in on conventional power plants and lock-out radical innovations that are at odds with its well-entrenched economic, organizational, legal, technological and other practices. This is why many promising energy innovations eventually succumb or gain only marginal importance.

Alternatively radical energy innovations may develop in niches where they are temporarily shielded from dominant energy regime forces and pressures. SNM seeks to understand and promote sustainable innovation through the deliberate creation, sustenance, and up-scaling of such niche processes. It suggests how proponents can use protected niche spaces to experiment with technical and non-technical components of their novel technology, and thereby find a constellation that fits with opportunities and demand in the outside world. If the learning process works well, lessons learned in individual projects accumulate into a "global niche level". In this perspective, our work on the introduction of VLS-PV strategies in desert regions is an example of a global niche player that accumulates insights on the level of desert solar power niche as a whole. This work includes selection, comparison, framing, contestation, and interpretation of local lessons. Conversely, global niche level insights can be used to frame individual local projects so as to optimize the learning process from an overall niche perspective.

SNM does not merely consider internal niche processes, however. In order to systematically chart the opportunities and barriers for niche technologies in the outside world, it adds the analytical layers of the *sociotechnical regime* and the *sociotechnical landscape* (Figure A.22).

While niches nurture radical energy innovations, incumbent regimes host dominant energy stakeholders with vested interests and stable social networks; regulations, standards, and cognitive routines that may blind actors to developments outside their habits and focus; and conventional energy technologies with their sunk investments and historically grown technical complementarities, such as fits with existing infrastructure. For the niche of desert solar power plants, one may think of the incumbent regime of centralized electricity generation in fossil fuel or nuclear power plants. This regime has long been entrenched within national borders, though in some parts of the world it is rapidly internationalizing [33]. Regime components such as dominant stakeholders, government legislation, and conventional power plants tend to interlock, keep each other in place, and resist radical change. SNM needs to learn about the barriers and opportunities for niche technologies in incumbent regimes and feed these back into niche development processes.

The socio-technical landscape, finally, draws into the analysis exogenous forces on which both niche and regime players have little influence. In some cases such forces seem to constitute additional barriers to change. In the case of desert solar power, think of the political turmoil in desert regions, or financial crises that make financiers wary of risky investment. Other landscape forces and events, however, may put pressure on stable energy regimes and open up opportunities for niche technologies to enter. Examples that may benefit desert solar power include global CO_2 emission reduction agreements, national or international (e.g. European Union) renewable energy targets, or disasters; the Tohuku tsunami of 11 March 2011

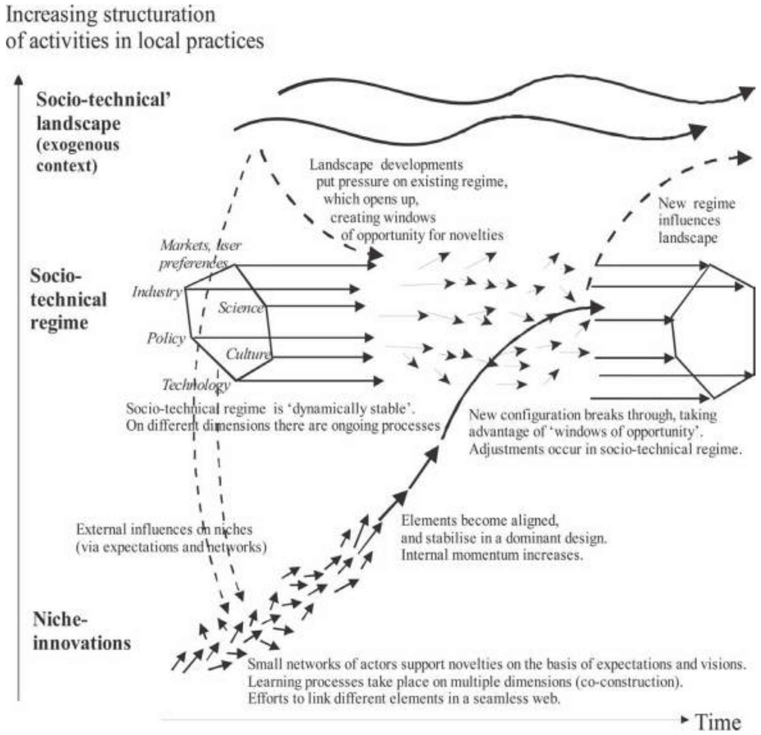

Figure A.22 A dynamic multi-level perspective on radical innovation journeys [32]

and subsequent crisis of the Fukushima nuclear power plants in Japan inspired – at least temporarily – a public and political distrust of nuclear power and renewed interest in renewable energy sources worldwide, as the Chernobyl disaster did decades ago.

In this three-layer analytical framework, the challenge is to propel promising energy technologies from deliberately protected technological niches into viable market niches and eventually latch on to (or even displace) incumbent energy regimes. Landscape pressures on existing regimes provide opportunities for such change. Successful innovation in this perspective is about navigating niche, regime, and landscape dynamics, so as to find a workable innovation journey for the novel technology. Today we can see similar processes emerging in the desert solar power niche. We interpret the recent reframing of desert solar power plants from a utopian very large scale technical possibility to a "utility-scale energy option" as an alignment with the existing electric power regime, and electric power producers in particular. In the EU-MENA region, linking up with forces for a Mediterranean Ring and a European super-grid makes Sahara desert power plants increasingly attractive. Simultaneously the connection of VLS-PV to seawater desalination plants links up the desert solar power niche with quite another regime, that of drinking water supply in desert regions. On the other hand desert solar power plants face particular challenges, especially when they involve international energy systems. Again the EU-MENA region illustrates this: Sahara solar power exports to Europe might prove difficult when European governments provide massive visible and invisible support to domestic conventional power plants that provide domestic employment, turnover, and energy independence. VLS-PV practitioners are already grappling with such opportunities and barriers. SNM is designed to learn about and manage such processes systematically.

For the SNM, ESTEEM (Engage STakeholdErs through a systEmatic toolbox to Manage new energy projects) [34] is about taking seriously and managing social resistance to local projects. Local resistance to novel energy technologies can take various forms, ranging from a simple lack of interest and denial of cooperation to emotional stress and actual sabotage. ESTEEM is a practitioner toolkit to deal with societal acceptance issues in the implementation stage of local projects, when adaptation of the project design is still possible. ESTEEM is typically facilitated by consultants.

New studies of business models

New approaches in the business models literature discuss how entrepreneurs may systematically search and design business models for radical innovations in unstable contexts [34, 35]. Business models are about describing "the rationale of how an organization creates, delivers, and captures value" [36] and are increasingly seen as a source of competitive advantage for a company. Business models are key instruments for bringing new technologies such as VLS-PV to the market [37]. Several scholars are currently working on combining SNM with business model development into one framework, but this work is still in its initial phases. We limit ourselves to outlining selected business model insights and thereby mobilize these for our thinking about the implementation of desert solar power plants. It could be said that the business models approach addresses the project level, but creates a sort of global niche infrastructure to facilitate a joint exchange and learning process [36]. Either way, in terms of content it is used as practitioner experiences to distill the building blocks that a good business model should address. It also defines for instance collaboration with partners and customer involvement. This applies to commercial companies as well as non-commercial organizations such as NGOs or government institutes that aim at creating environmental or social value.

Solar power plants in desert regions are on the brink of finding their way into the world's energy systems. This could mean that preparatory work, done by the International Energy Agency VLS-PV group and others, is currently being "overtaken by market developments" and can be concluded. From the innovation science perspectives, this would be a false conclusion. As policy makers and entrepreneurs experiment with projects and implementation models, now is the time for systematic learning about VLS-PV on a global niche level. For only the confrontation with real life conditions can reveal the technological, business, socio-economic, and geopolitical fits and misfits of solar power plants in desert regions with the demands of the modern energy world. It is now that the main (potential) stakeholders need to learn about expected and unexpected bottlenecks that emerge in individual local projects, accumulate such lessons on an overall niche level, experiment with ways to navigate these real world opportunities and barriers, and invent viable innovation pathways. Importantly, socio-economic or geopolitical bottlenecks might very well feed back into the technology design process: the redesign of solar power concepts for desert regions, originally conceived to serve long-distance international energy flows, to accommodate local economic development and sea water desalination illustrate technology adaptations in the (early) market implementation phase. In sum, the coordination between individual local projects and the overall desert solar power niche community is more important now than ever. The VLS-PV niche requires continued reflection on strategic management on a niche level, and a continued search for social acceptance and business models on a project scale. To facilitate this process we have tapped into innovation sciences work on sustainability transitions. This chapter has outlined the approach of SNM and briefly introduced ESTEEM and business model experimenting. This initial mapping of the territory, however, has merely opened up the topic. A next step would be a more VLS-PV specific and fine-tuned inquiry. A follow-up study should systematically examine existing or ongoing projects for current niche dynamics (in terms of articulating expectations, building social networks, organizing learning processes, shielding and empowering the niche, and emerging business models) and initial encounters with real life contexts (in terms of technological, business, socio-economic, and geopolitical opportunities and barriers, and expected/unexpected bottlenecks that pop up). With the practical tools, we may translate these lessons into a learning-based implementation strategy for policy makers and entrepreneurs.

A.6 CONCLUSIONS

Understandings

Solar energy resources, PV technologies, and renewable energy will help to realize important economic, environmental and social objectives in the twenty-first century, and will be critical elements in achieving sustainable development.

In order to promote renewable energy, the diversity of challenges and resource options, as well as the financing and market conditions among and within regions and countries, implies that different approaches are required. Establishing policies for developing markets, expanding financing options, and developing the required capacity have been discussed in order to initiate and adopt policy changes and to incorporate the goals of sustainable development into their policies.

Since our previous works [1, 2, 3], solar power plants in desert regions increasingly count as a realistic energy option. Very large scale solar power plants have started to appear around the world. In order to accelerate the current transition towards renewable energy, development of VLS-PV power generation systems that can be deployed on a massive scale is needed.

Based on such background, this report presented an overview of relevant issues and the potential of VLS-PV, guidelines for VLS-PV systems, and technical as well as strategic options for implementing VLS-PV.

Our conclusions are summarized as follows.

Projection for the future

Many scenarios for future global energy supply exist, but the roles of PV and other renewable energy options vary greatly between the scenarios. These are heavily dependent on underlying assumptions and projection approaches. In general, the share of PV is expected to increase drastically in most of the scenarios, but it may take a few decades for PV to be a main energy source in the global energy mix.

Our study using a simplified model for sustainability issues suggests that:

- VLS-PV can contribute greatly to global sustainability, but the main contribution will come after 2050.
- The contribution of VLS-PV is heavily dependent on the "business as usual" scenario assumed. Energy efficiency and other renewable energy measures are also of major importance.
- Taking into account energy depletion issues (resulting in increasing energy costs), VLS-PV could be a

cost-effective alternative, although it will still need continuous improvement.
- It should be kept in mind that such innovative changes in the energy supply system require a certain lead time. Also, delay in actions would lead to more serious problems since the driving forces are gaining importance.
- Although the contribution of VLS-PV will be marginal in the next 10 years, immediate action is very important from a sustainability perspective.

PV has already obtained a higher share in the energy mix than some projections presented in the past (for example, IEA: World Energy Outlook), and should continually beat the projections in order to become a main energy source. Meeting the projection by IEA: PV Roadmap [4] and Energy Technology Perspectives [5] until 2050 should be the minimum requirement. Only then can we visualize the VLS-PV roadmap toward 2100 as we proposed in our previous edition [3].

Socio-economic and environmental benefits

Solar electricity generation at utility scale can offer the possibility for socio-economic growth in the region. Because of local availability of energy in desert regions, clean water can be provided, irrigation can be optimized, local food can be produced and local sources of raw materials can be exploited. The generated electricity can directly be used for lighting, communication, education, entertainment and for industrial purposes. Excess electricity can be exported to neighboring regions or beyond. By adapting a regional policy for solar electricity generation at utility scale, a sustainable local market for solar electricity modules and other related components and services will be created and this market can be served by local production. Technology transfer from industrialized countries can provide and improve education and learning, research and development and manufacturing and sales. Local solar electricity generation also provides for security of energy supply in a sustainable way, provides fair access to energy for everybody and reduces the threat of climate change. If managed in the right way, the closed circle between local resources and local needs offers extensive possibilities for further development of the region.

Needless to say, PV technology is environmental friendly. From a life-cycle viewpoint, VLS-PV could contribute to saving and mitigating fossil fuel consumption and greenhouse gas emissions. In addition, applying a VLS-PV policy for decreasing our ecological footprint reveals that VLS-PV has significant potential to implement a sustainable ecological balance.

Engineering and financing approach

Assessment and evaluation of VLS-PV takes place with economic and financial considerations in mind. These are always in coherence with a basic understanding of technical issues.

The quality of execution of the planning is mainly dependent on the qualification and experience of engineers and site managers involved. Beside electrical know-how, basic knowledge of related fields like testing procedures, mechanics and statics as well as soil science and meteorology are required. VLS-PV systems contain a large number of connected conversion devices, a lot of power electronics, measuring systems etc. Depending on the region, more and more VLS-PV installations are located far away from living environments. Therefore the issues of safe, secure and trouble-free operation, maintenance and servicing should increasingly be considered in the course of plant design. From these viewpoints, the technical engineering guidelines we developed in this report facilitate the access to a basic technical understanding of VLS-PV.

The development of a VLS-PV system is a long process where almost all parameters change until the financial closing is reached. The preliminary technical design will continually evolve during the development process, taking into account the economic, financial and legal issues that are raised along the way. In a VLS-PV transaction, the development costs and risks are quite high and the studies are complex. In this respect, the support of governments and development agencies should be directed toward removing the major barriers. Complete studies should point them out and suggest a pluri-disciplinary approach and management of the PV sector support. The study should also anticipate the requirements of the credit and investment committees and the contents of technical and legal due diligences. A high quality level, pluri-disciplinary feasibility study is therefore necessary to secure the financing. It should address, together with the technical aspects, all the key financial and legal issues.

Technical potential

Solar energy resources are available in all populated regions in the world. Looking at the technical variation of PV systems, fixed optimally tilted PV systems are the standard PV power plant system type today. However, depending on local conditions, adapted tracking systems will increase the annual yield per installed unit of capacity and lower the power generation costs.

Considering the technical potential of hybridization between VLS-PV and other renewable energy technology, the weaknesses of such technologies might be solved by engineering ingenuity. For example, due to the complementarity of solar PV and wind power, market expectations for PV may not need to be lowered. Moreover, PV together with wind power might become the backbone of the global energy supply in the coming decades. Hybrid PV-Wind systems are likely to start to strongly influence the global power system in the next decade by means of sophisticated hybrid concepts, like renewable power methane technology.

In addition, a worldwide grid of ultrahigh voltage DC power lines (or perhaps ambient temperature superconducting cables) fed by the various VLS technologies may be envisaged. Not only conventional PV but also CPV, CSP and wind, each located in climatic regions appropriate to its most favorable economic performance, may be included in the future.

On the other hand, thinking about simple utilization of VLS-PV into the grid, predicting intermittence and energy storage will be important issues. It could be concluded that VLS-PV systems' power output intermittence and prediction can be performed at various time scales, with the use of different instruments, important databases, and mathematical and statistical tools to predict the power output variations. There are some technical options for energy storage. Supporting integration through flexibility enhancement with "storage on grid" can be done with batteries. "Onsite storage" should be conjointly done with batteries for short-term uses and large scale storages, such as pumped-hydro or compressed-air, for power shifting purposes. These may be the best candidates at the moment; further discussion should take place.

International collaboration

In the near future, VLS-PV systems should become an economically viable option to meet the electricity needs of communities in remote desert regions around the world. In the long term, further expansion of large-scale PV generation can not only provide increasing energy supply in sustainable way but also will stimulate a local PV industry and create enough demand to justify local manufacturing of PV system components locally.

As a VLS-PV system of several hundred MW or GW scale capacity will require an increasing amount of investment, innovative and favourable financing approaches and active international collaboration are required, especially in developing countries located in deserts. This international collaboration should include R&D in all areas of the VLS-PV concept, but especially in policy, regulation, standards and business model development, and would stimulate the strengthening of international collaboration of existing institutions and activities, as well as the creation of new joint initiatives at regional and global level. As results, various kinds of high-tech knowledge and experience, know-how will be transferred to local renewable energy institutes, utilities and energy companies in order to keep track of worldwide technology developments, technology exchange between universities and scientific institutes.

The future expansion of VLS-PV depends on successful international cooperation to advance knowledge on development of the VLS-PV concept. In addition, a clear political commitment of governments and a stable regulatory framework towards creating a long-term stable policy is essential for further deployment of the VLS-PV concept worldwide.

Strategic niche management, social acceptance, and business models

Solar power plants in desert regions are on the brink of finding their way into the world's energy systems. This might mean that our preparatory work, is currently being "overtaken by market developments". However, from the innovation science perspective, this would be a false conclusion, and now is the time for systematic learning about VLS-PV on a global niche level. For only the confrontation with real life conditions can reveal the technological, business, socio-economic, and geopolitical fits and misfits of solar power plants in desert regions with the demands of the modern energy world. It is now that the main stakeholders need to learn about expected and unexpected bottlenecks that emerge in individual local projects, accumulate such lessons on an overall niche level, experiment with ways to navigate these real world opportunities and barriers, and invent viable innovation pathways. Importantly, socio-economic or geopolitical bottlenecks might very well feed back into the technology design process: the redesign of solar power concepts for desert regions, originally conceived to serve long-distance international energy flows, to accommodate local economic development and sea water desalination illustrate technology adaptations in the market implementation phase. In sum, the coordination between individual local projects and the overall desert solar power niche community is more important now than ever.

The VLS-PV niche requires continued reflection on strategic management on a niche level, and a continued search for social acceptance and business models on a project scale. To facilitate this process we tapped into innovation sciences work on sustainability transitions, outlined the approach of Strategic Niche Management, and briefly introduced ESTEEM and business model experimenting. This initial mapping of the territory, however, has merely opened up the topic. A next step would be a more VLS-PV specific and fine-tuned inquiry.

Next step and strategy of Task8 activity

Since it was established in 1999, IEA PVPS Task8 has been examining and evaluating the potential of VLS-PV systems from various points of view and with the consideration of different aspects concerning feasibility and practicability. With the present volume and past publications [1, 2, 3], a comprehensive summary of these analyses has been made available. The work of Task8 has shown that VLS-PV can be a viable and competitive building block in the world's future energy supply.

Task8 has observed and analyzed PV, CPV and CSP with the same agnostic interest. The technological development of the three technologies, along with the cost reduction of the energy production especially for PV, leads to the conclusion that PV is or may become the predominant technology to harvest electricity from the power of the Sun.

Throughout the last two decades we have experienced a slight but continuous paradigm shift in economies, which gains more and more momentum as the topic gets more social perception: a more sustainability-oriented energy mix with an important role of renewable energy sources is socially and politically favored in most societies around the globe. With this, as well as with the accompanying maturing of the PV industry, the ideas and proposals presented in the Task8 publications have made their way into common knowledge of all stakeholders – politicians as well as industry players, institutional investors, transnational and non-governmental organizations. The technological aspects in terms of feasibility as well as potential applications worldwide have been and are discussed in depth.

With this in mind, we will conclude that the focus of our work should be refined to add further value to the discussion about VLS-PV. Therefore we decided to widen the scope of our evaluation and to focus on one question: What has to be done besides aspects of feasibility and practicability, to ensure that solar power plants will be a viable and sustainable option for the world's future electrical power supply?

It became clear that besides the public and the governmental/administrative side, the way of thinking and the approaches of the national and transnational electricity utilities have to be understood.

We intend to continue our work to gain further understanding of the requirements for VLS-PV from the utility point of view. Then, we will make a detailed and worldwide analysis of the requirements and expectations of major utilities. The outcome will be a competitive list of suggestions and recommendations for governments as well as for PV manufacturers to fulfill the needs of the utilities as important stakeholders for the future of VLS-PV.

Apart from utilities, we see governments and international organizations as important stakeholders and will make further efforts to understand their requirements and concerns. Eventually, conclusions, suggestions and recommendations of how to overcome hurdles/barriers, from technical and non-technical viewpoints, will be proposed for potential VLS-PV owners/developers.

Also, we have started to learn about the approach of Strategic Niche Management. As our next step, a follow-up study focusing on VLS-PV specific and fine-tuned inquiry will systematically examine existing or ongoing projects for current niche dynamics and initial encounters with real life contexts. With this practical approach, we may translate these lessons into a learning-based implementation strategy for policy makers and entrepreneurs.

As announced in January 2012, the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) signed a partnership agreement which will strengthen cooperation between the two organizations. There will also be increased collaboration between the two agencies at the Secretariat level, and in energy technology networks, including the IEA PVPS. Our activity, Task8, will be able to contribute to further advance international collaboration to stimulate the global deployment of large scale PV power generation systems.

NOTE

1 Thermal storage will not be reviewed as it is more in the scope of CSP power plants, which produce higher levels of temperature than PV plants could achieve.

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Very Large Scale Photovoltaic Power Generation (VLS-PV) systems installed in the desert provide economic, social and environmental benefits. This book shows how to develop practical proposals to set-up VLS-PV systems.

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