

PVPS

annual report 2017

PHOTOVOLTAIC POWER SYSTEMS
TECHNOLOGY COLLABORATION PROGRAMME

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

ANNUAL REPORT 2017



COVER PHOTO:

A WORLD LEADER IN RENEWABLE ENERGY

Operational since late 2016, the photovoltaic plant El Romero Solar, which represented a major logistical and technological challenge for ACCIONA, was successfully completed. The facility, installed in the Atacama Desert, is able to supply clean energy to Google data servers in Chile, among others customers. It is the highest capacity PV plant in South America.

With 246 MWp peak capacity, El Romero Solar produces energy equivalent to the consumption of around 240 000 Chilean homes.

Located in the Atacama Region, the facility is able to generate 495 GWh of clean energy a year on average, avoiding the emission of around 485 000 metric tons of CO₂ into the atmosphere that would have come from coal-fired power stations.

The El Romero Solar plant covers 280 hectares at one of the driest places on the planet. It has a high level of solar radiation and very clean air, which facilitates the capture of the sun's energy. These factors have been crucial, as well, in the installation of astronomical observatories in the area.

The plant is equipped with 776 000 polycrystalline silicon photovoltaic modules, making up a solar capture surface of over 1,5 million m² (equivalent to 211 professional soccer pitches). The panels are installed on static metal structures which, if lined up, would have a total length of over 196 kilometers.

KEY POINTS

- Owned by ACCIONA, with an 343 MUSD investment
- 495 GWh annual average output
- Enough clean energy to power 240 000 Chilean homes
- Part of its production supplies the Google's data center in Chile
- Emission of 485 000 metric tons of CO₂ a year avoided from coal-fired power stations
- Total area of 280 hectares, with 150 hectares of solar capture surface
- 776 000 polycrystalline silicon photovoltaic modules
- With more than 55 million solar cells
- Mounted on metal static structures covering 196 kilometers if lined-up
- 180 converters DC/AC of 1,089 MW
- New substation (33/220 kV) connected with the Pan de Azucar-Maitencillo line, belonging to the SIC grid

ACCIONA Energy is the biggest global energy company operating exclusively in the renewable energy sector, present in over 20 countries on five continents. The company operates 9 000 Megawatts (MW) of own capacity, annually producing some 21 Terawatt-hours (TWh) of emission-free electricity, the equivalent of consumption by over six million homes.

Credits: Cover photo and above, courtesy of ACCIONA.

CHAIRMAN'S MESSAGE



It is a great pleasure to present the 2017 annual report of IEA PVPS, the Photovoltaic Power Systems Programme of the International Energy Agency, to you. 2017 has confirmed the strong development of the global photovoltaic market of previous years and a further increase in competitiveness of solar photovoltaic (PV) power systems whereby PV is rapidly entering the energy world. Measured by net installed capacity, PV has now become the fastest growing energy technology. Achieving levelized costs of electricity from PV as low as under 2 USDcents/kWh, establishing Gigawatt (GW) scale markets in an increasing number of countries around the world and a continuous evolution of the market framework set the scene for our global collaborative efforts.

2017 has seen close to 100 GW, more precisely 98 GW, of additional installed PV capacity worldwide, raising the cumulative installed capacity to 402,5 GW. China, the USA, India and Japan represented the largest markets in 2017, accounting for more than 80 % of the additional installed capacity in these four countries alone. Meanwhile, 55 % of the global PV capacity is being installed in the Asia-Pacific region with China ahead of all others at more than 53 GW of installed capacity in 2017. 29 countries have now reached cumulative installed capacities above 1 GW, 16 countries installed at least 500 MW during 2017 and in at least 28 countries, PV contributes with 1 % or more to the annual electricity supply. In 2017, PV has contributed to roughly 2 % of the world's electricity generation.

These dynamic market developments, progress in PV technology and industry and a rapidly changing overall framework form the basis for the activities of the IEA PVPS Programme. During 2017, IEA PVPS discussed and determined its future strategy for the term 2018 – 2023, focussing on the integration of PV in the energy system as a whole. Indeed, as PV is increasingly becoming a part of the energy system, integration at all levels becomes a key strategic matter. Keeping our overall mission to foster global cooperation and working on both technical and non-technical issues, IEA PVPS widens its scope, both in content and in cooperation with other organizations. Our key collaborative projects are related to environmental assessment of PV, reliability and performance assessment, cost reduction, grid and building integration, best practice in various applications, as well as the rapid deployment of photovoltaics. Anticipating future needs, IEA PVPS also addresses recent policy and market issues, new business models, sustainable policy frameworks, as well as technical and market related integration of photovoltaics in the electricity and energy system at large.

As PV matures with a growing number of stakeholders and organizations, providing well targeted, high-quality information about relevant developments in the photovoltaic sector, as well as policy advice to our key stakeholders, remain our highest priorities. Due to the increasing recognition of photovoltaics as an important future energy technology, the interest in the work performed within IEA PVPS is constantly expanding and the outreach of our efforts becomes more and more relevant. Besides the continuous exchange and cooperation within the IEA technology network, stronger ties are being built with organizations such as IRENA and the IEC, as well as with the utility sector.

Interest and outreach for new membership within IEA PVPS continued in 2017. With Chile becoming a PVPS member in 2017, IEA PVPS now has its first participant from South America and thus covers all five continents. At the end of 2017, IEA PVPS had 31 members and is one of the largest IEA technology collaboration programmes (TCPs). Morocco is in the process of joining IEA PVPS and exploration for membership continued with India, New Zealand, Singapore and ECREEE (ECOWAS Regional Centre for Renewable Energy and Energy Efficiency). IEA PVPS continues to cover the majority of countries active in development, production and installation of photovoltaic power systems.

During 2017, IEA PVPS started work on its collaborative project Task 16 on Solar Resource for High Penetration and Large Scale Applications and decided to set up a new Task 17 on PV and Transport, thereby marking the trend of PV entering an even broader range of applications.

The detailed results of the different PVPS projects are given in the Task reports of this annual report and all publications can be found at the PVPS website (www.iea-pvps.org). Learn about the current status of photovoltaics in all PVPS member countries described within the country section of this annual report.

Our work would not be possible without a committed community of experts and colleagues. I therefore wish to thank all Executive Committee members, Operating Agents and Task Experts, for their ongoing and dedicated efforts and contributions in making IEA PVPS a great success!

A handwritten signature in black ink that reads "S. Nowak". The signature is written in a cursive, slightly slanted style.

Stefan Nowak
Chairman



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PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

IEA

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD), which carries out a comprehensive programme of energy cooperation among its member countries. The European Union also participates in the IEA's work. Collaboration in research, development and demonstration (RD&D) of energy technologies has been an important part of the Agency's Programme.

The IEA RD&D activities are headed by the Committee on Research and Technology (CERT), supported by the IEA secretariat staff, with headquarters in Paris. In addition, four Working Parties on End Use, Renewable Energy, Fossil Fuels and Fusion Power, are charged with monitoring the various collaborative energy agreements, identifying new areas of cooperation and advising the CERT on policy matters. The Renewable Energy Working Party (REWP) oversees the work of ten renewable energy agreements and is supported by a Renewable Energy Division at the IEA Secretariat in Paris.

IEA PVPS

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the Technology Collaboration Programmes established within the IEA, and since its establishment in 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

The overall programme is headed by an Executive Committee composed of representatives from each participating country and organisation, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By late 2016, sixteen Tasks were established within the PVPS programme, of which seven are currently operational.

The thirty-one PVPS members are: Australia, Austria, Belgium, Canada, the Copper Alliance, Chile, China, Denmark, European Union, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, the Netherlands, Norway, Portugal, SEIA, SEPA, SolarPower Europe, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey and the United States of America. Chile, joined PVPS in 2017.

IEA PVPS CURRENT TERM (2013 – 2017)

As one of the few truly global networks in the field of PV, IEA PVPS can take a high level, strategic view of the issues surrounding the continued development of PV technologies and markets, thus paving the way for appropriate government and industry activity. Within the last few years, photovoltaics has evolved from a niche technology to an energy technology with significant contributions to the electricity supply in several countries. IEA PVPS is using its current term to put particular emphasis on:

- Supporting the transition and market transformation towards self-sustained PV markets;
- Working with a broader set of stakeholders, especially from utilities, financiers and industry;

- Assessing and sharing experience on new business approaches and business models;
- Providing targeted and objective information on PV energy services for successful implementation and high penetration;
- Providing a recognised, high-quality reference network for the global development of PV and related matters;
- Attracting new participants from non-IEA countries where PV can play a key role in energy supply.
- Carrying out relevant activities of multinational interest;
- Specifically, IEA PVPS will carry out collaborative activities related to photovoltaics on the topics: Quality and reliability, environmental aspects, grid integration, urban, hybrid and very large-scale systems, off-grid energy services, policy and regulatory frameworks, as well as a broad set of information and communication efforts;
- Finally, where appropriate from an energy system point of view, IEA PVPS will increase the efforts to share its results and cooperate with stakeholders from other energy technologies and sectors.

The overall desired outcomes of the co-operation within IEA PVPS are:

- A global reference on PV for policy and industry decision makers from PVPS member countries and bodies, non-member countries and international organisations;
- A global network of expertise for information exchange and analysis concerning the most relevant technical and non-technical issues towards sustainable large-scale deployment of PV;
- An impartial and reliable source of information for PV experts and non-experts about worldwide trends, markets and costs;
- Meaningful guidelines and recommended practices for state-of-the-art PV applications to meet the needs of planners, installers and system owners. Data collected and the lessons learned are distributed widely via reports, internet, workshops and other means;
- Advancing the understanding and solutions for integration of PV power systems in utility distribution grids; in particular, peak power contribution, competition with retail electricity prices, high penetration of PV systems and smart grids. Monitoring these developments and giving advice from lessons learned will be increasingly useful for many parties involved.
- Establish a fruitful co-operation between expert groups on decentralised power supply in both developed and emerging countries;
- Overview of successful business models in various market segments;
- Definition of regulatory and policy parameters for long term sustainable and cost effective PV markets to operate.

IEA PVPS MISSION

The mission of the IEA PVPS programme is:

To enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems.

The underlying assumption is that the market for PV systems is rapidly expanding to significant penetrations in grid-connected markets in an increasing number of countries, connected to both the distribution network and the central transmission network.

This strong market expansion requires the availability of and access to reliable information on the performance and sustainability of PV systems, technical and design guidelines, planning methods, financing, etc., to be shared with the various actors. In particular, the high penetration of PV into main grids requires the development of new grid and PV inverter management strategies, greater focus on solar forecasting and storage, as well as investigations of the economic and technological impact on the whole energy system. New PV business models need to be developed, as the decentralised character of photovoltaics shifts the responsibility for energy generation more into the hands of private owners, municipalities, cities and regions.

IEA PVPS OBJECTIVES

The IEA PVPS programme aims to realise the above mission by adopting the following objectives related to reliable PV power system applications, contributing to sustainability in the energy system and a growing contribution to CO₂ mitigation:

1. PV Technology Development

Mainstream deployment of PV is in its infancy and will continue to need technology development at the PV module and system levels in order to integrate seamlessly with energy systems around the world. Performance improvements, specialised products and further cost reductions are still required. In addition, renewable energy based technologies, such as PV, by definition rely on the natural cycles of the earth's energy systems and their output therefore varies with the hourly, daily and seasonal cycles of sun, wind and water. This contrasts with energy supplies based on fossil fuels and nuclear, where the energy source is stored and thus available when required. As renewables contribute increasingly to mainstream electricity supply, the need to balance varying renewable energy inputs to meet demand also increases. For optimised PV deployment, this means that synergies with other renewables as well as storage, forecasting and demand-side related activities will become more important and suitable technology development will be required.

IEA PVPS shall:

- Evaluate and validate emerging PV technologies that are still at pre-commercial level and to provide guidelines for improvement of the design, construction and operation of photovoltaic power systems and subsystems to increase reliability and performance and to minimise cost;

- Contribute to the development of new standards, accreditation and approval processes, objective operational experience, grid interconnection-standards; investigation of barriers and communication of success stories;
- Assess the impact of PV on distribution networks, in mini- and micro-grids as well as in other applications and provide analysis of the issues and possible solutions;
- Examine the use of demand management and storage as elements in optimisation of renewable energy system deployment;
- Identify technical opportunities and provide best practice for emerging applications (non-domestic systems, community systems, hybrids, mini-grids, weak grids);
- Foster industry – academia interaction focusing on PV technology development.

2. Competitive PV Markets

Until recently, PV mainly relied on support schemes provided by governments or aid organisations. Within the next few years, the transition towards PV as a competitive energy source will need to take place in most of the energy markets. Therefore, this process needs to be accompanied by reliable information and credible recommendations.

IEA PVPS aims:

- To assess economic performance of PV across member countries and undertake collaborative research to overcome current issues;
- To develop material that will assist in the development of standardised contractual agreements between PV system owners and utilities;
- To encourage private and public sector investments that facilitate the sustainable deployment of PV in new markets and within mainstream energy markets;
- To investigate the synergies between PV and other renewables for optimum power supply in different regions;
- To stimulate the awareness and interest of national, multilateral and bilateral agencies and development and investment banks in the new market structures and financing requirements for economic deployment of PV systems;
- To collate information and prepare reports on market structures suitable for long term sustainable PV deployment;
- To identify economic opportunities as well as promising business models and provide best practice examples for emerging applications (non-domestic systems, community systems, hybrids, mini-grids, weak grids);
- To evaluate and promote "bankability" and innovative business models in PV projects namely:
 - Identifying criteria banks / financiers use in order to determine the terms of potential funding of projects (now and in the future, after the end of subsidized tariffs);
 - Identifying and evaluating insurance or innovative bridging products that would allow banks / financiers to fund more projects and apply better conditions;
 - Identifying, characterizing and potentially develop innovative business models in the PV sector aiming at the definition of clear market rules and legislation that potentiates such business models.



50th IEA PVPS Executive Committee Meeting, Melbourne, Australia, December 2017.

3. An Environmentally and Economically Sustainable PV Industry

The PV industry, even though with many years of experience, is still in its juvenile phase. The huge market growth in recent years needs to be followed by a phase of consolidation. IEA PVPS shall contribute to sustainable industry development around the globe. Development of human resources by adequate education and training, caring for quality in the products and services, aspects of environmental health and safety in the production (e.g. collection and recycling, as well as the whole life cycle of PV products) are essential to establish this new sector as a pillar in the new energy economy.

IEA PVPS shall:

- Investigate the environmental impact of PV products in their whole life cycle;
- Assist the development of collection infrastructure by examining and evaluating the collection infrastructure of other recyclables (e.g., electronics, liquid crystal displays);
- Enhance the interaction among industry players so that they share information and resources for collection and recycling;
- Show the technical and cost feasibility of collection and recycling to environmental-policy makers;
- Create a clear understanding of safety and provide recommendations on the use and handling of hazardous substances and materials during the manufacturing process;
- Foster industry – academia interaction focusing on PV's sustainability.

4. Policy Recommendations and Strategies

As PV moves into mainstream energy markets, standards, laws and regulatory arrangements made when fossil fuels dominated energy supply may no longer be suitable. Where PV is connected to distribution networks, market structures will need to be developed which accommodate on-site generation, two-way electricity flows, and associated energy efficiency and demand management opportunities,

whilst also providing signals for ancillary services to enhance grid stability. Guidelines are needed for adapted innovation processes to achieve a sustainable PV industry, as well as best practice of the frame conditions in industry-policy for a competitive photovoltaic industry. For central PV-generation, new rules may be required to cater to variable generators, and market signals provided for accurate forecasting, synergies with other renewables and storage. In off-grid applications, cross subsidies currently provided across the world for diesel generation will need to be examined if PV is a more cost effective solution, while tax structures and other arrangements designed around annual fuel use may need to be changed to cater for the up-front capital investment required for PV.

IEA PVPS shall:

- Contribute to long term policy and financing schemes namely to facilitate implementation of innovative business models, national and international programmes and initiatives;
- Share the activities and results of national and regional technology development and deployment programmes;
- Provide objective policy advice to governments, utilities and international organisations;
- Identify successful policy mechanisms leading to self-sustained market growth;
- Examine and report on international examples of PV as a significant player in national and regional energy systems;
- Investigate the impact of the shift towards renewables on other – mainly fossil and nuclear – generation businesses in high PV scenarios.
- Develop strategies for markets where PV power is already economically competitive with end-user power prices.
- Develop long term scenarios and visionary papers and concepts namely developing a Multi – PV Technology Roadmap, by that contributing to new strategies and innovation.

5. Impartial and Reliable Information

PVPS is well established as a highly credible source of information around the PV sector. Even though many PV communities, agencies and other organisations exist, this role remains as one of the key IEA PVPS objectives. This role as a global reference for PV related issues will experience significant development within the upcoming period, including the impact of PV technology on the environment, existing energy systems and the society at large.

IEA PVPS shall:

- Collect and analyse information on key deployment issues, such as policies, installations, markets, applications and experiences;
- Present/publish the reliable and relevant parts of this information in appropriate forms (presentations, brochures, reports, books, internet, etc.);
- Increase awareness of the opportunities for PV systems amongst targeted groups via workshops, missions and publications;
- Respond to the IEA and other organizations' needs regarding the worldwide development of PV technology and markets;
- Identify the needs for PV specific training and education;
- Develop education and awareness materials which remove informational barriers among key target audiences, including consumers, developers, utilities and government agencies;
- Prepare material and tools for training and education in industry.

IEA PVPS TASKS

In order to obtain these objectives, specific research projects, so-called Tasks, are being executed. The management of these Tasks is the responsibility of the Operating Agents. The following Tasks have been established within IEA PVPS:

- Task 1. Strategic PV Analysis and Outreach;
- Task 2. Performance, Reliability and Analysis of Photovoltaic Systems (concluded in 2007);
- Task 3. Use of PV Power Systems in Stand-Alone and Island Applications (concluded in 2004);
- Task 4. Modelling of Distributed PV Power Generation for Grid Support (not operational);
- Task 5. Grid Interconnection of Building Integrated and other Dispersed PV Systems (concluded in 2001);
- Task 6. Design and Operation of Modular PV Plants for Large Scale Power Generation (concluded in 1997);
- Task 7. PV Power Systems in the Built Environment (concluded in 2001);
- Task 8. Study on Very Large Scale Photovoltaic Power Generation System (concluded in 2014);
- Task 9. Deploying PV Services for Regional Development;
- Task 10. Urban Scale PV Applications. Begun in 2004; follow-up of Task 7 (concluded in 2009);
- Task 11. PV Hybrid Systems within Mini-Grids. Begun in 2006; follow-up of Task 3 (concluded in 2011);
- Task 12. Environmental Health and Safety Issues of PV. Begun in 2007;

- Task 13. Performance and Reliability of PV Systems. Begun in 2010;
- Task 14. High Penetration PV in Electricity Grids. Begun in 2010;
- Task 15. BIPV in the Built Environment. Begun in late 2014.
- Task 16. Solar Resource for High Penetration and Large Scale Applications. Begun in 2016.
- Task 17. PV and Transport. Begun in late 2017.

The **Operating Agent** is the manager of his or her Task, and responsible for implementing, operating and managing the collaborative project. Depending on the topic and the Tasks, the internal organisation and responsibilities of the Operating Agent can vary, with more or less developed subtask structures and leadership. Operating Agents are responsible towards the PVPS ExCo and they generally represent their respective Tasks at meetings and conferences. The Operating Agent compiles a status report, with results achieved in the last six months, as well as a Workplan for the coming period. These are being discussed at the Executive Committee meeting, where all participating countries and organisations have a seat. Based on the Workplan, the Executive Committee decides to continue the activities within the Task, the participating countries and organisations in this Task commit their respective countries/organisations to an active involvement by their experts. In this way, a close cooperation can be achieved, whereas duplication of work is avoided.

TASK STATUS REPORTS

TASK 1 – STRATEGIC PV ANALYSIS & OUTREACH

Task 1 shares a double role of expertise (on PV markets, industry, and policies) and outreach, which is reflecting in its name "Strategic PV Analysis & Outreach".

Task 1 activities support the broader PVPS objectives: to contribute to cost reduction of PV power applications, to increase awareness of the potential and value of PV power systems, to foster the removal of both technical and non-technical barriers and to enhance technology co-operation.

It aims at promoting and facilitating the exchange and dissemination of information on the technical, economic, environmental, and social aspects of PV power systems.

Expertise

- Task 1 researches market, policies and industry development.
- Task 1 serves as think tank of the PVPS programme, by identifying and clarifying the evolutions of the PV market, identifying issues and advance knowledge.

Outreach

- Task 1 compiles the agreed PV information in the PVPS countries and more broadly, disseminates PVPS information and analyses to the target audiences and stakeholders.
- Task 1 contributes to the cooperation with other organizations and stakeholders.

Task 1 is organized in four Subtasks, covering all aspects, new and legacy of the activities.

SUBTASK 1.1: Market, Policies and Industrial Data and Analysis

Task 1 aims at following the evolution of the PV development, analyzing its drivers and supporting policies. It aims at advising the PVPS stakeholders about the most important developments in the programme countries and globally. It focuses on facts, accurate numbers and verifiable information in order to give the best possible image of the diversity of PV support schemes in regulatory environment around the globe.

National Survey Reports

National Survey Reports (NSRs) are produced annually by the countries participating in the IEA PVPS Programme. The NSRs are funded by the participating countries and provide a wealth of information. These reports are available on the PVPS public website www.iea-pvps.org and are a key component of the collaborative work carried out within the PVPS Programme. The responsibility for these national reports lies firmly with the national teams. Task 1 participants share information on how to most effectively gather data in their respective countries including information on national market frameworks, public budgets, the industry value chain, prices, economic benefits, new initiatives including financing and electricity utility interests.

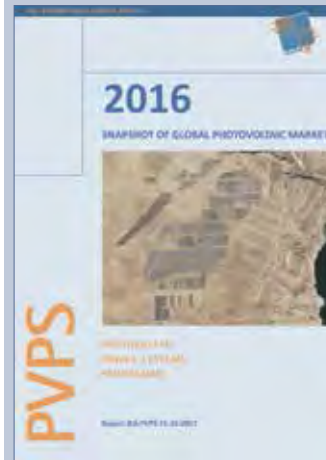


Fig. 1 – PVPS Report: A Snapshot of Global PV 1992-2016; Report IEA PVPS T1-31:2017.



Fig. 2 – PVPS Report: Trends in Photovoltaic Applications – Survey Report of Selected IEA Countries between 1992-2016; Report: IEA PVPS T1-32:2017.

22nd Edition of the TRENDS in Photovoltaic Applications Report

Each year the printed report, *Trends in Photovoltaic Applications*, is compiled from the National Survey Reports (NSRs) produced annually by all countries participating in the IEA PVPS Programme, and additional information provided by a network of market and industry experts. The Trends report presents a broader view of the current status and trends relating to the development of PV globally. The report aims at providing the most accurate information on the evolution of the PV market, the industry value chain, with a clear focus on support policies and the business environment. In recent years, the *Trends* report team has developed an in-depth analysis of the drivers and factors behind PV market, as well as development and analyses the complete global PV market and industry.

The report is prepared by a small editorial group within Task 1 and is funded by the IEA PVPS Programme. Copies are distributed by post by Task 1 participants to their identified national target audiences, are provided at selected conferences and meetings and can be downloaded from the website. From 1995, twenty-two issues of Trends have been published. They are all available on the IEA-PVPS website.

A Snapshot of Global PV Report

Since 2013, an additional report, *A Snapshot of Global PV*, is compiled from the preliminary market development information provided annually by all countries participating in the IEA PVPS Programme. The Snapshot report aims at presenting a first sound estimate of the prior year's PV market developments and is published in the first quarter of the year. Task 1 aims at producing this report every year in order to communicate the PV market developments, including policy drivers' evolution, early in the year.



Fig. 3 - 48th IEA PVPS Task 1 Experts Meeting in Rome, Italy, April 2017



Fig. 4 - The 3rd IEA PVPS PV & Utilities Workshop, "How Utilities can Incorporate Photovoltaics in Their Business Deals" took place in Vienna, Austria, 12 December 2017, with 11 utilities from Europe present (Photo: Hubert Fechner, University of Applied Sciences, Technikum Wien).

SUBTASK 1.2: Think Tank Activities

Task 1 aims at serving as the PVPS programme's Think Tank, while providing the Executive Committee and dedicated PVPS Tasks with ideas and suggestions on how to improve the research content of the PVPS programme. In that respect, Task 1 has identified several subjects from 2013 to 2017, that have led to specific activities.

- *PV for Transport*: The electrification of transport is one of the key elements to decarbonize that sector. And the connections between PV and electric vehicles are numerous: from embedded PV cells in cars, bus, trucks, trains or planes to the use of e-mobility as an accelerator of PV development, all these subjects will be part of our research activities in the coming months and years.
- *New Business Models for PV Development*: With the emergence of a PV market driven in some countries by the sole competitiveness of PV, the question of emerging business models receives a continuous interest. In 2017 Task 1's work was focused on studying emerging models through dedicated workshops and conferences.
- *PV and Utilities*: Electric utilities, producing, distributing and selling electricity to final customers have been identified as crucial actors for a large-scale development of PV. In that respect, Task 1 organized several workshops where utilities and PV experts exchanged information and visions about the role of utilities. The "How Utilities can Incorporate Photovoltaics in Their Business Deals" Workshop, took place in Vienna, Austria, 12 December 2017. IEA PVPS will continue to provide a platform where these actors can meet and exchange information.
- *Recommendations and Analysis*: PV's fast development on all continents requires from regulators and authorities to perfectly understand the key features of the PV technology development. IEA PVPS will provide a set of recommendations in various fields, to disseminate the vast experience acquired by its experts over the last several years.

SUBTASK 1.3: Communication Activities

Task 1 aims at communicating about the main findings of the PVPS programme through the most adequate communication channels. In that respect, five main type of communication actions are conducted throughout the year.

Events: Task 1 organizes events or participates in them during energy or PV-related conferences and fairs. Workshops are organized on

various subjects, sometimes in cooperation with other PVPS Tasks or external stakeholders. In 2017, the following workshops were organized in several locations around the world:

- Rome, Italy: A conference was organized in cooperation with GSE during the 48th Task 1 meeting in Rome. It focused on the rebirth of the Italian PV market, including industry developments and connection with local stakeholders.
- Amsterdam, The Netherlands: A PVPS Task 1 and IRENA Workshop on "New and Emerging PV Applications" were held in September 2017 at the 33rd EU-PVSEC; focusing on PV market development, as well as costs and new applications for competitive PV.
- Santiago de Chile, Chile: During the 49th Task 1 Experts Meeting in Chile, Task 1 participated in the GENERA event in Santiago de Chile, focused on solar PV development in the country.
- Antofagasta, Chile: On the same occasion, a workshop was organized with local PV stakeholders together with CORFO.
- Shiga, Japan: A workshop was held during PVSEC-27 in Japan on PV and electro-mobility. It was co-organized with NEDO.
- Vienna, Austria: The 3rd IEA PVPS PV and Utilities Workshop was organized in Vienna with European utilities, in order to exchange on business models for PV managed by utilities.
- In addition, IEA PVPS was partner to several events in 2017. Task 1 speakers represented the programme in several conferences in various places.

Webinars: to increase its visibility, Task 1 speakers participated to three webinars organized by Leonardo Energy (a part of Copper Alliance, the IEA PVPS member) and ISES on PV markets, policies and industry development.

Publications: The publications of Task 1 have been described above. PVPS Task 1 publications aim at providing the most accurate level of information regarding PV development.

Website and Social Networks: Task 1 manages the IEA PVPS website www.iea-pvps.org. IEA PVPS is also present on Twitter and LinkedIn.

PV Power Newsletter: Two issues were published in 2017, the 39th edition and a special one for EU-PVSEC, with the ambition to provide accurate and complete information to the worldwide PV audience about the IEA PVPS programme, at least twice a year.



Fig. 5 - IEA PVPS Task 1 & IRENA Workshop on "New and Emerging PV Applications" at the 33rd EU-PVSEC 2017.



Fig. 6 - 49th IEA PVPS Task 1 Meeting in Antofagasta, Chile, October 2017.

IEA PVPS in the Media

New publications are disseminated by press releases to around 500 contacts from media and national PV associations. This contact list is continuously expanded, and recently with more media from Asian, African and Latin American countries in a progressive way. Translation of IEA PVPS press releases is done by some PVPS member countries to expand visibility.

Five press releases have been issued in 2017, covering new reports.

All reports and activities are also promoted through Twitter. IEA PVPS Twitter account had more than 800 followers by the end of 2017.

SUBTASK 1.4: Cooperation Activities

In order to gather adequate information and to disseminate the results of research within Task 1, cooperation with external stakeholders remains a cornerstone of the PVPS programme.

This cooperation takes places with:

- The IEA itself, for market data and system costs and prices,
- Other Technology Collaboration Programmes of the IEA,
- Stakeholders outside the IEA network: IRENA, ISES, REN21, etc.

SUMMARY OF TASK 1 ACTIVITIES AND DELIVERABLES PLANNED FOR 2018

Task 1 activities will continue to focus on development of quality information products and effective communication mechanisms in support of the PVPS strategy. Further, Task 1 will continue to analyze PV support policies and provide adequate and accurate information to policy makers and others stakeholders. In addition to the recurrent market and industry analysis, Task 1 will continue to study the evolution of business models, the role of utilities and policies enabling PV as a key component of the energy transition.

SUBTASK 1.1: Market, Policies and Industrial Data and Analysis

National Survey Reports will start to be published from Q3 2018 on the IEA PVPS website.

The target date for publication of the 6th issue of the *Snapshot of Global PV* report is the end of Q1 2018.

The target date for publication of the 23rd issue of the *Trends in Photovoltaic Applications* report is the Q4 2018. Other smaller reports are foreseen.

SUBTASK 1.2: Think Tank Activities

The main subjects to be developed in 2018 through the PVPS Think Tank activities can be described as follows:

- Expand the analysis on self-consumption based business models, including DSM and storage capabilities. PV for transport and the built environment, Solar fuels and other enablers of the energy transition are foreseen.
- The role of utilities with regard to PV development continues to be a cornerstone of the activities.
- Liaison with all PVPS Tasks and the Executive Committee in order to better exchange on defining the future of the PVPS programme.

SUBTASK 1.3: Communication Activities

Task 1 will continue its communication activities in 2018. First by communicating about the publications and events organized within Task 1 and second, by contributing to disseminating the information on publications and events of the entire PVPS programme.

SUBTASK 1.4: Cooperation Activities

Task 1 will continue to cooperate with adequate stakeholders in 2017. It will reinforce the link with IEA in particular and enhance its cooperation with IRENA, ISA, ISES and other organizations. Regarding the cooperation among other IEA TCPs, a special focus could be put on subjects such as heating and cooling in buildings, as well as electric vehicles.

INDUSTRY INVOLVEMENT

Task 1 activities continue to rely on close co-operation with government agencies, PV industries, electricity utilities and other parties, both for collection and analysis of quality information and for dissemination of PVPS information to stakeholders and target audiences. This is achieved through the networks developed in each country by the Task 1 participants.

MEETING SCHEDULE (2017 AND PLANNED 2018)

The 48th Task 1 Experts Meeting was held in Rome, Italy in April 2017.

The 49th Task 1 Experts Meeting was held in Antofagasta, Chile in October 2018.

The 50th Task 1 Experts Meeting will be held in Kuching, Malaysia, in April 2018.

The 51st Task 1 Experts Meeting will be most probably held in Europe in Q3 or Q4 2018.

TASK 1 PARTICIPANTS IN 2017 AND THEIR ORGANIZATIONS

In many cases the following participants were supported by one or more experts from their respective countries:

COUNTRY	PARTICIPANT	ORGANIZATION
Australia	Warwick Johnston	SUNWIZ
Austria	Hubert Fechner	University of Applied Sciences Technikum Wien
Belgium	Grégory Neubourg	APERe
Canada	Christopher Baldus-Jeursen	NRCAN/RNCAN
Chile	Guillermo Jiménez Estévez	University of Chile
China	Lyu Fang	Electrical Engineering Institute, Chinese Academy of Science
Copper Alliance	Angelo Baggini	ECD
Denmark	Peter Ahm	PA Energy AS
European Commission	Arnulf Jaeger-Waldau	European Commission, Directorate General for Energy
Finland	Jero Ahola	Lappeenranta University of Technology
	Christian Breyer	
France	Tristan Carrere	ADEME
Germany	Georg Altenhöfer-Pflaum	Forschungszentrum Jülich
Israel	Honi Kabalo	PUA
Italy	Salvatore Guastella	RSE SpA
	Giosuè Maugeri	
	Francesca Tilli	GSE
	Luisa Calleri	Elettricità Futura
	Andrea Zaghi	
Japan	Izumi Kaizuka	RTS Corporation
	Masanori Ishimura	NEDO
Korea	Inchul Hwang	KEA
Malaysia	Wei Nee Chen	SEDA
Mexico	Jaime Agredano Díaz	Instituto de Investigaciones Electricas, Energías no Convencionales
Norway	Øystein Holm	Multiconsult
Portugal	Pedro Paes	EDP
SolarPower Europe	N/A	SolarPowerEurope
South Africa	Stephen Koopman	CSIR
Spain	José Donoso	UNEF
Sweden	Johan Lindahl	Swedish Solar Association
Switzerland	Pius Hüsser	Nova Energie
Thailand	Pathamaporn Poonkasem	Department of Alternative Energy Development and Efficiency
	Thanyalak Meesap	
	Thidarat Sawai	
The Netherlands	Otto Bernsen	Agentschap NL
Turkey	Kemal Gani Bayraktar	Gunder
USA	Christopher Anderson	DoE
	Daniel Boff	
	David Feldman	NREL

TASK 9 – DEPLOYING PV SERVICES FOR REGIONAL DEVELOPMENT



Fig. 1 - PV training in Ghana (Photo: GSES).



Fig. 2 - Quality of PV equipment on a Pacific Island (Photo: GSES).

INTRODUCTION

In December 2015, the Paris climate accord was reached on limiting the impact of climate change to below 2 degrees Celsius. This agreement formally acknowledges the importance of upscaling and distributing renewable energy as well as the need for universal access to energy through renewable energy solutions. In the very same year 2015, the Agenda 2030 with 17 Sustainable Development Goals (SDGs) was adopted to end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda. SDG 7 is specifically addressing universal energy access, energy efficiency and renewable energies. To address **both**, the Paris Agreement as well as the Agenda 2030, renewables and in particular solar PV systems should play an important role. The IEA member countries have mature power systems and broad experience on technical and policy aspects on how to apply available technologies successfully. Following this logic, Task 9 is dealing with deploying PV services for regional development.

With declining PV costs, PV applications are competitive in an increasing number of situations, thus providing numerous opportunities for energy services which lead to accelerated development.

To quote Mr. Fatih Birol, the Executive Director of IEA, "...the IEA intends to become a real global network, building new bridges with emerging countries and establishing outreach activities especially in **non-IEA member countries**." This statement gave a strong mandate to Task 9 and consequently, decision has been made to continue **focusing on developing and emerging countries by adapting and transferring relevant knowledge and information for such countries**.

OBJECTIVES

Task 9's vision is to act as a facilitator for large scale deployment of PV in emerging and developing regions to foster a sustainable economic and social transition process and regional development. Through its impartial, best of class research work and active dissemination of research results, Task 9 significantly contributes to this vision. By cooperating with other PVPS Tasks and national and international development partners, the outreach of Task 9 outputs

is leveraged and research activities and field work of co-operating institutions are complemented and strengthened.

The current Task 9 members consider developing and emerging countries as an important focus for the deployment of PV technology. Consequently, it was agreed to continue focusing on emerging and developing countries:

- I. By selecting topics of high relevance for these countries
- II. By strengthening and extending its existing network with emerging countries and relevant bi- and multilateral organisations to ensure significant outreach and impact

During its last four year program 2012-2015, Task 9 started moving away from the more classical solar home systems for individual households and "pico" uses to a broader range of PV applications including village mini-grid power systems, in particular hybrid systems. For its new program phase 2016-2018, a clear decision was made to focus on PV in mini grids and distributed PV in bigger grids (grid-connected PV) including high penetration of renewable energies on islands.

Past experience has shown that SHS and pico appliances have become highly commercial businesses. Simultaneously, centralised electricity supply systems (mini grids for communities) and the extension of the national grid (including grid-connection of RE systems) are playing more and more an important role, also in developing and emerging countries.

Task 9 intends to strengthen its outreach and dissemination activities. Close cooperation and exchange with international and development organisations ensures the demand-driven work of Task 9 in line with practitioners' problems in the field and with the needs of policymakers and other relevant stakeholders. Furthermore, it is considered crucial to closely cooperate with other PVPS Tasks, to analyse their activities and outputs with regard to their relevance for emerging countries and where useful "translate" such results to the specific conditions in emerging countries. E.g. in countries, where the national grid is



Fig. 3 – Task 9 Report: Guideline to Introducing Quality Renewable Energy Technician Training Programs.

still characterized by frequent breakdowns, fluctuating voltage and frequency etc., feeding into such a grid with distributed PV systems encounters a lot of problems – quite different from industrialised countries.

Although the technology gap between OECD and non-OECD countries is narrowing, it is still necessary to translate newest outputs from PVPS to emerging countries realities.

APPROACH

Task 9 is subdivided into four topical Subtasks well reflecting the above stated topics of high relevance. The fifth Subtask “outreach and impact” is contained as an activity within each of the four Subtasks as described below. In addition, the contribution to standardization bodies and other groups is part of this fifth Subtask.

ACCOMPLISHMENTS OF IEA PVPS TASK 9

The two most recent accomplishments from the last phase which also resulted in respective publications are briefly described below.

Guideline to Introducing Quality Renewable Energy (RE) Technician Training Programs

High quality technical training for Renewable Energies (RE) technicians – in training institutes, technical colleges or polytechnics – is a crucial precondition for successful sector development. Incorrect installations are not only dangerous but can also discredit a technology in a country. Though RE has increased dramatically over the last 10–15 years, training of technicians within accredited training centres has not kept pace with the industry requirements. Only in a few countries specific RE training is already included in the training framework. In April 2017, Task 9 and the International Solar Energy Society (ISES) jointly published a “Guideline to Introducing Quality Renewable Energy (RE) Technician Training Programs” (see Figure 3). It addresses the RE industry, multi-lateral and bi-lateral donors, as well as government ministries/departments that want to introduce quality training programs for technicians. The guide helps to introduce RE courses into an existing quality training framework or, if one does not exist, to establish a process whereby the training being provided is following quality procedures.



Fig. 4 – Important components of a Quality Training Framework (Photo: GSES).

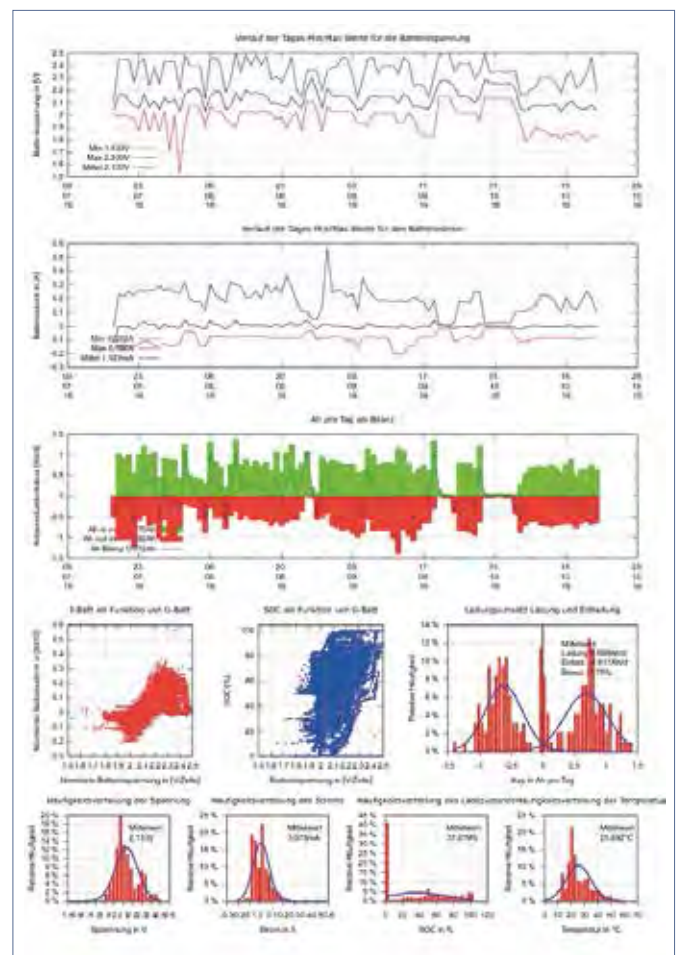


Fig. 5 – One-page standardized graphical analysis of the battery status in a PV mini grid (Source: Fraunhofer ISE).



Fig. 6 - Solar panel on residential house, Cambodia, 2017 (Photo: IED, France).



Fig. 7 - 216 kWc PV power plant, Mali, 2011 (Photo: IED France).

Monitoring of Hybrid Systems in Rural Areas

Based on field experiences with PV-diesel hybrid systems and literature reviews a user guide has been developed **"to simple monitoring and sustainable operation of PV-diesel hybrid systems"**. This activity was led by Sweden and the guideline was published in December 2015. The guideline offers system users a way of understanding if their system is operated in a way that will make it last for a long time. It gives suggestions on how to act if there are signs of unfavourable use or failures. The application of the guide requires little technical equipment, but daily manual measurements. It provides information on required measurement equipment, required measurements, short and long term evaluation of the results, recommendations on measures to be taken in case of blackouts, etc. For the most part, the monitoring can be managed by pen and paper, by people with no earlier experience with power systems. At the time of being published, the guide had not been tested in full on any real case, meaning that - depending on feedback from users - it might be adapted in a later stage.

SUBTASKS AND ACTIVITIES

SUBTASK 1: Minigrids Integrating Diesel Generation and PV

This Subtask is subdivided into two main work packages:

- a) Evaluation of existing PV hybrid systems
- b) "PV as Fuel Saver"

SUBTASK 1a): Evaluation of Existing PV Hybrid Systems

This first work package evaluates existing PV hybrid systems with regard to their operation experience, technical, institutional, organisational and financial challenges. Such systems are typically **in the range of less than 100 kW, consisting of a PV- and a battery-component and a small diesel generator** only used as a back-up in case the battery capacity is not sufficient. The activity can build on results from a former activity related to "PV Hybrid Systems within Mini-grids" which elaborated an overview on best practise systems. Besides, newly installed systems are analysed by means of a literature review. For the identified systems, their topology, operation, maintenance and financial data as well as non-technical information are collected and analysed to evaluate: performance, grid stability, fuel consumption and cost, load profile, maintenance effort and cost, levelized cost of energy, logistical problems and organisational issues. In addition, options to connect the respective system to the national grid - if this is approaching - are identified. The analysis will consider smaller DC coupled hybrid systems as well as bigger AC coupled systems (inverter managed and genset managed grids) and also mixed systems. Based on the results, a detailed

catalogue of recommendations for policy makers and utilities will be developed as part of a final evaluation report. So far, the definition of the data format has been completed and was sent to potential partners. In addition, a data analysis tool has been created which will finally provide a one page standardised graphical analysis showing the details of battery use, as presented in Figure 5.

SUBTASK 1b): "PV as Fuel Saver"

In the second work package, the research focus is on **bigger systems in the range of more than 100 kW which typically consist of a diesel generator supplemented by a small PV-component** (often not exceeding 20-25 % of the overall installed capacity) but without any battery component. The latter is not necessary since with a diesel generator being the "dominant part" no storage is required. For such types of systems, the potential of PV to support electricity generation is analysed. The work starts with a literature research to analyse state of the art and countries relevant for the study. The objective here is to do a case study based simulation of a specific system as it is and as it could be if the PV generation part is increased. The analysis again includes parameters like performance, grid stability, fuel consumption, load profile, maintenance effort and levelised cost of energy. A detailed catalogue of recommendations will be developed and be part of a final evaluation report for policy makers and utilities including critical preconditions for system improvement, an overview on existing tools, e.g. HOMER and others and a flowchart for decision making.

Although a number of PV-diesel systems had been identified worldwide (Brazil, Canada, Haiti, Namibia, Senegal, Bolivia), the major barrier to analyse these systems was always lack of access to relevant data. Even an effort of contacting 20 further experts and institutions was of no avail, so that finally the decision has been taken to do a case study based simulation of a typical PV diesel system instead. This analysis will show the diesel saving potential and thus provide substantial output for the planned evaluation report for utilities and policy makers.

SUBTASK 2: Deployment of 100 % Renewables in (Small) Island States

Being a hotly debated topic, this Subtask is attracting increasing interest in the research community. A number of small-island countries, e.g. Cook Islands have ambitious 100 % RE targets, while many others have high targets such as 60 to 80 %. In most of the countries the objective is to reduce their dependency on imported

fossil fuels, in particular diesel, for electricity generation. Targets often being set by politicians, the relevant government departments and utilities are then "left alone" with the task to identify and address all the technical and non-technical requirements to meet the target. This Subtask intends to collect documentary evidence of the technical and non-technical (social, economic and regulatory) issues that have been identified and addressed in small island countries that are working towards 100 % RE targets. A series of case studies will be compiled. The areas to be addressed in a final guideline will include: penetration level of different renewable energy technologies, size of systems and the required land areas, energy storage, grid stability and control requirements, ownership of systems, power purchase agreements, tariff structure, regulatory requirements, capacity building, community and social issues. Gathering case study data and collating the information in a suitable format will provide guidance for other small island countries.

SUBTASK 3: Guideline to Introducing Quality Renewable Energy Training Programs

Under this Subtask which is now accomplished, a guide has been developed for The RE Industry, multi-lateral and bi-lateral donors and government ministries/departments that want to introduce competency based quality RE training programs for technicians into a country or region. The guide provides an overview of:

- 1) Quality training frameworks;
- 2) The processes involved in developing competency based quality-training programs; and
- 3) The capacity building requirements for the technical and vocational education sector.

It supports stakeholders in identifying the best way to introduce RE courses into an existing quality training framework or, if one does not exist, to establish a process whereby the training being provided is following quality procedures. The guide concludes with recommendation that the global RE industry should consider the introduction of an international framework that would provide a mechanism for renewable energy training programs to be accredited by a third party.

SUBTASK 4: PV Development as Prosumers

Under PVPS Task 1, a study on this topic was concluded in 20 industrialised countries. The objective of the current Subtask is to broaden the study scope by including emerging and developing countries.

The analysis focuses on the net-metering and auto consumption regulatory and financial schemes applying for urban residential, administrative and commercial "prosumers" (producer-consumer); it does not cover industrial and rural prosumers. Furthermore, the study focuses mainly on political/regulatory and financial/fiscal issues related to the technology. Even though technical aspects like grid stability, data transmission and storage are important aspects, they cannot be studied extensively.

About three countries already having a policy in place and four countries intending to establish a net metering policy are selected in Asia and Africa. The selected countries, i.e. Kenya, South Africa, Benin, Burkina Faso, Cap Verde, India, Philippines and Ghana, reflect problems as well as success stories but also schemes of different scale. The conceptual phase has been important to well identify partners (e.g. ECREEE, GIZ, IRENA, ARE, CLUB ER, ASEF, etc.), understand the needs of developing countries interested in prosumers development in terms of knowledge transfer and capacity building, and to define the target group(s) and appropriate dissemination strategy for the deliverables.

Based on the analysis and comparison of different countries, an evaluation is made to identify main hindrances, best practices, etc. The results being compared with those from the former study will be an excellent tool to facilitate N-S exchange with regard to self-consumption and net-metering policies through compilation and dissemination of good practices in this field (promoting experience sharing for institutional decision-makers in developing countries). The analysis mostly focuses on residential prosumers' development. The idea is to develop a prospective view on the main opportunities and challenges arising from rapid urbanization in developing countries in terms of access to modern energy.

The study can also contribute to knowledge building for European companies targeting PV "net-metering" development in emerging markets.

SUBTASK 5: Outreach and Dissemination

In the current situation of strengthening Task 9 activities, of consolidating networks for outreach and for gaining new members to support Task 9, this Subtask of "outreach and dissemination" is of outstanding importance. Switzerland having the role of Operating Agent, leads this Subtask but also involves further Task 9 members wherever possible. The activities mainly focus on:

- 1) coordination, support and management of activities of the Subtasks
- 2) making contacts, dissemination of existing and new outputs and networking

The main objectives of these activities are to identify new Task 9 members and to improve the outreach of the Task 9 activities. A focus is put on building international relationships, e.g. with IRENA, SE4ALL, GIZ, SDC, AfDB, etc. but also new initiatives, such as the International Solar Alliance (ISA, founded by France and India) and the Mission Innovation Challenge No 2.

Under this Subtask 5, Task 9 experts also contribute to various standardization bodies and other working groups:

- **IEC 62109 (Safety of Charge Controllers)** within IEC-TC-82 (Solar PV energy systems): overall goal is to separate requirements of inverters from those of charge controllers; DE, ES → work has started, T9 participation in meetings in 2016 and 2017.
- **Contribution to CIGRE, C6.28 WG; DE**, relevant contribution from Task 9 to the technical brochure "Hybrid Systems for



Fig. 8 – Task 9 members at their meeting 2016 in Bad Hersfeld, Germany (Photo: Hedi Feibel).

Off-grid Power Supply (Remote Grids)”. Review of existing chapters and contribution of several subchapters.

- **Contribution to IEA working group 28** (IEA Wind Energy TCP), IEA PVPS **Task 1**, IEA PVPS, **Task 13** and IEA PVPS **Task 14**; DE, DK, ES; content to be determined.

In addition, the following dissemination activities have been implemented:

- The OA wrote an article for the **most recent ARE Newsletter** on capacity building and training to promote the most recent Task 9 Publications: Guideline to introducing Quality RE Technician Training Programs and User Guide on Monitoring and Sustainable Operation of PV-diesel Hybrid Systems. The aforementioned first of the two publications was presented in a **webinar on Nov 30, 2017** and the second one will most probably be presented in March 2018.
- Task 9 publications are now also on **Energypedia** to reach a broader public in particular among practitioners in development cooperation https://energypedia.info/wiki/Deploying_PV_Systems_for_Regional_Development_-_Publications and <https://energypedia.info/wiki/Portal:Solar>
- Task 9 has been represented by its member Michael Müller at the **Intersolar, India** on Dec 7, 2017. A presentation was given at the ARE Off-Grid Workshop during the event.
- The OA has been in contact with Cécile Martin-Phipps Strategic management & Operations Director at **International Solar Alliance ISA** to exchange on planned activities and possible cooperation.

PUBLICATIONS

PUBLISHED IN 2015/2016

- December 2015: “A User Guide to Simple Monitoring and Sustainable Operation of PV-diesel Hybrid Systems; Handbook for System Users and Operators”.
- September 2016: “Deploying PV Services for Regional Development, Products and Future Activities of the IEA Working Group” in OTTI Conference Proceedings “International Conference on Solar Technologies & Hybrid Mini Grids”.

PUBLISHED in 2017

April 2017: “Guideline to Introducing Quality Renewable Energy Training Programs”.

PLANNED FOR 2018

April 2018: “Study on PV Development as Prosumers: the Role and Challenges Associated to Producing and Self-consuming PV Electricity”.

TASK 9 MEETING SCHEDULE (2015-2017 AND PLANNED 2018)

Concluded Activities 2015 – 2017

- 45th IEA PVPS ExCo Meeting Paris, France, 28-29 April 2015
- IEA PVPS & Günder Workshop Istanbul, Turkey, 27 October 2015; Task 9 OA participation
- 45th Task 1 Meeting Istanbul Turkey, 27-30 October 2015; Task 9 OA participation
- 46th IEA PVPS ExCo Meeting Daegu, Korea, 10-11 November 2015; Task 9 OA participation
- 47th IEA PVPS ExCo Meeting Leuven, Belgium, 26-27 April 2016; Task 9 OA participation
- 48th IEA PVPS ExCo Meeting Vienna, Austria, 15-16 November 2016; Task 9 OA participation
- 49th IEA PVPS ExCo Meeting Denver, USA, 9-10 May 2017; Task 9 OA participation
- 50th IEA PVPS ExCo Meeting Melbourne, Australia, 30 Nov – 1 Dec 2017; Task 9 OA participation

Organized by Task 9 and/or Task 9 contribution:

- IEA PVPS Task 9 Workshop, Zurich, Switzerland, 29 February 2016
- Virtual Meeting on Subtask “100 % Renewables in Island Countries”, 16 June 2016
- Task 9 Side Event at the OTTI Conference, “International Conference on Solar Technologies & Hybrid Mini Grids to Improve Energy Access”, 20 September 2016
- PVPS Workshop at PVSEC 26, Singapore, Task 9 represented by Katarina Uherova Hasbani / ARE, 26 October 2016
- Task 9 at Intersolar, India on Dec 7, 2017; presentation at ARE Off-Grid Workshop

Task 9 Experts Meetings

Task 9 Experts Meeting, Istanbul, Turkey, 30 October 2015

Task 9 Experts Meeting, Zurich, Switzerland, 1 March 2016

Task 9 Virtual Experts Meeting, 4 May 2016

Task 9 Experts Meeting, Bad Hersfeld, Germany, 20 September 2016

Task 9 Experts Meeting, Dusseldorf, Germany, 13 March 2017

Task 9 Experts Virtual Meeting, 9 November 2017

Planned 2018

Task 9 Experts Virtual Meeting, March 2018

TABLE 1 - TASK 9 PARTICIPANTS

COUNTRY	NAME	ORGANIZATION
Australia	Geoff Stapleton	GSES
China	Zhao Dongli	Beijing Corona
Denmark	Peter Ahm	PA Energy Ltd.
Finland	Christer Nyman	Soleco Oy
France	Anjali Shanker	IED
	Andréanne Roux	
Germany	Georg Bopp	Fraunhofer ISE
	Michael Müller	STECA
	Caspar Priesemann	GIZ
	Roland Rösch	IRENA, Bonn
Japan	Takayuki Nakajima	Japan Photovoltaic Energy Association (JPEA)
Japan	Masanori Ishimura	NEDO
Netherlands	Erik Lysen	Lysen Consulting Engineer
Norway	Hanne Cecilie Geirbo	
Spain	Xavier Vallvé	TTA, Trama TecnoAmbiental, Spain
	Alberto Rodriguez Gomez	
	Vicente Salas	Universidad Carlos III de Madrid (UC3M)
Sweden	Frank Fiedler	Dalarna University
	Caroline Bastholm (Nielsen)	Dalarna University (SERC)
Switzerland	Hedi Feibel (OA)	SKAT Consulting Ltd.
Turkey	Muhyettin Sirer	UNDP
	Yesilata, Bulent	Gunder
	Kemal Gani Bayaktar	Gunder, Izocam
Austria, SE4ALL	Martin Niemetz	Country Action Officer, SE4ALL, GFT

- Although not officially, GIZ (Germany), Dalarna University (Sweden) and IRENA actively contributed to the work of this Task.
- Observers: Thailand, Ministry of Energy and EGAT, Malaysia, ECREEE, Austria/SE4ALL/GFT Martin Niemetz; future observers: Morocco, South Africa

TASK 12 - PV ENVIRONMENTAL HEALTH & SAFETY ACTIVITIES

INTRODUCTION

The deployment of photovoltaic (PV) systems has followed an exponential growth pattern over the last years. In order to support the decarbonization of the global energy system towards the middle of the century, that growth is bound to continue over the next decades, eventually leading to multiple Terawatts of installed PV capacity. An increasing interest of stakeholders from society, regulatory bodies and non-governmental organizations on sustainability performance of these technologies can be ascertained from public tenders, commercial power purchase agreements in the business-to-business segment, international standards and regulations. Discussions on eco-design requirements, eco-labels and environmental footprinting have gained significant momentum in many world regions over the last years. Shaping and channeling the transformation of the global energy system requires an understanding of the sustainability PV - the environmental, resource and social implications - which should be made accessible to a variety of societal, political and scientific stakeholders. Informing such assessments through development of methods, international guidelines and research is the mission of Task 12, which was renewed in 2017 for another 5 year term.

OVERALL OBJECTIVES

Within the framework of PVPS, Task 12 aims to foster international collaboration in the area of photovoltaics and sustainability and to compile and disseminate reliable environment, health, and safety (EH&S) information, as well as providing insight to social and socio-economic implications associated with the life cycle of photovoltaic technology to the public and policy-makers. Whether part of due diligence to navigate the risks and opportunities of large PV systems, or to inform consumers and policy makers about the impacts and benefits of residential PV systems, accurate information regarding the environmental, health and safety impacts and social and socio-economic aspects of photovoltaic technology is necessary for continued PV growth. By building consumer confidence, as well as policymaker support, this information will help to further improve the uptake of photovoltaic energy systems, enabling the global energy transition. On the supply-side, environment, health, and safety initiatives set standards for environmental, economic and social responsibility for manufacturers and suppliers; thus improving the solar supply-chain with regard to all dimensions of sustainability.

The overall objectives of Task 12 are to:

1. Quantify the environmental profile of PV electricity, serving to improve the sustainability of the supply chain and to compare it with the environmental profile of electricity produced with other energy technologies;
2. Help improve waste management of PV in collection and recycling, including assessing economics and environmental performance as well as supporting development of technical standards;
3. Distinguish and address actual and perceived issues associated with the EH&S, social and socio-economic aspects of PV technology that are important for market growth; and
4. Disseminate the results of the EH&S analyses to stakeholders, policymakers, and the general public.

The *first objective* is served with Life Cycle Assessment (LCA) that describes energy, material and emission flows in all stages of the life cycle of PV, as well as human health risk assessment.

The *second objective* is accomplished by proactive research and support of industry-wide activities (e.g., input to Industry Associations, like SolarPower Europe or Industry standardization activities to develop and help implementing voluntary or binding policies - such as WEEE and the Product Environmental Footprint Guidelines for photovoltaics in Europe, as well as the development of a Sustainability Leadership Standard for Photovoltaic Modules in the United States).

The *third objective* is addressed by advocating best sustainability practices throughout the solar value chain, exploring and evaluating frameworks and approaches for the environmental, social and socio-economic assessment of the manufacturing, installation and deployment of PV technologies and thus assisting the collective action of PV companies in this area.

The *fourth objective* is accomplished by presentations to broad audiences, peer review articles, reports and fact sheets, and assisting industry associations and the media in the dissemination of the information.

Task 12 has been subdivided into three topical Subtasks reflecting the first three objectives stated above. The fourth objective, dissemination of information, is contained as an activity within each of the three Subtasks: recycling, life cycle assessment and safety in the PV industry.

ACCOMPLISHMENTS OF IEA PVPS TASK 12 SUBTASK 1: Recycling of Manufacturing Waste and Spent Modules

The Task 12 group has a long history of bringing the issue of PV module recycling to the fore by organizing workshops on PV recycling, such as during the 34th IEEE Photovoltaic Specialists Conference (PVSC) in Philadelphia in June 2009, and supporting the 1st and 2nd International Conference on PV Module Recycling, in 2012 and 2013, hosted by EPIA and PV CYCLE. The publication of the report "End-of-Life Management: PV Modules" in collaboration with the International Renewable Energy Agency, providing the first ever global waste projection for PV modules in 2016 marked another milestone achievement of this Subtask. That seminal report has been downloaded more than 70 000 times.

Carrying on this long history, Task 12 completed three additional reports on the topic of recycling of PV modules in 2017, one on the "Life Cycle Assessment of current Photovoltaic Module Recycling" (T12-11:2017), a report summarizing the "Life Cycle Inventories of Current European PV Recycling" (T12-12:2017) and one on the "Trends in PV Module Recycling Technologies" (T12-10:2017).

The technology trends report provides an overview of trends in the development of PV module recycling technologies from the perspectives of patents and national R&D projects, and addresses expected upcoming issues related to PV module recycling technologies.



Fig. 1 - Visit of Task 12 Delegation to a PV Recycling Pilot Facility during 2017 Autumn Meeting in Osaka, Japan.



Fig. 2 - Group Picture of Task 12 Expert Group in Autumn 2017, Osaka, Japan.

The life cycle assessment report describes the environmental life cycle assessment of the current generation recycling of crystalline silicon (c-Si) and cadmium telluride (CdTe) PV modules. Life cycle inventories of the recycling of c-Si and CdTe PV modules are compiled following two recycling approaches. The recovery of glass, metals, and semiconductor material from c-Si and CdTe PV modules causes lower environmental impacts than the extraction, refinement and supply of the respective materials from primary resources. The highest potential benefits are observed in the indicator for mineral, fossil and renewable resource depletion.

The inventory report addresses the issue that even though waste treatment is considered part of a module's life cycle, only a few life cycle inventories (LCI) of energy and materials flows are available for the industrial recycling processes that are used today to recycle crystalline silicon-based (c-Si) PV modules. The report presents the results of a survey of European recyclers, which was performed to characterize existing commercial recycling processes and share associated life cycle inventory data. The LCA report (above) evaluated the LCI data collected here.

SUBTASK 2: Life Cycle Assessment

Task 12 brings together an authoritative group of experts in the area of the life-cycle assessment (LCA) of photovoltaic systems, who have published a large number of articles in high-impact journals and presented at international conferences. One of the flagship activities under this Subtask was the development of Product Environmental Footprint Category Rules (PEFCRs) for PV electricity generation in the framework of the European Commission Environmental Footprint Pilot Phase. This project is nearing its completion by beginning of 2018. Most recent milestones in the PEFCR Pilot Project include the presentation of the results of the Pilot Phase as well as lessons learned during a Plenary Talk at the 33rd EU PVSEC in Amsterdam 2017. The paper has also been published in Progress in Photovoltaics (The Product Environmental Footprint (PEF) of Photovoltaic Modules – Lessons Learned from the Environmental Footprint Pilot Phase on the way to a Single Market For Green Products in the European Union; DOI:10.1002/pip.2956).

Without doubt, the water-energy nexus is one of the major topics of the global energy transformation in this century. Hence it is of major importance to develop an understanding of the water footprint of PV technologies. The report titled "Water Footprint of European Rooftop Photovoltaic Electricity based on Regionalised Life Cycle Inventories" assesses the water consumption and water withdrawal

of electricity generated by PV systems by considering all life cycle stages and by taking account of country-level regional differences in water availability. The water use in the life cycle inventories of European rooftop PV systems and conventional electricity generation technologies was regionalised to the country or region (such as continents, political or geographic entities of several countries) level and complemented by the share of water lost by evaporation. The AWARE (Available WATER REMaining) method was used to assess the water stress impact caused by water consumption and water withdrawal of electricity generation by European rooftop PV systems as well as by reservoir hydroelectric power plants and large-scale hard coal and nuclear power plants in Europe.

Task 12 experts participated in developing two international PV sustainability standards. The first, was completed in 2017, resulting in the publication of a new ANSI standard (NSF 457 – Sustainability Leadership Standard for PV Module Manufacturing). This standard establishes criteria and thresholds for determining leadership in sustainability performance that is meant to identify the top third of the market. Availability of this standard will allow large purchasers to more easily incorporate sustainability criteria in their purchasing requests. Secondly, in a collaboration with the IEC TC82 a Technical Specification (IEC PT 62994 - ENVIRONMENTAL HEALTH & SAFETY (EH&S) RISK ASSESSMENT OF THE PHOTOVOLTAIC (PV) MODULE THROUGH THE LIFE CYCLE – General Principles and Definition of Terms) has been drafted and is in Draft Technical Specification status – finalization and publication is expected within the next year.

SUBTASK 3: Safety in PV Industry

A comprehensive review report on fire safety standards for PV systems in various jurisdictions has been published in 2017 (Photovoltaics and Firefighters' Operations: Best Practices in Selected Countries. IEA PVPS Task 12 Report T12-09:2017).

ACTIVITIES IN 2017

In the most recent period, the approved Workplan has been progressed towards completion with four new reports sent to ExCo for approval as presented above. All but one activity listed in the work program concluding in 2017 were successfully finalized. The activity on socio-economic and social impact indicators has been planned to be pursued in the new work period from 2018 to 2022 and hence will continue.

The other main activity of the group has been the finalization of the development of a Workplan for the Task extension to a third

phase, 2017-2022. As suggested by the expert group and approved by the Executive Committee, Task 12 will be progressed in the new work period under a new name: **PV Sustainability**. The new name communicates a broadening of the scope of Task 12, which includes not just environmental, health and safety dimensions, but also social and economic aspects of sustainability. In keeping with the enlarged scope, Subtask 3 has been renamed "Broader Sustainability Topics" instead of the previous, narrower "Safety". Likewise, Subtask 1 is also broadened to "Recycling and End-of-Life Management of PV Systems" (from just Recycling). Subtask 2 remains focused on Task 12's core capability of Life Cycle Assessment.

During Asia PVSEC in November 2017, Task 12 organized a parallel event on the topic of PV and Sustainability which covered the presentation of the latest Task 12 reports as well as an expert feedback session on social and socio-economic impact indicators and categories in the wider context of sustainability. With over 70 attendees, the event was very well attended and the feedback gathered on the latter topic will provide valuable input into the analysis of socio-economic and social indicators for PV going forward.

Following the Task 12 meeting in Spring 2017 in Madrid, hosted by Spain, Japan hosted the last Task 12 meeting of the work period in Osaka in November 2017.

In addition to the Task 12 expert meeting, the deputy Operating Agent of Task 12 has been invited to the final expert meeting of Task 13 in October 2017, to present the proposed Workplan and to discuss synergies for a future Workplan of the extended Task 13.

GOVERNANCE, DISSEMINATION AND NEXT MEETINGS

Membership

Total membership now stands at 11 countries and one industry association, with approximately 14 active experts. Sweden and Australia have joined most recently.

EXPERT MEETINGS (PLANNED 2018)

Concerning continuation of the regular cadence of expert meetings, the Spring 2018 meeting shall be hosted by SolarPower Europe in Brussels, Belgium, and the Autumn meeting in a location to be determined.

Also, Task 12 is working on organizing a parallel event during the upcoming World Conference on Photovoltaic Energy Conversion in Hawaii in June 2018.

PLANS FOR 2018

2018 will see the kick-off of the new Workplan as approved by the ExCo in November 2017.

PUBLICATIONS

Wambach K, Heath G, Libby C. 2018. Life Cycle Inventory of Current Photovoltaic Module Recycling Processes in Europe. IEA-PVPS Task 12 Report T12-12:2017. ISBN 978-3-906042-67-1.

Stolz P, Frischknecht R, Wambach K, Sinha P, Heath G. 2018. Life Cycle Assessment of Current Photovoltaic Module Recycling, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12-13:2018

K. Komoto, J.-S. Lee, J. Zhang, D. Ravikumar, P. Sinha, A. Wade, G. Heath, 2018, End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12-10:2018. <http://www.iea-pvps.org/index.php?id=459>

Namikawa S, Kinsey G, Heath GA, Wade A, Sinha P, Komoto K. 2017. Photovoltaics and Firefighters' Operations: Best Practices in Selected Countries. International Energy Agency Photovoltaic Power Systems (IEA PVPS) Task 12. Report IEA-PVPS T12-09:2017. ISBN 978-3-906042-60-2.

IRENA and IEA-PVPS (2016), End-of-Life Management: Solar Photovoltaic Panels. International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. ISBN 978-3-906042-36-7. IEA-PVPS Report Number: T12-06:2016. <http://www.iea-pvps.org/index.php?id=381>.

Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, 3rd edition, IEA PVPS Task 12, International Energy Agency Photovoltaic Power Systems Programme. Report IEA-PVPS T12-06:2016, ISBN 978-3-906042-38-1.

Methodological guidelines on Net Energy Analysis of Photovoltaic Electricity, IEA-PVPS Task 12, Report T12-07:2016, ISBN 978-3-906042-39-8.

Life cycle assessment of future photovoltaic electricity production from residential-scale systems operated in Europe, Subtask 2.0 "LCA", IEA-PVPS Task 12, Report IEA-PVPS T12-05:2015. ISBN 978-3-906042-30-5.

Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, 2nd edition, IEA PVPS Task 12, International Energy Agency Photovoltaic Power Systems Programme. Report T12-03:2011. ISBN: 978-3-90642-01-5

Life Cycle Inventories and Life Cycle Assessment of Photovoltaic Systems, International Energy Agency Photovoltaic Power Systems Programme. Task 12, Report T12-02:2011. ISBN: 978-3-906042-00-8.

Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, 1st edition, IEA PVPS Task 12, International Energy Agency Photovoltaic Power Systems Programme. Report T12-01:2009.

In addition to the collectively published IEA reports, task 12 members published extensively in peer-reviewed journals and presented at international conferences. A few important papers in 2016 from Task 12 members include:

P Pérez-López, B Gschwind, P Blanc, R Frischknecht, P Stolz, Y Durand, G Heath, L Ménard, I Blanc. 2016. ENVI-PV: an interactive Web Client for multi-criteria life cycle assessment of photovoltaic systems worldwide. Progress in Photovoltaics: Research and Applications (Special Issue), DOI: 10.1002/pip.2841. <http://onlinelibrary.wiley.com/doi/10.1002/pip.2841/full>

Raguei M, Sgouris Sgouridis, David Murphy, Vasilis Fthenakis, Rolf Frischknecht, Christian Breyer, Ugo Bardi, Charles Barnhart, Alastair Buckley, Michael Carbajales-Dale, Denes Csala, Mariska de

Wild-Scholten, Garvin Heath, Arnulf Jæger-Waldau, Christopher Jones, Arthur Keller, Enrica Leccisi, Pierluigi Mancarell, Nicola Pearsall, Adam Siegel, Wim Sinke, Philippe Stolz. 2016. Energy Return on Energy Invested (ERoEI) for photovoltaic solar systems in regions of moderate insolation: A comprehensive response. Energy Policy 102: 377-384. <http://dx.doi.org/10.1016/j.enpol.2016.12.042>

For more information, contact the Task 12 Operating Agent: Garvin Heath, National Renewable Energy Laboratory (NREL), USA and Deputy Operating Agent: Andreas Wade (SolarPower Europe), Brussels, Belgium

TABLE 1 - TASK 12 PARTICIPANTS

COUNTRY	PARTICIPANT	ORGANISATION
Australia	Jose Bilbao	University of New South Wales (UNSW)
Austria	Susanne Schidler	University of Applied Science, Fachhochschule Technikum Wien, Department of Renewable Energy
China	Lu Fang	Institute of Electrical Engineering, Chinese Academy of Sciences
	Zhang Jia	
France	Isabelle Blanc	MINES ParisTech
Japan	Teiji Minami	NEDO (Technology Development Organisation)
	Keiichi Komoto	Mizuho Research Institute Japan
Korea	Jin-Seok Lee	Korea Institute of Energy Research (KIER)
Norway	Ronny Glöckner	ELKEM solar
Solar Power Europe	Andreas Wade	Solar Power Europe
Spain	Marco Raugei	ESCi (Escola Superior de Comerç Internacional) and Oxford Brookes University
	Natalia Caldes Gomez	CIEMAT
Sweden	Linda Kaneryd	Swedish Energy Agency
Switzerland	Rolf Frischknecht	treeze Ltd., fair life cycle thinking
	Philippe Stolz	
The Netherlands	Mariska de Wild-Scholten	SmartGreenScans
	Carol Olson	Energy Research Center of the Netherlands (ECN)
USA	Garvin Heath	National Renewable Energy Laboratory (NREL)
	Parikhit Sinha	First Solar

TASK 13 – PERFORMANCE AND RELIABILITY OF PV SYSTEMS

INTRODUCTION

The PV community has a continued high interest in obtaining information on performance and reliability of PV modules and systems. In addition, financial models and their underlying technical assumptions have gained increased interest in the PV industry, with reliability and performance being key parameters used as input in such models.

Accurate energy yield predictions in different climates as well as reliable information on operational availability of PV systems are vital for investment decisions and, thus, for further market growth. In this context, performance and yield data, reliability statistics and empirical values concerning quality of PV systems are far more relevant today than they used to be in the past. The availability of such information is, however, rather poor.

Within the framework of PVPS, Task 13 aims at supporting market actors to improve the operation, the reliability and the quality of PV components and systems. Operational data of PV systems in different climate zones compiled within the project will allow conclusions on the reliability and on yield estimations. Furthermore, the qualification and lifetime characteristics of PV components and systems shall be analysed, and technological trends identified.

Presently, there are 70 members from 40 institutions in 20 countries collaborating in this Task, which had started its activities in May 2010. The second phase of Task 13 work is completed and was undertaken from September 2014 to December 2017. Task 13 will be continued with a new work programme starting in 2018 to 2021.

OVERALL OBJECTIVES

Task 13 engages in focusing the international collaboration in improving the reliability of photovoltaic systems and subsystems by collecting, analyzing and disseminating information on their technical performance and failures, providing a basis for their technical assessment, and developing practical recommendations for improving their electrical and economic output.

The overall objectives of Task 13 are to:

1. Address and analyze the economic aspects of PV system performance and reliability by reviewing the current practices used in financial modelling of PV investments with focus on the input that reflect the technical risks related to the PV module and other key components, the technical design of the PV system as well as the operation and maintenance of the plant over the system's service life time.
2. Provide available performance data for any kind of decision maker for different PV applications and system locations (e.g. different countries, regions, climates). This data is evaluated for its applicability and quality in both a quantitative approach, using very large data sets and statistical methods, and a qualitative approach, where evaluations on individual component performances are conducted.
3. Perform activities on PV module characterization and failure issues in order to allow an in-depth assessment of PV module conditions in the field. The comprehensive collection and analysis of field data of PV module defects will increasingly become important as a growing number of PV installations world-wide fail to fulfil quality and safety standards, which work of this Task will help to overcome.
4. Disseminate the results of the performance and reliability analyses to target groups in industry and research, financing sector, and the general public.

APPROACH

Various branches of the PV industry and the finance sector will be addressed by the national participants in their respective countries using existing business contacts. Given the broad, international project consortium, cooperation will include markets such as Europe, Asia-Pacific, and the USA.

Task 13 is subdivided into three topical Subtasks reflecting the first three objectives stated above. The fourth Subtask, dissemination of information, utilizes the output of the three subtasks and disseminates the tailored deliverables produced in the three subtasks.

ACCOMPLISHMENTS OF IEA PVPS TASK 13

SUBTASK 1: Economics of PV System Performance and Reliability

Subtask 1 addresses and analyzes the economic aspects of PV system performance and reliability. This has been achieved by reviewing current practices used in financial modelling of PV investments with focus on the input parameters reflecting the technical risks related to the PV module and other key components, the technical design of the PV system as well as the operation and maintenance of the plant over the system's service life. The impact of the uncertainties and failure statistics of these technical parameters and input to the financial models has been analysed in terms of economic importance reflected in both investment costs and Levelized Cost of Electricity (LCOE). Based on the internal analysis, screening of the scientific literature and discussions with key stakeholders during a couple of public meetings, the current practices have been compared with available scientific data and state-of-the-art methods to identify important gaps. The main weaknesses when dealing with technical assumptions and risks in PV financial models today are summarized and presented as fact sheets in the report. The analysis highlights that a likely method for managing the risk of losing the validity of an assumption made during the financial planning is to focus on the technical aspects of the engineering, procurement and construction (EPC) and operation and maintenance (O&M) scopes of work to manage the technical risks linked to the capital expenditures (CAPEX) and operational expenditures (OPEX) of PV investments. To this end the final report describes these aspects in each segment of a PV project; energy yield estimates and the solar resource on which these are based and the CAPEX and OPEX, summarizing the shortcomings encountered in the survey. Furthermore, the reliability and failures of PV system

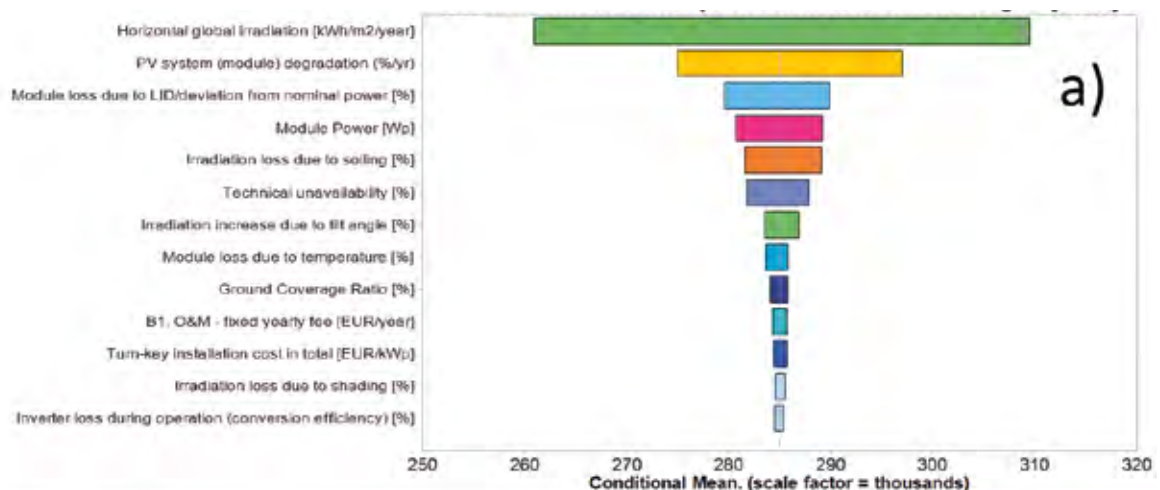
components, specifically the PV modules and inverters as well as the handling and transporting of these and other elements of the project are discussed in detail in the report.

Methods for increasing the accuracy of the assumptions and for mitigating risks to these assumptions are proposed. The report presents fact sheets of the shortcomings found in the review and analysis on the current practices accompanied by methods to mitigate these shortcomings in the technical management of the project during the design, construction and operational phases. Special attention is paid to mitigating the uncertainty parameters calculated or assumed for the inputs to the business model. One of the keys to mitigate and hedge financial risks as highlighted in the report, is to ensure that the financial model prepared during the feasibility and early development stages of a project will continue to reflect the financial activity of the plant over the 20–30 years of operation. The necessity for ensuring that the design and construction of the plant will enable the

assumptions to be realized is extremely important. The guidelines and assumptions necessary to fulfil this task must also include suggestions regarding the project pre-feasibility, plant design, procurement and construction, acceptance, and operation of the plant.

Finally, the Subtask 1 report suggests detailed guidelines and recommendations for undertaking the design, construction and operation of a PV plant in a manner that will enable fulfilling the calculated financial plan. Furthermore, a method of calculating final business model values for produced energy, revenue and IRR (internal return of revenue) using statistical tools such as Monte Carlo calculations on the input values, and then again on the output values is introduced. This method demonstrates how a P50 and P90 model can be generated. Further statistical graphic tools, such as the tornado (e.g. Figures 1a) and b) below) and spider plots are introduced as tools to visualize the relative effect of each of the input parameters on the final calculated output values.

Tornado Plot for Power production delivered to the grid [MWh]



Tornado Plot for Project IRR by CAPEX

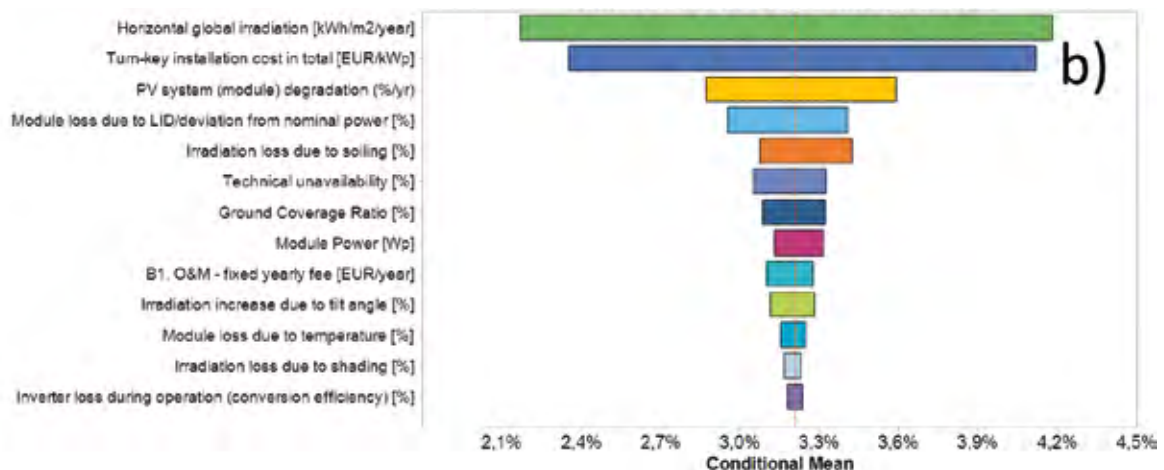


Fig. 1 - In the tornado plot above (a) it can be seen that the two parameters that have the highest impact on the energy delivered to the grid (within the estimated uncertainty range), are the horizontal irradiation and the PV module degradation. However, if we assess what affects the IRR of the project the most (b), we learn that the turn-key installation cost is ranked as more important than the PV module degradation.



Fig. 2 - Task 13 Expert Meeting at TÜV Rheinland, Cologne, Germany, 12-13 October, 2017 (Photo: Thomas Nordmann).

The final Subtask 1 report has been published in May 2017 and can be downloaded from in the IEA-PVPS website <http://www.iea-pvps.org/index.php?id=426> [3].

SUBTASK 2: System Performance and Analysis

Entire PV systems and their performance are in the focus of Subtask 2. With this work topic, a broad variety of components and their interplay are of relevance. In turn, this implies that various scientific disciplines are involved already. In addition, various stakeholders are involved as well. In fact, with PV becoming mainstream, this base of stakeholders seems to be ever increasing: Presumably millions of individuals own small PV systems as of today, and individual large-scale systems are closing in to the Gigawatt range of installed capacity. In order to approach the broad range of related work topics, the Task 13 group has structured its work programme of the extended Task period such that four distinct activities are addressed.

The following gives a brief summary of each of these four activities and work conducted in 2017:

- Subtask 2.1 – Performance Databases
- Subtask 2.2 – Improving Efficiency of PV Systems Using Statistical Performance Monitoring
- Subtask 2.3 – Uncertainty Framework for PV Monitoring and Modelling
- Subtask 2.4 – PV Performance Modelling Collaborative

Within Subtask 2.1 – Performance Databases, observed performance figures of PV systems are collected. This data is then structured and presented such that actual PV performance values are easier to access and evaluate as in previous times. To this end, the "Task 13 Performance Database" allows almost instant access to monthly averages of PV performance data, for anyone who is interested. The link to the internet server hosting the database can be found prominently on the PVPS webpage since it went online in 2014. New data is continuously collected and added to the Performance Database, but it remains a large challenge to contribute substantial amounts of data for all countries of high PV market penetration.

Within Subtask 2.2, the topic is "Improving Efficiency of PV Systems Using Statistical Performance Monitoring". This topic examines the use of advanced statistical methodologies to ascertain the existence of a fault, failure or loss of efficiency in a PV system. Current state of the art depends on simple comparative algorithms and the use of sensors to calculate efficiency based on irradiation and temperature conditions, such as the Performance Ratio (PR)

or temperature corrected PR. It has become apparent that closer monitoring is necessary for PV systems as solar energy takes a larger share of generated energy. The subtask reviewed four statistical methodologies developed by three research teams in three different countries, Australia, the USA and Israel.

Each of these methods use statistical analysis of the parameters produced by the PV system to ascertain the system health, evaluate the efficiency, find faults, predict next day hourly energy and even to predict future faults before they occur.

The statistical methods range from regression algorithms, machine learning and artificial neural networks [4].

In Subtask 2.3, the focus is on uncertainties in PV system yield predictions and assessments. Long-term yield predictions (LTYP) are a prerequisite for business decisions on long-term investments into PV power plants. The preparation of a LTYP report typically relies on numerical modelling and prediction of the expected electrical yield, based on experience with previous PV power plants and with laboratory measurements. However, even though PV system modelling has been performed for decades, not much effort has been spent on a comprehensive investigation of the uncertainties related to this task.

Therefore, Subtask 2.3 collected insights into the field of uncertainties of several technical aspects of PV system yield prediction and assessment. On one side are typical measurements, dealing either with PV system component's properties or with PV system performance.

The uncertainties related to the most important measurements in PV solar energy: the solar resource, PV module properties, and system output and performance—including long-term effects were covered. On the other side, several of the modelling steps for gains and losses in a PV system were investigated, including the solar resource and its long-term trends, PV module properties, and system output and performance. The economic impact and how uncertainties are considered in modelling of financial risks are part of Subtask 1.

Subtask 2.4 bundles activities of Task 13 participants within the PV Performance Modelling Collaborative (PVP MC, <https://pvpmc.sandia.gov>). The PVP MC website maintains a collection of open-source and well-documented simulation models and provides

a platform for technical information and data sharing and model publication. Contributions have been accepted from several Task 13 members. In addition, since 2010, the PVPMC has organized nine international modelling workshops. Since 2015, Task 13 members have hosted and presented at many of these events. All presentations are available for download on the PVPMC website under "Resources and Events". A technical report on the results from the 4th PV Performance Modelling Collaborative Workshop in Cologne was published in 2017 [1].

SUBTASK 3: Module Characterisation and Reliability

Subtask 3 aims to provide recent scientific and technical findings and recommendations on suitable measurement, testing and characterization methods for performance and reliability assessments of PV modules in the field. This work is based on close collaboration and exchange of results between international laboratories for PV module characterization and qualification in Europe, USA and Asia. For the completed phase of Task 13, the scope of this subtask was extended towards PV module uncertainties and propagation into modelling as well as characterization of PV module conditions and PV module failures in the field:

Activity 3.1: The two Technical Reports D2-7 *Uncertainty framework for data acquisition and modelling* and D3-1 *Recommended practices for model parameter determination from indoor and outdoor measurement data under consideration of measurement uncertainties* were merged into a single Technical Report entitled D2-7 *Uncertainties in PV System Yield Predictions and Assessments*. Due to a remarkable overlap between the two activities, the merged report attempts to collect some insights into the field of uncertainties of several technical aspects of PV system yield prediction and assessment.

Activity 3.2: *Module Energy Yield Data from Test Fields in Different Climates* aims to assess the today available approaches and to suggest how to harmonize the equipment requirements, measurements procedures and uncertainty determination and to apply it to a set of selected data which will be made available to team members and external partners working on modelling and energy rating. The data should cover the most important technologies and climatic zones in order to improve the comparability of data from different institutes and locations.

Activity 3.3: *Characterization of PV Module Condition in the Field - Guidelines on IR and EL in the Field* consists of two parts. For part 1, we have collected and analysed field data of 1200 PV modules from various sources with minimum two years field exposure. The results of the visual inspection field data analysis of PV modules are included in the technical report on *Assessment of PV Module Failures in the Field* [2].

Part 2 provides an overview of different methods to collect infrared (IR) and electroluminescence (EL) images in the field. The goal is to provide recommendations and guidelines for using IR and EL imaging techniques to identify and assess specific failure modes of PV modules

and systems in field applications. The team has prepared a review of existing guidelines and best practices for recording and processing IR and EL images in the field. In the technical report, we present the current practices for IR and EL imaging of PV modules and systems, looking at environmental and device requirements on one hand, and on the interpretation of sample patterns with abnormalities on the other hand. The technical report *Review on Infrared and Electroluminescence Imaging for PV Field Applications* will be published in early 2018.

Activity 3.4: *Assessment of PV Module Failures in the Field* aims to provide the status of the ability to predict the power loss of PV modules for specific failure modes. The team summarizes interactions and incompatibilities of lamination materials to better understand PV modules failures. For well-known PV module failures modelling approaches to forecast the power loss are summarized from literature. To identify the impact of specific failures on the module's performance, a survey on the impact of PV system failures in different climatic zones has been conducted. The data is collected from various sources and about 150 PV system failure reports have been included and analysed. The results of the survey were presented in a webinar to 294 registered participants, which was recorded and is available on youtube [6]. These results are evaluated to assess the relevance of standard test methods for the application of PV modules in different climate zones. Furthermore, the technical report on *Assessment of PV Module Failures in the Field* includes new methods, which are introduced to qualify PV modules for various climate zones [2].

SUBTASK 4: Dissemination

This subtask is focussed on the information dissemination of all deliverables produced in Task 13. The range of activities in this Task includes expert workshops, conference presentations, technical reports and international webinars.

The following Task Reports were published in 2017 (Fig. 3):

- [1] Joshua S. Stei, Boris Farnung, IEA-PVPS T13-06:2017 "PV Performance Modeling Methods and Practices - Results from the 4th PV Performance Modeling Collaborative Workshop", ISBN 978-3-906042-50-3, <http://www.iea-pvps.org/index.php?id=423>
- [2] M. Köntges, G. Oreski, U. Jahn, M. Herz, P. Hacke, K.-A. Weiss, G. Razongles, M. Paggi, D. Parlevliet, T. Tanahashi, R. H. French, M. Richter, C. Tjengdrawira, A. Morlier, H. Li, L.-E. Perret-Aebi, K. A. Berger, G. Makrides, W. Herrmann, IEA-PVPS T13-09:2017 "Assessment of PV Module Failures in the Field", ISBN 978-3-906042-54-1, <http://www.iea-pvps.org/index.php?id=435>
- [3] M. Richter, C. Tjengdrawira, J. Vedde, M. Green, L. Frearson, B. Herteleer, U. Jahn, M. Herz, M. Köntges, B. Stridh, K. Berger, E. Janknecht, D. Moser, G. Belluardo, N. Reich, IEA-PVPS T13-08:2017 "Technical Assumptions Used in PV Financial Models - Review of Current Practices and Recommendations", ISBN 978-3-906042-46-6, <http://iea-pvps.org/index.php?id=426>
- [4] Mike Green, Eyal Brill, Birk Jones, Jonathon Dore, IEA-PVPS T13-07:2017 "Improving Efficiency of PV Systems Using Statistical Performance Monitoring", ISBN 978-3-906042-48-0"

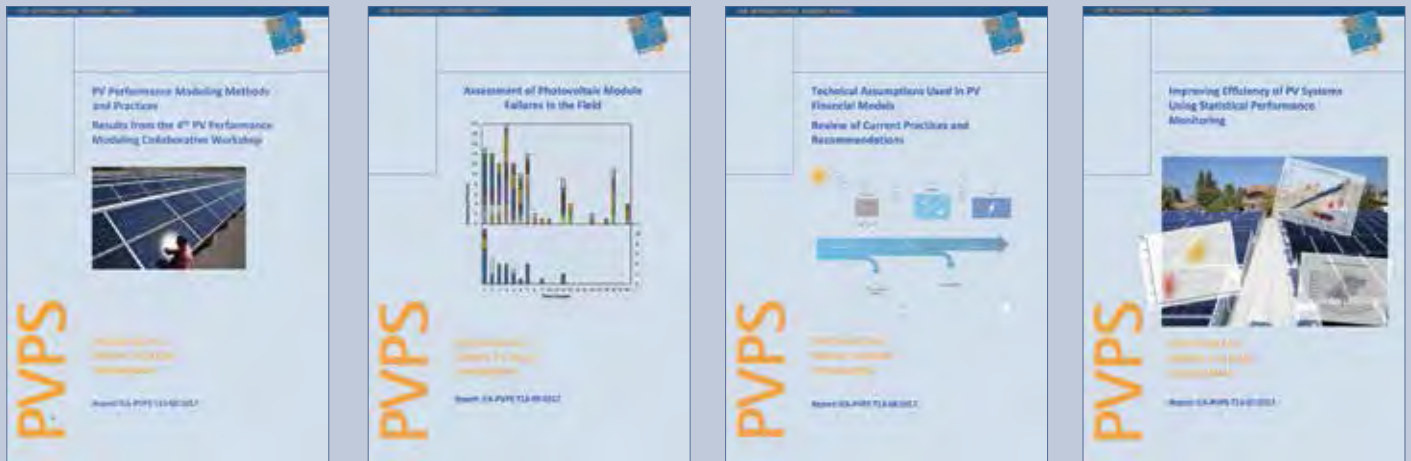


Fig. 3 - Four Technical Task 13 Reports published in 2017 and available at: <http://www.iea-pvps.org/index.php?id=427>.

The following Expert Workshops took place in 2017:

- 7th PV Performance Modelling and Monitoring Workshop, SUSPI, Lugano, 30-31 March, 2017
- PVPS Task 1 Workshop „PV 2.0 - Post FIT Era: New Opportunities, New Players“, GSE, Rome, 27 April, 2017
- Climate Sensitive Photovoltaics, Leoben, Austria, 23 May, 2017
- Task 13 Workshop as part of the Intersolar Europe's conference programme: "PV Reliability & Assessment of Technical Risks in PV Investments", Intersolar Europe, Munich, Germany, 30 May, 2017 (Fig. 4, left)
- SOPHIA Reliability Workshop, Freiburg, 6-7 July, 2017
- Task 13 Workshop as part of the European PVSEC's conference programme, "PV System Performance and PV Module Reliability", EU PVSEC 2017, RAI Amsterdam, Netherlands, 26 September, 2017 (Fig. 4, right)
- World Class Photovoltaic Systems - a Workshop on Performance and Reliability, Stockholm, Sweden, September 2017
- 2nd International Workshop on the Sustainable Actions for "Year by Year Aging" under Reliability Investigations in Photovoltaic Modules - SAYURI-PV 2017, Kyoto, Japan, 11-12 November, 2017.

All publications and Task 13 presentations from the expert workshops held in 2017 are publicly available for download at the workshops section on the IEA PVPS website: <http://www.iea-pvps.org/index.php?id=387>.

The following international Webinars are given:

- [5] Technical Assumptions Used in PV Financial Models: Review of Current Practices and Recommendations. Speakers: Mauricio Richter (3E), Mike Green (M.G. Lightning), 103 of 377 registered participants, 5 July 2017.
- [6] Assessment of Photovoltaic Module Failures in the Field. Speakers: Gernot Oreski (PCCL), Ulrike Jahn, (TÜV Rheinland), 107 of 294 registered participants, 16 October 2017, available at Youtube <https://www.youtube.com/watch?v=BGcLoXQoMEM>, accessed on 18.01.2018.

The webinar presentations (visual and audio) can be downloaded at: <http://www.iea-pvps.org/index.php?id=2>



Fig. 4 - 150 participants from Europe, the US, Asia and Australia at the Intersolar Europe 2017, Munich, Germany, 30 May 2017 and 95 participants worldwide from industry at the European PVSEC in Amsterdam, 26 September 2017.

MEETING SCHEDULE (2017)

The 16th PVPS Task 13 expert meeting was hosted by SUPSI and took place in Canobbio, Switzerland, 27-29 March 2017.

The final PVPS Task 13 expert meeting was hosted by TÜV Rheinland and took place in Cologne, Germany, 12-13 October 2017 (Fig. 2 , above).

TABLE 1 - TASK 13 PARTICIPANTS IN 2017 AND THEIR ORGANIZATIONS

COUNTRY	ORGANIZATION	COUNTRY	ORGANIZATION
Australia	<ul style="list-style-type: none"> Ekistica Murdoch University The University of New South Wales (UNSW) 	Italy	<ul style="list-style-type: none"> European Academy Bozen/Bolzano (EURAC) Gestore dei Servizi Energetici - GSE S.p.A. IMT Institute for Advanced Studies Lucca Ricerca sul Sistema Energetico - RSE S.p.A.
Austria	<ul style="list-style-type: none"> Austrian Institute of Technology (AIT) Österreichisches Forschungsinstitut für Chemie und Technik (OFI) Polymer Competence Center Leoben (PCCL) GmbH 	Japan	<ul style="list-style-type: none"> National Institute of Advanced Industrial Science and Technology (AIST) New Energy and Industrial Technology Development Organization (NEDO)
Belgium	<ul style="list-style-type: none"> 3E nv/sa KU Leuven 	Malaysia	<ul style="list-style-type: none"> Universiti Teknologi Malaysia (UTM) Universiti Teknologi MARA (UiTM)
China	<ul style="list-style-type: none"> Institute of Electrical Engineering, Chinese Academy of Sciences (CAS) 	Netherlands	<ul style="list-style-type: none"> Utrecht University, Copernicus Institute
Canada	<ul style="list-style-type: none"> CANMET Energy Technology Centre 	Norway	<ul style="list-style-type: none"> Institutt for Energieteknikk (IFE)
Denmark	<ul style="list-style-type: none"> SiCon • Silicon and PV consulting 	Spain	<ul style="list-style-type: none"> DNV GL - Energy - Renewables Advisory National Renewable Energy Centre (CENER)
Finland	<ul style="list-style-type: none"> Fortum Power & Heat Oy Turku University of Applied Sciences 	Sweden	<ul style="list-style-type: none"> ABB AB, Corporate Research Paradisenergi AB Solkompaniet SP Technical Research Institute of Sweden
France	<ul style="list-style-type: none"> Commissariat à l'Énergie Atomique et Énergies Alternatives / Institut National de l'Énergie Solaire (CEA / INES) Electricité de France (EDF R&D) 	Switzerland	<ul style="list-style-type: none"> Scuola Universitaria Professionale della Svizzera Italiana (SUPSI) TNC Consulting AG
Germany	<ul style="list-style-type: none"> Fraunhofer Institute for Solar Energy Systems (ISE) Institute for Solar Energy Research Hamelin (ISFH) TÜV Rheinland 	Thailand	<ul style="list-style-type: none"> King Mongkut University of Technology Thonburi (KMUTT)
Israel	<ul style="list-style-type: none"> M.G.Lightning Electrical Engineering 	USA	<ul style="list-style-type: none"> Case Western Reserve University (SDLE) National Renewable Energy Laboratory (NREL) Sandia National Laboratories (SNL)

Updated contact details for Task 13 participants can be found on the IEA PVPS website www.iea-pvps.org.

TASK 14 – HIGH PENETRATION PV IN ELECTRICITY GRIDS

INTRODUCTION

Following its ongoing growth, PV has today become a visible player in the electricity generation not only on a local level, but also on nationwide levels in more and more countries.

Following the wide scale deployment of grid connected PV in recent years, High Penetration PV has become a truly global issue today in regions around the world. This development is supported by significant technical advancements at the research as well as the industrial level. With PV becoming a game changer on the bulk power system level in several markets, new fundamental challenges arise, which are being addressed through global cooperation.

To ensure further smooth deployment of PV and avoid the potential need for costly and troublesome retroactive measures, proper understanding of the key technical challenges facing high penetrations of PV is crucial. Key issues include the variable nature of PV generation, the power electronics interconnection to the grid and its primary connection to the distribution grids typically designed only for supplying loads. Power system protection, quality of supply, reliability and security may all be impacted.

Resolving the technical challenges is critical to placing PV on an even playing field with other energy sources in an integrated power system operation and augmentation planning process, as well as to allow PV to be fully integrated into power system, from serving local loads to serving as grid resources for the interconnected transmission and generation system.

OVERALL OBJECTIVES

As part of the IEA PVPS programme, Task 14's main objective is to promote the use of grid connected PV as an important source in electric power systems on a high penetration level where additional efforts may be necessary to integrate the dispersed generators in an optimum manner.

The overall aim of these efforts is to reduce the technical barriers in order to achieve high penetration levels of distributed renewable systems on the electric power system. Task 14 focuses on working with utilities, industry, and other stakeholders to develop the technologies and methods enabling the widespread deployment of distributed PV technologies into the electricity grids.

From its beginning as a global initiative under the PVPS TCP, Task 14 has been supporting stakeholders from research, manufacturing as well as electricity industry and utilities by providing access to comprehensive international studies and experiences with high-penetration PV.

Tackling these urgent issues, Task 14 addresses high penetration PV throughout the full interconnected electricity system consisting of local distribution grids and wide-scale transmission grids. Furthermore, also autonomous power systems such as "mini grids", which are an increasingly used solution to electrify remote villages and towns, are within the scope of Task 14, in particular in those countries where such power systems form significant parts of the national electricity system.

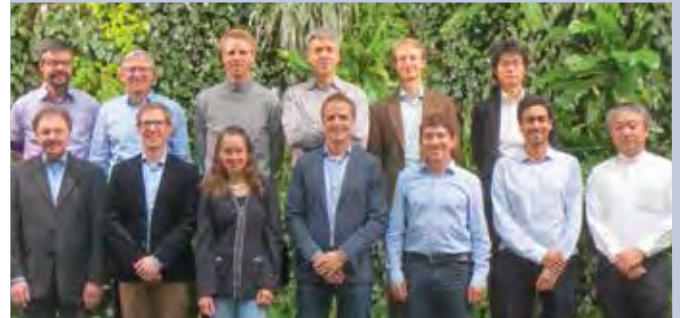


Fig. 1 - Task 14 Experts at the 16th Experts Meeting, Fraunhofer-Forum Berlin, Germany, October 2017 (Photo: IEA PVPS Task 14).

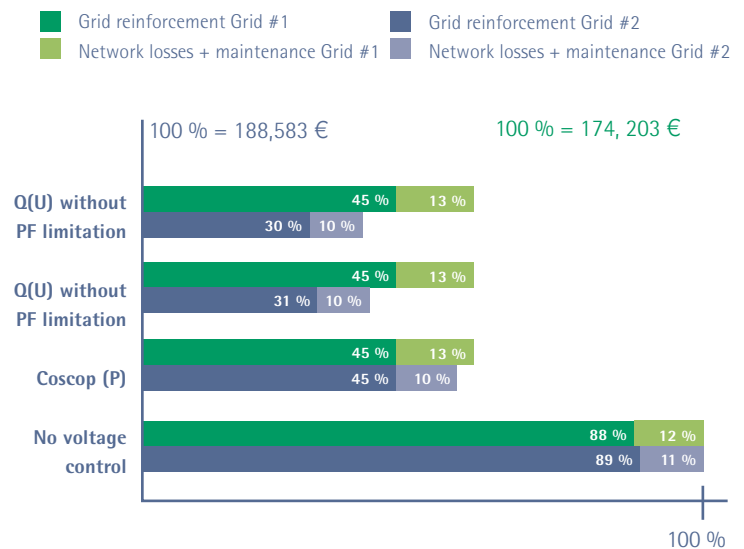


Fig. 2 - Total cost net present value of a real LV grid as a percentage of the total cost when applying no voltage control. (Source: T. Stetz, Fraunhofer IWES.).

SUBTASKS AND ACTIVITIES

Task 14's work programme addresses the foremost technical issues of high penetration of PV in electricity networks. Issues related to implications of high-penetration PV on the level of electricity markets are considered in close cooperation with PVPS Task 1.

Technical issues which are covered by the Task 14 work programme include energy management with PV on the local, regional and system wide levels, grid integration and penetration related to local distribution grids and central PV generation scenarios. In addition to these grid-related topics, the work also addresses requirements for key components such as PV power converters acting as the smart interface between the PV generator and the electricity grid.

The smart grid integration of decentralized solar photovoltaics (PV) strongly interlinked with the development of (future) smart grids complements the research in Task 14. To ensure that PV grid integration solutions are well-aligned with such comprehensive requirements it is indispensable to analyse also in detail the challenges and solutions for PV grid integration from a smart grid perspective

and to suggest future-compliant solutions. Within a dedicated Task 14 Subtask, appropriate control strategies and communication technologies to integrate a high number of distributed PV in smart electricity networks are being analysed and eventually lead to formulating smart PV grid recommendations for different kinds of infrastructures.

PROGRESS AND ACHIEVEMENTS

The massive deployment of grid-connected PV in recent years has brought PV penetration into the electricity grids to levels where PV – together with other variable RES such as Wind – have become visible players in the electricity sector. This fact not only influences voltage and power flows in the local distribution systems, but also influences the demand-supply balance of the overall power system. In parallel, the size of PV systems has continued to grow to the extent that GW-scale systems could be commonplace in the coming years. Complementing its technical work, Task 14 continued the successful series of high penetration workshops and conferences with well received events in the US and Europe:

- In June 2017, Task 14 organized a joint area session as a part of the IEEE PVSC44, held in Washington DC, USA. The topics addressed in the session “Multinational Collaboration on Photovoltaic Grid Integration” covered Transmission Level Integration of Renewables: Best Practices and Latest, High-Penetration PV Integration on the Distribution System: Best Practices in Modeling, Operation, and Interconnection, the integration of Smart Inverters into a Secure Energy Information System and latest developments on Grid Codes.
- In October 2017, Task 14 together with IEA WIND Annex 25 organized a joint session on Recommended Practices for Wind/PV Integration Studies at the 2017 Wind Integration Workshop (WIW2017), Berlin. In four presentations, the latest results from both TCPs were presented, highlighting the importance of an integrated view on RES integration to the electricity system.

The collaboration between IEA PVPS Task 14 and IEA WIND Task 25 on “Recommended Practices for integration study methodologies” has been intensified in 2018, with a joint recommended practice guide to be published in early 2018.

All Task 14 Workshop presentations are publicly available for download from the IEA PVPS website’s “Workshops” section.

On the technical level, several PVPS reports, publications and presentations from Task 14 experts highlight the Task’s activities. Related to distribution system integration recommendations on operational and long-term planning using advanced capabilities of PV systems are given in the report “Do it locally: Local Reactive Power Control by Distributed Generation”, published in March 2017. The management summary gives an overview on the state-of-the-art of voltage support functionalities by means of local reactive power control from distributed generators.

Focusing on the system-wide integration of PV, the survey and investigation of flexible resources for flexible transmission system operation was finalized. The results and recommendations were



Fig. 3 – Experts at the “Multinational Collaboration on Photovoltaic Grid Integration” session at the IEEE PVSC44, held in Washington DC, USA (Photo: IEA PVPS Task 14).

compiled in the summary report “Flexible Resources for Flexible Transmission System Operation”, published in October 2017. This report provides a review of present and expected scenarios about flexibility in system operation. It summarizes and integrates results of a survey involving national experts in six countries; namely Belgium, Germany, Greece, Italy, Japan, and Switzerland.

SUMMARY OF TASK 14 ACTIVITIES PLANNED FOR 2018

In mid-2018, the second term of Task 14 (2014–2018) will end. Besides the conclusion of the second term’s activities, the main strategic activity will be related to the development of the work programme for the proposed Phase 3 of Task 14.

Based on current plans, the work programme for the next phase will be strongly dedicated to prepare the technical base for Solar PV in a future 100 % RES based power system. This reshaping of the main objectives will also result in a new organizational structure, which will be focusing on integrating distribution and transmission aspects, operational planning and management of power grids with 100 % RES based supply.

INDUSTRY INVOLVEMENT

As from the beginning, industry has been directly involved in the development of Task 14’s concept and Workplan. In addition, a number of PV industry and utility representatives also participate in the Task 14 group.

Based on the results achieved so far within the Task 14, further activities towards integrating industry are constantly being organized, such as special workshops (see also section 3.1) for intensive knowledge exchange. The utility interest in Task 14 work is also highlighted by the broad attendance of utility representatives at the recent events organized by Task 14.

Furthermore, the workshops also form the basis to present national activities related to high penetration PV, together with other relevant international projects which address research and demonstration of High Penetration PV.

PUBLICATIONS AND DELIVERABLES

The products of work performed in Task 14 are designed for use by experts from the electricity and smart grid sector, specialists for photovoltaic systems and inverters, equipment manufacturers and other specialists concerned with interconnection of distributed energy resources.

In 2017 Task 14 published the following official reports:

- "Do It Locally: Local Voltage Support by Distributed Generation" – A Management Summary of IEA Task 14 Subtask 2 – Recommendations Based on Research and Field Experience Report IEA-PVPS T14-08:2017
- Subtask 3.4: "Flexible Resources for Flexible Transmission System Operation" Report IEA-PVPS T14-09:2017

Besides PVPS related dissemination activities, Task 14 experts contributed to a number of national and international events and brought in the experience from the Task 14 work. Highlights include:

- June 2017, a Joint Area Session as a part of the IEEE PVSC44 (<http://www.ieee-pvsc.org/PVSC44/>), held in Washington DC, USA.
 - Introduction to IEA PVPS Task 14 – High-Penetration of PV in Electricity Grids, Christoph Mayr (AIT)
 - Transmission Level Integration of Renewables: Best Practices and Latest Status in Japan, Kazuhiko Ogimoto (University of Tokyo)
 - High-Penetration PV Integration on the Distribution System: Best Practices in Modeling, Operation, and Interconnection, Barry Mather (NREL)
 - Integration of Smart Inverters into a Secure Energy Information System, Gerd Heilscher (DEU)
 - Developments on Grid Codes: Coordination and Gaps, Roland Bründlinger (AUT)
- September 2017: Large Scale Grid Integration of Renewable Energy in India, Conference, 6-8 September 2017, New Delhi, India
 - Variable Renewable Energy Sources in Distribution Networks, M. Braun (DEU)
 - Reactive Power Coordination Strategies with Distributed Generators in Distribution Networks, H. Wang, M. Krafczy, S. Wende – von Berg, E. Kämpf, B. Ernst, S. Schmidt, F. Wirtz, M. Braun (DEU)
- September 2017: ISGAN Public Workshop "Building the Flexible Power Systems: From Analog to Digital, from Lorry to EV, from Customers to Prosumers"; PVPS presentation by R. Bründlinger (OA)
- Solar Integration Workshop, 24–25 October 2017, Berlin, Germany:
 - Remuneration of controllable reactive power inside so far free of charge ranges: Cost-Benefit Analysis, Erika Kaempf, Martin Braun, Haonan Wang, Bernhard Ernst (DEU)
- In October 2017, Task 14 contributed presentations to the 2017 Wind Integration Workshop (WIW2017), Berlin, Germany, 25 October 2017
 - Session 2B – IEA PVPS Task 14 and IEA WIND Task 25: Recommended Practices for Wind/PV Integration Studies
 - "Getting Wind and Solar onto the Grid – An IEA Manual for Policy Makers", S. Mueller, P. Vithayasrichareon (International Energy Agency, Paris, France)
 - "Recommendations for Wind and Solar Integration Studies", H. Holttinen, J. Kiviluoma (VTT, Finland), T. K. Vrana (SINTEF, Norway), E. Neau (EdF, France), D. Flynn, J. Dillon (UCD, Ireland), L. Söder (KTH Royal Institute of Technology, Sweden), N. Cutululis (DTU, Denmark), B. Mather, B.-M. Hodge (National Renewable Energy Laboratory – NREL, USA), K.



Fig. 4 - IEA PVPS Task 14 Organization.

Ogimoto (University of Tokyo, Japan), J. C. Smith (UVIG, USA) -> Joint paper between IEA PVPS Task 14 and IEA Wind Task 25

- "IEA PVPS Recommended Practices for Wind/PV Integration Studies – Focus on PV Integration" presented by K. Ogimoto (University of Tokyo, Japan)
- Transmission Grid and System Dynamics: Recommended Practices for Wind/PV Integration Studies", D. Flynn (University College Dublin, Ireland), H. Holttinen (VTT, Finland)

Presentations of all Task 14 events organised so far are publicly available for download from the IEA PVPS website's "Archive" section: <http://www.iea-pvps.org/index.php?id=9>.

The successful series of utility workshops related to high PV penetration scenarios in electricity grids will be continued in 2018, in order to involve industry, network utilities and other experts in the field of PV integration in the Task 14 work. These events will be announced on the IEA PVPS website.

Presentations of all Task 14 events which have been organised thus far are publicly available for download from the Workshops section of the IEA PVPS website: <http://www.iea-pvps.org/index.php?id=212>

MEETING SCHEDULE (2017 AND PLANNED 2018)

2017 Meetings

The 15th Experts' Meeting was held in Washington DC, USA, 25-25 May 2017, hosted by EPRI

The 16th Experts' Meeting was held in Berlin, Germany, 26-27 October 2017, hosted by Fraunhofer IWES

2018 Meetings (tentative)

The 17th Experts' Meeting will take place in Kuching, Malaysia, 8-9 April 2018, hosted by SEDA in the range of the ISES2018 conference. In addition, a joint session with Task 1 as well as a special Deep Dive Workshop is planned in conjunction with the Task 14 meeting

The 18th Experts' Meeting will take place in Vienna, Austria, 15–16 October 2018, hosted by AIT and the Austrian Ministry for Transport, Infrastructure and Technology in the range of the IRED2018 conference. For this event, a further joint meeting with IEA-ISGAN Annexes is planned.

TABLE 1 –LIST OF TASK 14 PARTICIPANTS 2017 (INCLUDING OBSERVER)

COUNTRY	PARTICIPANT	ORGANISATION
Australia	Iain McGill	University of NSW
	Glen Platt	CSIRO
Austria	Roland Bründlinger	AIT Austrian Institute of Technology
	Christoph Mayr	
Canada	Ravi Seethapathy	RAVI
	Patrick Bateman	CANSIA
Chile	Ana Maria Ruz Frias	Comité Solar
	Bernardo Serverino	TU Berlin
China	Wang Yibo	Chinese Academy of Science
	Yang Zilong	
Denmark	Kenn H. B. Frederiksen	Kenenergy
EC	Arnulf Jäger-Waldau	European Commission
Finland	Jesse Kokkonen	ABB
Germany	Gunter Arnold	Fraunhofer IWES
	Martin Braun	
	Bernhard Ernst	
	Markus Kraiczky	
	Gerd Heilscher	Hochschule Ulm
Italy	Giorgio Graditi	ENEA-Portici Research Centre
	Adriano Iaria	RSE
Japan	Koichi Asano	NEDO
	Ken Obayaski	
Japan	Kazuhiko Ogimoto	The University of Tokyo
Malaysia	Akmal Rahimi	SEDA
	Koh Keng Sen	
Portugal	Catarina Calhau	EDP Energias de Portugal
Spain	Ricardo Guerrero Lemus	University of La Laguna
Sweden	Antonis Marinopoulos	ABB Corporate Research
Switzerland	Christof Bucher	Basler & Hofmann AG
	Lionel Perret	Planair SA, Switzerland
	Davy Marcel	
	Jan Remund	Meteotest
United States	Barry Mather	National Renewable Energy Laboratory NREL
	Tom Key	EPRI
	Ben York	
Singapore (observer)	Thomas Reindl	SERIS
	Yanqin Zhan	

TASK 15 – ENABLING FRAMEWORK FOR THE ACCELERATION OF BIPV

INTRODUCTION

The built environment is responsible for up to 24 % of greenhouse gas emissions and accounts for 40 % of the world's total primary energy use. The numbers are increasing each year, due to the rising number of world population, as well as improved standards of living, and will confront us with energy shortage in the future and negative climate changes already in the present. There is ample evidence that the current energy system is not sustainable and that we have to shift to a system based on renewable sources, such as the sun.

Solar PV energy systems, applied in the built environment, offer the possibility of renewable energy closely located to the consumer, avoiding transportation losses and solving the challenges of climate change and energy shortage. To facilitate large-scale introduction of these systems, integration in the built environment is necessary. On the track towards large-scale introduction, five key developments are necessary; price decrease, efficiency increase, storage, improved durability, and building integration.

Building Integrated PV (BIPV) systems consist of PV modules doubling as construction products, which are integrated in the building envelope as part of the building structure, replacing conventional building materials and contributing to the aesthetic quality of the building as an architectural component.

Current BIPV technology has a very small market, but huge potential. To fully grasp this potential, a transition in the built environment has to be realized, in which regulatory barriers, economic barriers, environmental barriers, technical barriers and communicational barriers have to be broken down.

OBJECTIVE

Task 15's objective is to create an enabling framework to accelerate the penetration of BIPV products in the global market of renewables, resulting in an equal playing field for BIPV products, Building Added PV (BAPV) products and regular building envelope components, respecting mandatory issues, aesthetic issues, reliability and financial issues.

The main thresholds on the track of BIPV roll out cover the knowledge transfer between BIPV stakeholders (from building designers to product manufacturers), a missing link in business approach, an unequal playing field regarding regulatory issues and environmental assessment, as well as a transfer gap between product and application, and are reflected in the key developments of Task 15.

Task 15 contributes to the ambition of realizing zero energy buildings and built environments. The scope of Task 15 covers both new and existing buildings, different PV technologies, different applications, as well as scale difference from one-family dwellings to large-scale BIPV application in offices and utility buildings.

APPROACH

To reach the objective, an approach based on five Subtasks has been developed, focused on growth from prototypes to large-scale



Fig. 1 - Task 15's visit to the Frodeparken Building, Uppsala, Sweden.

producible and applicable products. The Subtasks with their target audiences are:

- BIPV project database - Designers and architects;
- Economic transition towards sound business models - Business developers / project managers;
- International harmonization of regulations - BIPV product manufacturers / installers;
- BIPV environmental assessment issues - Policy makers, building environmental assessors;
- Applied research and development for the implementation of BIPV- Researchers, BIPV product developers.

In this approach the most important process and policy thresholds are identified and breached.

ACTIVITIES OF IEA PVPS TASK 15 IN 2017

SUBTASK A: BIPV Project Database

Subtask experts from all countries have been requested to send in 10 BIPV projects that are representative for their country and suitable for international comparison and dissemination. Fourteen countries have responded at the moment of writing, and in total, over 145 projects have been received so far.

Out of these projects a selection is made by the country representatives for a total of 25 projects that will be analyzed in detail.

A questionnaire is written and sent around for comments. Based on the comments received, the questionnaire was updated and finalized. The questionnaire is used as a guideline for in-depth project interviews. Each participating country delivered the project information by the end of 2017.

A draft version of the model book is produced and sent around to support the country representatives for their completion. The result



Fig. 2 – Task 15's visit to the Solibro BIPV manufacturer, Uppsala, Sweden.

will be discussed during the next Task 15 Experts Meeting in Japan in February 2018. The book's final publication is expected in December 2018.

SUBTASK B: Transition towards Sound BIPV Business Models

Subtask B's objective is to make an in-depth analysis and understanding of the true total economic value of BIPV applications, and derive innovative Business Models that best exploit the full-embedded value of BIPV.

Several decisions were made in 2017:

1. Choice of representative BIPV sets updated to:
 1. Residential house rooftop and façade
 2. Tertiary building façade
 3. Industrial/Commercial "light construction" roof
2. A selection of BIPV cases to be reported in Activity B.1 was made during spring 2017; that is one case for each represented country in Subtask B.
3. Use of the [Business Model Canvas](#) in a workshop context led by UX Berlin Innovation Consulting to support the creative process during Task 15 Experts Meeting in Uppsala, Sweden, September 2017.
4. Monthly plenary conference call for all Subtask B participants.

Subtask B is further sub-divided in the following 4 activities:

B.1 – Analysis of Status Quo

Based on a selection of existing projects that are representative BIPV solutions/applications, Subtask B.1 experts have performed a detailed analysis and description of values and motives behind the projects, of the stakeholders that are economically involved, and of the overarching Business Model that prevails for establishing the financial viability of the solution.

- Decision on cases were made during the Task 15 Experts Meeting in Madrid, in April 2017, based on a presentation of the Subtask A cases. The previously developed interview guide was updated and a report template created. Cases were delivered in report format and the analysis was made. The report, including B.1 and B.2, was completed by December 2017.

B.2 – Analysis of Boundary Conditions

Subtask B.2 experts have analysed the current and forecasted evolution of the boundary conditions determining the financial attractiveness of BIPV solutions in this activity. These include the nature and importance of policy support, financial instruments, measures prevailing in terms of self-consumption, etc. This activity

is of particular importance as PV – and BIPV – are transitioning from a subsidized, policy driven deployment to a competitive based deployment.

The activity will focus on how this expected transition affects the deployment of BIPV solutions in particular.

- A template for reporting boundary conditions was created and Subtask B experts delivered country specific information. Analysis of boundary conditions were made and reported. Policy recommendations (B3) were also included the report.

B.3 – Development of New Business Models

This is the core activity of the Subtask. It will in particular perform an in-depth analysis on the definition of the true economic value of BIPV. It will analyze how new business models can be derived to fully exploit the values of BIPV and the possible need for new ad hoc financial instruments.

Task 15 then formulates key recommendations to policy makers, financial operators and BIPV stakeholders to best support the emergence of innovative business models supporting existing or new BIPV applications.

- Key recommendations have already been delivered in the first report with B.1 and B.2; and can be complemented.
- A workshop using the Business Model Canvas was held in connection to the Task 15 Experts meeting in Uppsala, Sweden, September 2017. The workshop results will be developed further during 2018 and lead to the B.3 report.

B.4 – Testing the New Business Models

This activity will document a selection of test and demonstration projects that illustrate the actual application of a selection of representative innovative Business Models.

SUBTASK C: International Framework of BIPV Specifications

The activities in Subtask C and their titles are:

- C.0 International Definition of "BIPV"
- C.1 Analysis of User Needs for BIPV & BIPV Functions
- C.2 BIPV Technical Requirements Overview
- C.3 Multifunctional BIPV Evaluation
- C.4 Suggest Topics for Exchange between Different

Standardisation Activities at the International Level

The current status of each activity is indicated below. Progress has been somewhat limited, due to the fact that the project providing funding for the Subtask Leader was finally approved to start on 01.11.2017. However, significant contributions by many Subtask C experts mean that preparatory work has been possible and that the first reports should become available early in 2018.

The work on BIPV standardisation has gained new impetus due to the decision by IEC/TC 82 to create a new Project Team (PT 63092) to prepare an international BIPV standard. A preparatory meeting was held in Neuchâtel, Switzerland, in October 2017, at which the intention was announced to base the IEC standard as closely as feasible on EN

50583. The first formal meeting of PT 63092 took place on 21.11.2017. Prior to that meeting and based on the work of Subtask C, the Subtask Leader provided the then current version of the C.0 draft report and a table of international standards corresponding to the European standards cited in EN 50583 as a resource to the convenor of PT 63092. A significant number of Subtask C participants are involved in these meetings. This is partly due to the unusual but welcome step taken by the IEC of actively informing Subtask C participants about the invitations for nomination of experts that were distributed by national mirror committees. We can expect ongoing interaction between the work of Subtask C and PT 63092 in future.

Subtask C Activities and Status:

- International definition of "BIPV" (Activity C.0) –final report submitted in January 2018 to all Task 15 experts.
- Analysis of user needs for BIPV & BIPV functions (Activity C.1) – draft report in progress; posting planned for February 2018.
- BIPV technical requirements overview (Activity C.2) – draft report in progress. Overview Tables will provide input to the IEC standardisation effort. An initial step was preparation of the Table of International Standards corresponding to the European ones cited in EN 50583 that has already been input to PT 63092.
- Multifunctional BIPV evaluation (Activity C.3) – Two questionnaires formulated and distributed; first responses received.
- Suggest topics for exchange between different standardization activities on international level (Activity C.4) – planned for 2018.

The next planned steps within Subtask C are:

- Complete reports on activities C0 and C1
- Continue to provide input to IEC 63092
- Analyse experience with implementation of EN 50583
- Identify potential for multifunctional BIPV evaluation

SUBTASK D: Environmental Benefits of BIPV

Nine experts from six countries are active in this Subtask, led by France. These experts are mainly from the PV community, and a bridge towards the building industry is still being constructed. The first activity, state of the art inventory, has started under the Subtask Leader's management. A first questionnaire to establish the international state of the art was sent to all participants (01.12.2015). The state of the art, realized by the University of Applied Sciences Technikum Vienna and by Cycleco, regarding different existing environmental assessment guidelines for both PV and building elements is finalized (however, participants comments may still result in changes). The second stage of the BIPV environmental assessment is in progress. This stage concerns the development of a methodology allowing a consistent environmental assessment at international scale. In order to create a robust international guideline, participant's contribution is essential. The development of the environmental assessment methodology for BIPV led by Cycleco follows 4 steps;

1. In order to not omit crucial elements, Cycleco and the University of Applied Sciences Technikum Vienna suggest a first draft of the methodological guidelines including a detailed product



Fig. 3 - Task 15's BIPV business modeling workshop input.

description and the important steps leading to the BIPV environmental assessment.

2. Experts involved in Subtask D share their inputs to complete the draft.
3. A strong collaboration with IEA PVPS Task 12 - PV Environmental, Health And Safety (E,H & S) Activities is intended to combine the knowledgebase concerning environmental assessments for PV, Buildings and BIPV.
4. Cycleco and the University of Applied Sciences Technikum Vienna adapt and finalize the guidelines.

SUBTASK E: BIPV Research and Field Testing

Out of 63 experts' list contacted, 35 experts from 11 countries are involved in Subtask E. Based on an inventory of existing test and demonstration sites, objectives are to identify assessment methods and performance characterization of BIPV solutions to highlight "reference technical solutions" and contribute to dissemination of reliable BIPV solutions. Within Subtask E, the inventory of existing demonstration sites (activity E1 and E2) has been completed and the report has been published.

Subtask E's work is carried out while taking into account the developments of Subtasks B (business model) and Subtask C, as well as taking into consideration the international definition of BIPV, based on EN 50583 as well as the European Construction Product Regulation CPR 305/2011.

Subtask E is composed of five Actions. Each Action is led by a person in charge of coordinating corresponding work and ensures the Workplan's follow-up in consultation with Subtask E's responsible expert. Each Action Leader identifies and manages their working group, and collects contributions to enrich the actions' reports. To form the working groups, surveys distributed among all Task 15 experts were conducted to identify the contributors to Subtask E and in which actions they wish to participate actively. The mapping of the experts is thus defined on the basis of the answers obtained and working groups constituted. Then, a dedicated list of experts involved for each Action is carried out and updated after each progress meeting.

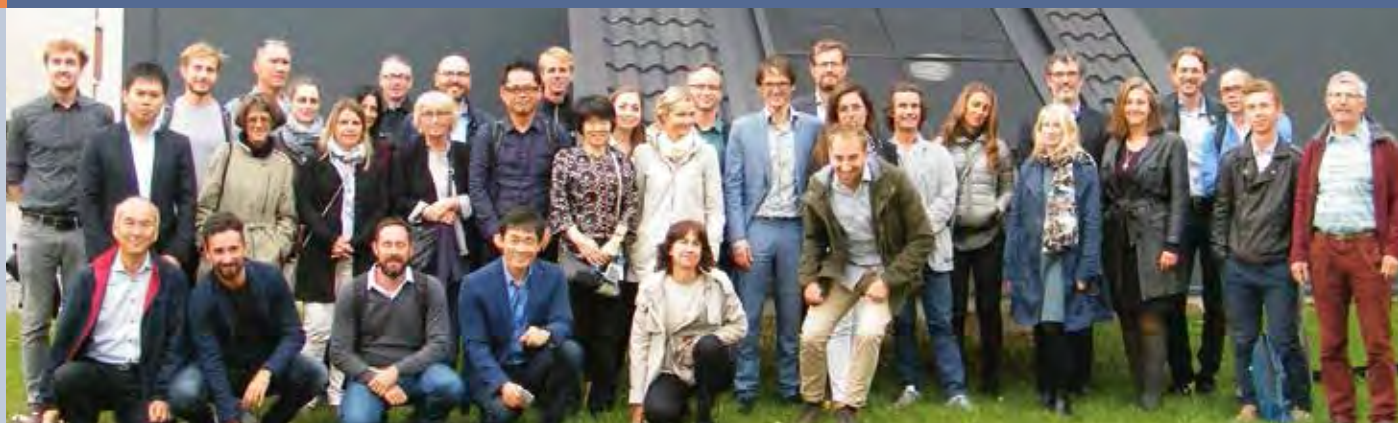


Fig. 4 - Task 15 Experts at the Task 15 Meeting in Uppsala, Sweden, September 2017.

E.1 - Inventory of Existing Test Sites

SEAC (NL) initially leads this action, in order to carry out a mapping of institutes involved in the field of research and development of BIPV components, and was finalized by the University of Applied Sciences Technikum Vienna.

E.2 - Comparison Fields and Reliability Tests

This action is led by OFI and the University of Applied Sciences Technikum Vienna, and brings together the work carried out within the framework of the E.1 action by carrying out important updates; notably by identifying the institutes and laboratories specifically involved in BIPV applications. In addition to an update of the E.1 report, which will be undertaken in 2018, a round-robin test activity has been conducted. This activity is initiated between different laboratories involved in the assessment of BIPV facade components. This work aims to identify the climatic sensitivity and aging of these BIPV components.

E.3 - Installation and Maintenance Issues

This action is led by CSTB and focuses on the definition of a data collection solution to identify issues encountered by BIPV solutions, during installation and/or during maintenance. The objective is to identify in each contributing country the feedback on PV installations integrated into buildings. A main questionnaire in numerical form is carried out with prior validation of the active contributors of Subtask E. Then a national manager is identified in each country to distribute this questionnaire. All data collected are centralized to identify returns by country and thus enables the definition of the classes of issues encountered according to BIPV solutions. The comparison of these returns will establish a critical scale of BIPV solutions and identify the quality criteria to support the BIPV and recommend methods for implementation and maintenance.

E.4 - Diversity of Product

This action is led by OFI and the University of Applied Sciences Technikum Vienna, and presents an investigation on the innovative components under development within the framework of the BIPV international market and to make an inventory (shape, color, materials). This overview of the diversity of BIPV products available or in the process of being deployed will help to define the scientifically key steps for validating these new components for BIPV applications according to the needs of the market and international standards. A report on design possibilities and technical improvements will be made.

E.5 - BIPV Design and Simulation

This action is led by POLIMI, and proposes to make a state of the art of the present software solutions and to suggest a classification on their capacity to answer the specific application of BIPV components.

Particular attention will be paid to the specific validation needs of the BIPV models (inputs and outputs), depending on the integration (Level of details) solutions selected. This work also focuses on the strength and weakness of all specific software to define the necessary and expected improvements. A new and improved tool specifically developed for BIPV applications is expected by this Subtask's end.

SELECTION OF OUTREACH EVENTS - 2017

September 23, 2017: EU PVSEC parallel session, Amsterdam, the Netherlands

June 6, 2017: National Days of Solar Energies JNES, Perpignan, France

November 14, 2017: Task 15 video presentation at the Austrian PV Days, Vienna, Austria

SUMMARY OF TASK 15 ACTIVITIES PLANNED FOR 2018

Task 15's general activity in 2017 focused on the finalization of the formal participation of the contributing countries through National Participation Plans and a clear distinction in activity responsibility, resulting in an adjusted Workplan for Task 15's remaining period. Activities planned for the Subtasks are the following: Finalizing information gathering and layout of the BIPV database book, resulting in two-thirds of projects per country in the book's final version.

Finalizing reports B.1 - B.3.

Finalizing reports C.0 - C.3.

Actively providing input from Subtask C to the IEC standardization PT 63092.

Finalizing reports on D.1 - D.3.

Finalizing report E.3 - E.4 and data collection on E.2.2.

PUBLICATIONS AND DELIVERABLES

Inventory of existing BIPV research and development facilities in the contributing countries (December 2017).

MEETING SCHEDULE (2017 AND PLANNED 2018)

The 5th Task 15 Experts Meeting was held in Madrid, Spain, 15-17 March 2017 (i.c.w. Task 12).

The 6th Task 15 Experts Meeting was held in Uppsala, Sweden, 4-8 September 2017.

The 7th Task 15 Experts Meeting will be held in Tokyo, Japan, 5-8 February 2018.

The 8th Task 15 Experts Meeting will be held in Vienna, Austria, 13-16 June 2018.

The 9th Task 15 Experts Meeting will be held in Denmark, December 2018.

TABLE 1 – CURRENT LIST OF TASK 14 PARTICIPANTS (INCLUDING OBSERVERS*)

COUNTRY	PARTICIPANTS	ORGANISATION	COUNTRY	PARTICIPANTS	ORGANISATION
Austria	Peter Illich	University of Applied Sciences Technikum Wien	Korea	Jun-Tae Kim	Kongju National University
	Karl Berger	AIT - Austrian Institute of Technology - Energy Department		Jae-Yong Eom	Eagon Windows & Doors Co.
	Astrid Schneider	OFI - Austrian Institute for Chemistry and Technology	The Netherlands (OA and lead subtask A)	Michiel Ritzen	Zuyd University of Applied Sciences
	Gabriele Eder			John van Oorschot	
	Susanne Woess- Gallasch	Joanneum Research		Tjerk Reijenga	BEAR
	Gerhard Peharz	Joanneum Research	Norway	Anne Gerd Imenes	Teknova
	Philipp Rechberger	FH Upper Austria (formerly ASIC - Austrian Solar Innovation Centre)		Anna Fedorova	NTNU
	Dieter Moor	ERTEX Solar GmbH		Reidun Dahl Schlanbusch	SINTEF
Belgium	Patrick Hendrick	Université libre de Brussels		Tore Kola	
	Veronique Delisle	Natural Resources Canada	Spain	Nuria Martin Chivelet	CIEMAT
Canada	Costa Kapsis	Canadian Solar Industries Association		Estefania Caamano	Technical University of Madrid
	China*			Javier Neila Gonzales	
Denmark	Karen Kappel	Solar City Denmark		Francesca Olivieri	
	Kenn Frederiksen	Kenergy		Machado Maider	
Germany (lead subtask C)	Helen Rose Wilson	ISE Fraunhofer		Román Eduardo	
	France (lead subtask D and E)	Simon Boddaert		Division Energies Renouvelables / Innovation Photovoltaïque, Centre Scientifique et Technique du Batiment	Ana Belen Cueli Orradre
Jerome Payet		Cycleco		Ana Rosa Lugasas	
Franceoise Burgun		CEA/INES	Sweden*	Bengt Stridh	ABB
Italy		Francesca Tilli		GSE	Peter Kovacs
	Alessandra Scognamiglio	ENEA Research Center Portici		Rickard Nygren	White arkitekter
	Laura Maturi	EURAC		Jessica Benso	RISE
	Stefano Avesani		David Larson	Solkompaniet	
	Nebosja Jakica	Politecnico di Milano, Architecture Dept.	Switzerland	Francisco Frontini	SUPSI
	Silke Krawietz	SETA Network		Pierluigi Bonomo	
Japan	Hiroko Saito	Photovoltaic Power Generation Technology Research Association (PVTEC)	Observers		
	Hisashi Ishii	Research and Development Division LIXIL Corporation	Lithuania	Juras Ulbikas	PVTP Mirror group national representative
	Seiji Inoue	AGC Glass Building & Industrial General Division ASAHI GLASS CO., LTD	Singapore	Dr Veronika Shabunko	Solar Energy Research Institute of Singapore (SERIS)

* To provide formal participation to the IEA.

TASK 16 – SOLAR RESOURCE FOR HIGH PENETRATION AND LARGE SCALE APPLICATIONS

INTRODUCTION

Solar resource Tasks have a long tradition in IEA Technology Collaboration Programmes (TCP). The first Task dealing with resource aspects was IEA Solar Heating and Cooling (SHC) Task 4, which started in 1977. The most recent Task, IEA SHC Task 46 "Solar Resource Assessment and Forecasting" ended in December 2016. The main report – the update of the Solar Resource Handbook – has been published end of 2017 (Sengupta, 2017).

The new IEA PVPS Task 16 was proposed to the IEA PVPS Technology Cooperation Programme mainly due to the fact that the main target audience is coming from PV nowadays.

Task 16 supports different stakeholders from research, instrument manufacturers as well as private data providers and utilities by providing access to comprehensive international studies and experiences with solar resources and forecasts. The target audience of the Task includes developers, planners, investors, banks, builders, direct marketers and maintenance companies of PV, solar thermal and concentrating solar power installation and operation. Task 16 also targets universities, which are involved in the education of solar specialists and the solar research community. In addition, utilities, distribution (DSO) and transmission system operators (TSO) are substantial user groups.

Task 16 is a joint Task with the IEA SolarPACES TCP (Task V). It will also maintain minimal collaboration with IEA Solar Heating and Cooling (SHC) – the TCP of the preceding solar resource and forecast Tasks. Meteotest leads the PVPS Task 16 as Operating Agent on behalf of the PVPS TCP with the support of the Swiss Federal Office of Energy (SFOE). Lourdes Ramirez of Ciemat, Spain, leads the IEA SolarPACES TCP's Task V.

OBJECTIVES

Task 16's main goals are to lower barriers and costs of grid integration of PV, as well as lowering planning and investment costs for PV by enhancing the quality of the forecasts and the resources assessments.

To reach this main goal the Task has the following objectives:

- Lowering uncertainty of satellite retrievals and Numerical Weather Prediction (NWP) models for solar resource assessments and nowcasting.
- Define best practices for data fusion of ground, satellite and NWP data (re-analysis) to produce improved datasets, e.g. time series or Typical Meteorological Year (TMY).
- Develop enhanced analysis of long-term inter-annual variability and trends in the solar resource.
 - Develop and compare methods, for:
 - Estimating the spectral and angular distributions of solar radiation (clear and all-sky conditions)
 - Describing the spatial and temporal variabilities of the solar resource

- Modelling point to area forecasts
- Probabilistic and variability forecasting
- Contribute to or for a setup international benchmark for data sets and for forecast evaluation.

The scope of the work in IEA PVPS Task 16 will concentrate on meteorological and climatological topics needed to plan and run PV, solar thermal, concentrating solar power stations and buildings. As in the preceding IEA SHC Task 46, solar resource assessment and forecasting are the main focus.

However the new Task 16's work will be more focused on user viewpoints and on topics, which can only be handled with the help of international cooperation, which is aside from the international exchange of knowledge, the major use of such a Task.

To handle this scope, the work programme is organized into three main technical Subtasks (Subtasks 1 – 3) and one dissemination Subtask (Subtask 4):

- Subtask 1: Evaluation of Current and Emerging Resource Assessment Methodologies.
- Subtask 2: Enhanced Data & Bankable Products
- Subtask 3: Evaluation of Current and Emerging Solar Forecasting Techniques
- Subtask 4: Dissemination and Outreach

Whereas Subtasks 1 and 3 are mainly focused on ongoing scientific work, Subtask 2 and 4 are mostly focused on user aspects and dissemination. See Tables 1 and 2 below.

APPROACH

The work programme of the proposed Task 16 addresses scientific meteorological and climatological issues to high penetration and large scale PV in electricity networks on one hand, but also includes a strong focus on user needs, and for the first time, a special dissemination Subtask. Dissemination and user interaction is foreseen in many different ways from workshops and webinars to paper and reports.

The project requires the involvement of key players in solar resource assessment and forecasting at the scientific level (universities and research institutions) and commercial level (companies). In the IEA SHC Task 46 this involvement was achieved. Most of its partners are willing to extend their work in the new IEA PVPS Task 16 and many new participants are interested, as well.

The Workplan is also focused on work that can only be done by international collaboration, such as definition and organization of benchmarks, definition of common uncertainty and variability measures; e.g. the measure P10/90 years, which is often used today, lacks a commonly accepted definition up to now.

TABLE 1 – TASK 16’s SUBTASKS AND ACTIVITIES

SUBTASK	ACTIVITY
Subtask 1: Evaluation of Current and Emerging Resource Assessment Methodologies	1.1 Ground-based Methods
	1.4 Numerical Weather Models
	1.3 Satellite-based Methods
	1.4 Benchmarking Framework
Subtask 2: Enhanced Data & Bankable Products	2.1 Data Quality and Format
	2.2 Merging of Satellite, Weather Model and Ground Data
	2.3 Spatio-temporal High Variability
	2.4 Long-term Inter-annual Variability
	2.5 Products for the End-users
Subtask 3: Evaluation of Current and Emerging Solar Resource and Forecasting Techniques	3.1 Value of Solar Power Forecasts
	3.2 Regional Solar Power Forecasting
	3.3 Variability Forecasting and Probabilistic Forecasting
Subtask 4: Dissemination and Outreach	4.1 Produce a Task Brochure
	4.2 Produce a Periodic (6-month) Task Newsletter
	4.3 Conduct Periodic (Annual) Subtask-level Webinars and/or Conference Presentations
	4.4 Update of Solar Resource Handbook

Whereas Subtasks 1 and 3 are mainly focused on ongoing scientific work, Subtasks 2 and 4 are mostly focused on user aspects and dissemination. Table 2 shows the scopes of the three scientific activities.

TABLE 2 – SCOPE OF THE SUBTASKS

SUBTASK	SCOPE
Subtask 1: Evaluation of Current and Emerging Resource Assessment Methodologies	<p>This Subtask is focusing on the evaluation of current and emerging resource assessment methodologies. Different methodologies are analysed and conclusions are formulated in the form of best practices guidelines and/or standards.</p> <p>The three methods (ground based methods, Numerical Weather Prediction models (NWP) and satellite-based methods – are evaluated in this Subtask. For each methodology a separate activity is defined.</p>
Subtask 2: Enhanced Data & Bankable Products	<p>Subtask 2 is mainly dedicated to end-users, notably in the PV domain. It is focusing on the main PV applications of the different types of solar resource products and datasets. End-users needs in concentrating solar thermal, solar heating and buildings will also be considered.</p>
Subtask 3: Evaluation of Current and Emerging Solar Resource and Forecasting Techniques	<p>Subtask 3 focuses on different aspects of forecast evaluation and comparison. In particular we will address the economic value of solar forecasting for a variety of different applications, the topic of regional forecasting important for transmission operators and variability and probabilistic forecasting.</p> <p>Depending of the application and the corresponding forecast horizon different models and input data are applied for solar irradiance and power forecasting. These include numerical weather predictions for several days ahead, satellite based cloud motion forecasts for several hours ahead, and sky imager forecasts for high resolution intra-hour forecasting as well as statistical models for measurement based forecasting and post-processing of physical model forecasts.</p> <p>Each of the Subtask 3 activities includes all of these different forecasting approaches.</p>

ACCOMPLISHMENTS OF IEA PVPS TASK 16

Task 16 officially started on July 1st 2017. 53 partners from 21 countries are taking part. Since Task 16 has recently started, aside from Subtask 4 (dissemination), no reports, workshops or other deliveries have been produced yet. However, scientific work has started in many fields. Spectral modelling was one of the focuses of the work. Some examples of activities that have started are noted below.

SUBTASK 1: Evaluation of Current and Emerging Resource Assessment Methodologies

In this Subtask many publications have been issued in 2017 mainly within activity 1.1 (ground based methods). Topics include spectral measurements, DNI measurements, extinction and soiling.

SUBTASK 2: Enhanced Data & Bankable Products

Jesus Polo (Ciemat, ESP) has started to organise a benchmark for short to long term site adaption techniques. IEA PVPS Task 16's Activity 2.2 & IEA SolarPACES Task V intends to perform a benchmarking exercise on correction methods for improving model-derived data (denoted as site adaptation methodologies). This will allow elaboration of general recommendations and conclusions on which and how to correct modelled irradiance data.

One of the key needs for this exercise is to gather pairs of datasets (modelled-ground) that overlap the same period and timestamp. As a starting point, this Subtask (with experts from CIEMAT, CENER and BoM) has been working in preparing different aspects of the exercise (possible metrics, steps and procedures and datasets).

Task 16's DLR expert from Germany took part in the kick-off meeting of the SolarPACES "Solar Products for End Users" Project during the SolarPACES 2017 Conference, held from 26th to 29th September 2017. Philippe Blanc (Mines ParisTech, FR) was invited by the EU commission to the workshop Copernicus4Energy to present an overview of user needs and challenges for the Solar Energy sector .

SUBTASK 3: Evaluation of Current and Emerging Solar Forecasting Techniques

Sky and Shadow Cameras at PSA

At Plataforma Solar Almeria PSA in Tabernas, Spain, a new shadow camera system has been installed. Six cameras on towers deliver images of the ground (Kuhn et al., 2017). Images are then transferred to shadow and irradiation maps (see Figure 1). Together with the numerous pyranometers, this system is planned to be used for a sky camera forecast benchmark within this Subtask.

Forecast Metrics

The Vallance et al. (2017) paper shows the great importance of metrics to evaluate solar forecasts. Figure 2 shows two examples of forecast which result in the same value of rmse – with totally different forecasts (one including variability, one only including the daily profile of solar path). Depending on usage, different metrics should be used and different metrics given for the evaluations and benchmarks. Vallance suggested including further metrics showing, e.g. the

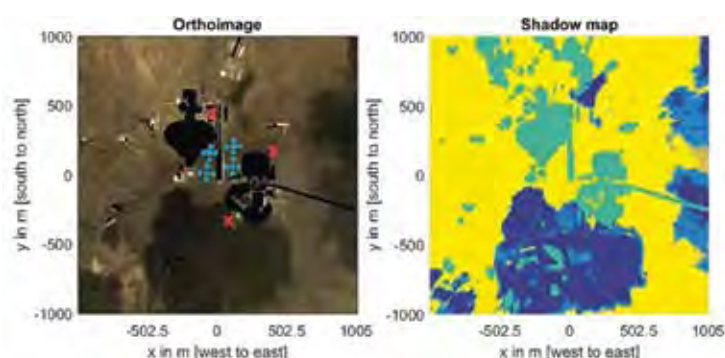


Fig. 1 - Shadow-camera system at PSA and derived shadow map.

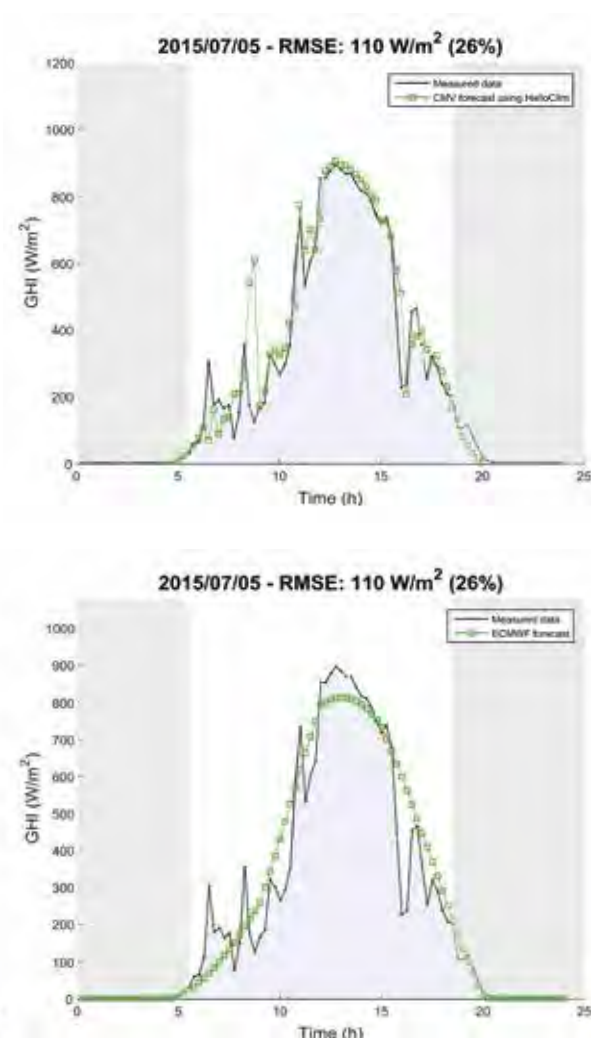


Fig. 2 - Examples of two different methods (left: Cloud Motion Vector based 15-minutes ahead of solar forecasts; right: ECMWF day-ahead solar forecast resampled at 15-minutes) giving the same score of RMSE on the same day but with different behaviours.

temporal deviations of radiation peaks. The drawback of those metrics are that they are complicated to calculate and difficult to explain to end users.

Sky Cam Networks

Two networks of sky cameras (or all sky imagers) are currently in preparation and will start operation in 2018. They will deliver new data with high spatio-temporal resolution for further evaluations, benchmarks and model development. One network with approximately 30 cameras and 10 meteo stations is planned in Northern Germany led by the new DLR Institute of Network Energy Systems in Oldenburg (the Energy Meteorology group of Oldenburg University is moving here). The other network led by CSEM Switzerland and supported by Meteotest consists of five cameras at three locations in Switzerland. It will deliver 10-second time resolution and also pictures in the infrared channel. The data will be publicly available after the one year measurement campaign.



Fig. 3 - Measurement station of Swiss skycam network in Bern. Left: Pyranometer (Hukseflux SR30); right: Sky camera (visible channel). Discussions of how to organise a benchmark of different sky cameras (presumably at Plataforma Solar, Almeria, Spain) have been started. Several groups are highly interested. An EU H2020 proposal and a COST action were initiated to organise this benchmark.

DLR also presented a talk on "Satellite-based DNI Nowcasting Based on a Sectoral Atmospheric Motion Approach" which is an outcome of the European Union's Seventh Programme for research, technological development and demonstration DNICast project run under grant agreement No [608623].

SUBTASK 4: Dissemination and Outreach

Task 16 has been presented at different conferences and at an ISES webinar by Meteotest:

- ISES Webinar (May 23rd 2017)
- Intersolar Europe Conference Munich, Germany, May 30th 2017
- International Conference on Energy & Meteorology, Bari, June 28th 2017
- 1st International Conference on Large-Scale Grid Integration of Renewable Energy, New Delhi, September 6th 2017
- EU PVSEC Conference, Amsterdam, September 26th 2017 (Remund et al., 2017)

- Asia-Pacific Solar Research Conference, Melbourne, December 5-7th 2017
- According to the Workplan, two topics have been accomplished:
- Publication of a Task Brochure: this Flyer was produced by Meteotest in September 2017 and has been distributed at the IEA PVPS booth at EU PVSEC 2017 (see Figure 4).
- Newsletter: The first newsletter has been published September 9th 2017. It was sent to more than 6 000 e-mail addresses.



Fig. 4 -Task Flyer and Logo.

One of the major outcomes of the previous solar resource Task (IEA SHC Task 46, 2010-16) is the new Solar Resource Handbook published by NREL in December 2017 (Sengupta et al., 2017).

GOVERNANCE AND NEXT MEETINGS

Membership

Total membership now stands at 15 countries with 53 active participating organizations. Members have made some progress on certain topics and assume some changes in the Workplan may be needed during 2018.

PLANS FOR 2018

Task 16 will continue its work in 2018. A benchmark of methods to calculate regionally aggregated global radiation and PV production will be started. Two workshops are planned: one on uncertainty measures and one on forecast needs:

- Workshop on "Uncertainty in Dependence of Local Climate (site, season, solar elevation, available satellites and their homogenization)"; planned March 7-9th 2018 in combination with the next Task Experts Meeting (Paris, France).
- User-Workshop on "Analysis of Forecast Requirements for Different Applications"; planned June 18-20th 2018 parallel to Intersolar 2018 (Munich, Germany).

MEETING SCHEDULE (2017 AND PLANNED 2018)

The 1st Task 16 Experts Meeting took place in Bern, June 6-7, 2017.

The 2nd Task 16 Experts Meeting shall be held in Paris, France, March 7-9, 2018 (organized by Mines Paristech).

The 3rd Task 16 Experts Meeting shall be held Rapperswil, Switzerland, September 17-19, 2018, organized by HSR/SPF.



Fig. 5 - Task 16 participants at 1st Task 16 Experts Meeting, Bern, Switzerland, June 6-7 2017.

TABLE 3 – TASK 16 PARTICIPANTS

COUNTRY	TCP	ORGANIZATION
Australia	PVPS	<ul style="list-style-type: none"> Bureau of Meteorology University of South Australia CSIRO
Austria	PVPS	<ul style="list-style-type: none"> Fachhochschule Oberösterreich (FH OOE) Blue Sky Wetteranalysen
Switzerland	PVPS	<ul style="list-style-type: none"> Meteotest Univ. of Applied Sciences Rapperswil HSR / SPF
Chile	PVPS SolarPACES	<ul style="list-style-type: none"> Pontificia Universidad Católica de Chile
Germany	PVPS SolarPACES	<ul style="list-style-type: none"> Fraunhofer (ISE & IWES) [not officially confirmed] DLR (only confirmed by SolarPACES) Suntrace GmbH (both TCPs)
Denmark	PVPS	<ul style="list-style-type: none"> Danish Meteorological Institute (DMI) Technical University of Denmark (DTU) Energinet.dk (TSO of Denmark)
Spain	PVPS SolarPACES	<ul style="list-style-type: none"> CIEMAT (both TCP) CENER Public University of Navarra University of Jaen Universidad Complutense de Madrid University of Seville (US) Irsolav
EU	PVPS	<ul style="list-style-type: none"> JRC
France	PVPS	<ul style="list-style-type: none"> MINES ParisTech Laboratoire PIMENT, Université la Réunion, EDF Univ. des Antilles et de la Guyane Reuniwatt Sunpower / Total Solar Ecole Polytechnique à Palaiseau

COUNTRY	TCP	ORGANIZATION
Italy	PVPS	<ul style="list-style-type: none"> i-em RSE
Netherlands	PVPS	<ul style="list-style-type: none"> Univ. Utrecht [not officially confirmed]
Norway	PVPS	<ul style="list-style-type: none"> Arctic Univ.
Singapore	PVPS	<ul style="list-style-type: none"> SERIS [not officially confirmed]
USA	PVPS	<ul style="list-style-type: none"> National Renewable Energy Laboratory (NREL) National Aeronautics and Space Administration (NASA) State Univ. of New York at Albany (SUNY) Univ. of California San Diego (UCSD) University of Oregon Clean Power Research (CPR) Vaisala/3Tier Solar Consulting Services (SCS)
Great Britain	SHC	<ul style="list-style-type: none"> Peakdesign Ltd. Rina Consulting World Energy & Meteorology Council (WEMC) Univ. East Anglia (UEA) Weatherquest Ltd.
Slovakia	SHC	<ul style="list-style-type: none"> Solargis [not officially confirmed]
Greece	SolarPACES	<ul style="list-style-type: none"> Univ. of Patras
Mexico	SolarPACES	<ul style="list-style-type: none"> Universidad Nacional Autónoma de México
Morocco	SolarPACES	<ul style="list-style-type: none"> IRESEN
UAE	SolarPACES	<ul style="list-style-type: none"> Masdar Institute

AUSTRALIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS
 RENATE EGAN, UNIVERSITY OF NEW SOUTH WALES
 WARWICK JOHNSTON, SUNWIZ

Annual Installations by Sector (MW)

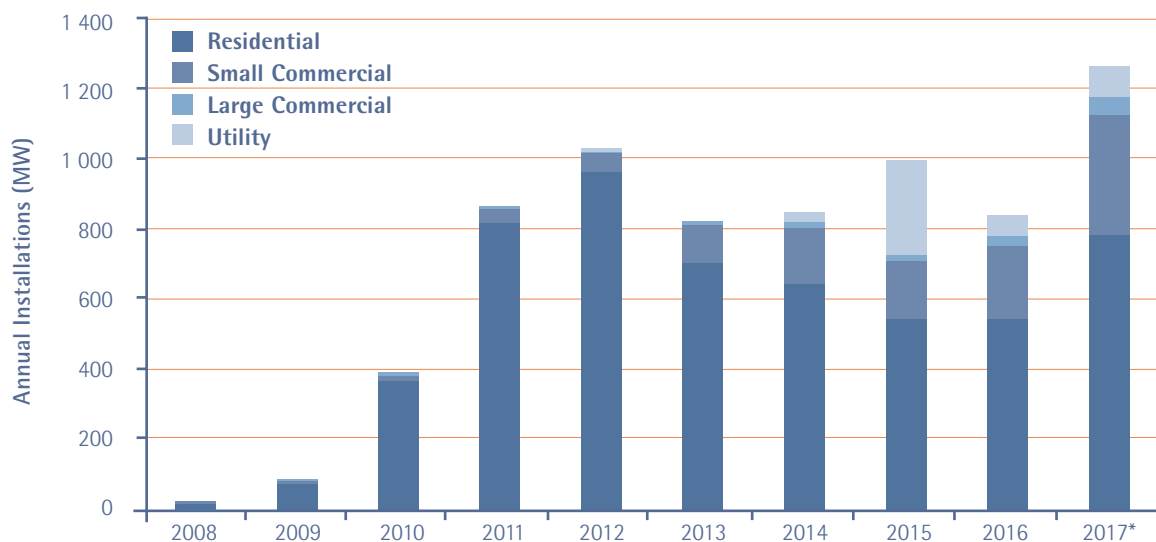


Fig. 1 - Historic Trends in Annual PV Installations in Australia by Sector.

GENERAL FRAMEWORK AND IMPLEMENTATION

2017 was a record year for Australian PV installations, with 1,25 GW recorded. 2017's record volume was driven by large increases in electricity prices, continued reduction in PV system prices, an increasing awareness of the benefits of PV to businesses, and the swift ramp-up of the Renewable Energy Target (RET).

Almost 1,8 million Australian homes and businesses are now powered by their own PV system – over 160 000 of which were added in 2017. Residential penetration levels average over 20 % of households and reach over 50 % in some urban areas. At the end of 2017, cumulative installed capacity of Australian PV installations was 7,0 GW. Solar continues to be supported with small and large generation certificates. Hundreds of thousands of customers had their feed-in tariff revert to an unsubsidised level at the beginning of 2017, which created an opportunity for early adopters of PV to expand their system size and/or add batteries. At the beginning of the year, the Victorian government took a nation-leading position in incorporating the value of carbon emissions into its feed-in tariff. Some small subsidies applicable to solar power systems and/or storage commenced in limited areas in 2017.

The broader national energy market became front-page news throughout 2017, following supply constraints in some states over summer that were exacerbated by the retirement of some major coal-fired power stations and the low availability of gas – both of which contributed to a doubling in wholesale electricity prices. The government adopted 49 of 50 recommendations from Australia's Chief Scientist about how to address the energy 'trilemma' of affordability, reliability, and low-emissions, but stopped short of adopting a Clean Energy Target in favour of proposing a National Energy Guarantee.

Further growth in the Australian market is expected in 2018, with over 1,3 GW of solar farms currently under construction, and 22 GW at various stages of development. However, by the end of 2017, it was clear that there were sufficient projects in advanced stages of development to meet the RET, creating a steep investment drop-off beyond 2020. Nevertheless, with incumbent businesses in the network, generation, and retail space progressively embracing renewable energy as an inevitability, momentum is building for the coming decade.



Fig. 2 - Map of Australian solar farms operating and under construction at the end of 2017.



Fig. 3 - The DeGrussa Solar Farm. The DeGrussa Solar Project was successfully commissioned at Sandfire's DeGrussa Copper-Gold Mine. It has 34 080 solar PV panels with a single-axis tracking system mounted on 4 700 steel posts.



Fig. 4 - Wicks Winery Estate. Woodside, South Australia. 80 kW system sold and installed by Venergy Australia (Photo: Matt Wilkins).

NATIONAL PROGRAMME

The main support for PV at a national level remains the RET, which undertook an extensive review in 2014 and 2015. Support for large systems is via the Large-scale RET (LRET) which in 2015 was reduced from 41,000 GWh to 33,000 GWh of renewable electricity by 2020. It operates via a market for Large-scale Generation Certificates (LGCs), with 1 LGC created for each MWh of electricity generated. Support for small-scale systems is via an uncapped Small-scale Renewable Energy Scheme (SRES), for which 1 MWh creates 1 Small-scale Technology Certificate (STC). All PV systems up to 100 kWp are also able to claim STCs up-front for the amount of deemed generation they will produce until the end of 2030. This means that the STCs for small systems act as an up-front capital cost reduction.

In 2016-17, the Australian Renewable Energy Agency (ARENA) committed 92 MAUD to support for twelve large scale solar farms totalling 480 MW, funding which unlocked 1 BAUD of additional investment. An additional 9 MAUD was invested in 2 other solar PV projects.

Deployment of large scale solar is increasingly being supported by the Clean Energy Finance Corporation (CEFC), a statutory authority established by the Australian Government. The CEFC works to increase the flow of finance into the clean energy sector by investing in a range of cleaner power solutions which can help reduce Australia's emissions, improve energy efficiency and lower operating costs. This includes large and small-scale solar, grid and storage projects. The CEFC invested 844 MAUD in 2016-17 to accelerate Australia's clean energy investment into low carbon electricity, towards total project value of 3 300 MAUD. This included 440 MAUD financing towards 10 large-scale solar projects totalling 500 MW.

RESEARCH, DEVELOPMENT & DEMONSTRATION

PV research, development and demonstration are supported at the national, as well as the State and Territory level. In 2017, research was funded by the Australian Research Council, Co-operative Research Centres and ARENA. ARENA is the largest funder of photovoltaics research in Australia. To date, ARENA has committed 434 MAUD towards photovoltaic projects, including 17 with the University of NSW, five with the Australian National University, two with the University of Melbourne, and one with the University of Queensland. Major projects supported included the establishment of the Australia-US Institute for Advanced Photovoltaics. During 2016-17,

ARENA supported 42 PhD scholars and post-doctoral fellows, plus 40 Research & Development projects with a total of 154 MAUD (though not all of these projects were PV related).

Most of the utility-scale solar farms that were commissioned in 2017 were supported by ARENA, including the 10 MW Gullen Solar Farm - collocated with a 166 MW wind farm; the 50 MW Kidston Solar Project which will later utilise an old mining pit to create 250 MW of pumped-hydro storage; and the Lakeland Solar & Storage Project which combines an 11 MWac solar farm with a 1,4 MW/5,3 MWh battery to improve the grid reliability.

INDUSTRY AND MARKET DEVELOPMENT

Growth occurred in 2017 every sector of the PV market. Residential PV (<10 kW) grew by 45 % to 786 MW, small commercial (10-100 kW) grew by 61 % to a record 335 MW, large commercial (101 kW-5 MW) also grew over 60 % to a 55 MW, and utility-scale grew 48 % to 88 MW. Average system sizes in the sub-100 kW market grew to 6,3 kW/system, off the back of faster growth and increasingly large commercial installations, plus growth in the typical size of residential systems. Average residential solar PV system prices continued to decline in 2017, to 1,45 AUD per Watt including STCs, or 2,10 AUD/Watt without STC support.

Between 14 000 and 20 000 home energy storage systems were deployed in 2017, most of which did not receive any subsidy. The Australian storage market is viewed favourably by overseas battery/inverter manufacturers due to its high electricity prices, low feed-in tariffs, excellent solar resource, and large uptake of residential PV. 2018 looks certain to be another record year for Australian PV. Notwithstanding that a record volume of utility scale PV will be deployed, the economic fundamentals for residential and commercial PV are outstanding. Australia's high electricity prices and inexpensive PV systems mean payback can commonly be achieved in 3-5 years, a situation that looks set to continue in 2018. Momentum is building for further acceleration of commercial PV deployment, and corporate interest in solar PPAs is emerging. However, the RET will soon be met, leaving over 10 GW of PV projects searching for an alternative pathway towards commercialisation. Though a policy gap may occur, there is acceptance amongst incumbent electricity businesses and regulators that renewable energy is the least cost source of new-build electricity, and will soon outcompete Australia's existing generation fleet that are progressively needing refurbishment.

AUSTRIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 1 - Penken Cable Car Station, Tyrol (Photo: © ATB Becker).

GENERAL FRAMEWORK AND NATIONAL PROGRAMME

Currently, about 75 % of Austria's electricity supply is based on renewable energy; predominantly by large hydropower at more than 60 %, wind energy at about 9 %, some bio-electricity and an increasing amount of photovoltaics, at nearly 2 % in 2017. Austria has never produced electricity from nuclear energy and has a clear policy against nuclear. Austria's new government, inaugurated by the end of 2017, has for the first time officially fixed the target of 100 % electricity from renewable energy by 2030.

Meanwhile, many national energy and climate studies have clearly indicated that PV has the highest potential for reaching the Austrian 100 % electricity target.

The "Technology Roadmap for Photovoltaics in Austria" published in 2016 described a 15,3 % share until 2030 which might be needed for reaching the above-mentioned political target. This share is not only needed to replace fossil energy power plants, but also to cope with a significant electricity growth which is expected, due to the mobility (electric vehicles) sector and heating (heat pumps) sector, as well as to digitalisation.

The current official target for the national photovoltaic market is laid down in the national green-electricity act (GEA), firstly issued in 2002, and revised several times since then. The official market target is currently set at 1 200 MW in 2020. This target was already reached in 2017. A new green-electricity act with new targets for photovoltaics and the other renewable sources is currently in its early phase of discussions.

A total of approximately 1,1 GW of PV power had been installed in Austria by the end of 2016. No final figures are available for 2017 yet, but it is expected that the installations in 2017 were in the same range as in previous years; leading to about 1,25 GW in total. Reaching the Photovoltaic Roadmap targets would require an increase in the installation rate by at least a factor of four compared to the last years.

Austria's support schemes are essential for the installation rates; besides some regional support mechanisms, two federal support schemes are still dominating:

- The feed-in-tariff system is designed only for systems larger than 5 kWp; Feed-in tariff is provided via the national green-electricity act. The "new RES" are supported by this act mainly via up to 13 years guaranteed feed-in tariffs. The annual cap, which started with 50 MEUR in 2012 is reduced every year by one million; with photovoltaics obtaining 8 MEUR out of that. The feed-in-tariffs are stated by the Federal Ministry for Economics and financed by a supplementary charge on the net-price and a fixed price purchase obligation for electricity traders. For 2017, the tariff was set at 7,91 EURcent/kWh for PV on buildings (8,24 EURcent/kWh in 2016) and no incentive for PV on open landscapes. As in 2016, an additional 375 EUR subsidy per kWp (or 40 % of total invest cost) was offered.

About 7,7 MEUR were dedicated to PV investment support for small systems up to 5 kWp in 2017 by the Austrian "Climate and Energy Fund". This additional support scheme has existed since 2008 and is well-co-ordinated with the feed-in scheme. With 275 EUR per kWp for roof-top systems and 375 EUR per kWp for building integrated systems, the support per kWp was the same as in 2016. This support has led to about 6 300 new PV systems with a total capacity of 42,0 MWp in 2017.

For the third time, there was an additional offer for the agricultural sector – systems from 5 kWp to 30 kWp, owned by farmers, obtained the same incentive per kWp (275/375 EUR) as other private owners, which might have led to approx. 7,5 MWp installed in 2017. Regions that participate in the Programme "Climate and Energy Pilot Regions" are eligible to receive funding for PV installations that are in special "public interest". In 2017, 92 PV installations were funded with 0,85 MEUR (ELER + Klima- und Energiefonds). In total, 2,4 MW were submitted.

Additionally, some provinces provide PV support budgets as well, amongst them very specific support, e.g. only for municipal buildings or for tracked PV systems.

The mean system price for private systems went gradually further down to 1,645 EUR/kWp (excluding VAT) for a 5 kW system.

In 2017, support schemes for battery-storage systems in combination with PV systems were offered by several provinces. This scheme is dedicated to small, mainly private systems, with the support schemes being very different; typically ranging to storage capacities of up to a maximum of 10 kWh. Until now, these initiatives have led to a total of a few hundred storage systems.

At the end of 2017, a federal subsidy system for battery storages, in combination with PV systems was introduced; which shall start in 2018. The total budget is 15 MEUR; from that, at least 9 MEUR is for PV systems.

RESEARCH AND DEVELOPMENT

In 2017, Austria announced its interest to join the "mission innovation" network, aiming at more research and the energy and climate sectors. The National Photovoltaic Technology Platform, founded in September 2008 and exclusively financed by the participating industry, research organisations and universities is aiming at creating better coherence of Austria's national PV research. Once again, the platform experienced good development in 2017. Initially supported by the Ministry of Transport, Innovation and Technology, this loose platform has been acting as a legal body since 2012. The PV Technology Platform brings together about 30 partners, active in the production of PV relevant components and sub-components, as well as the relevant research community in order to create more innovation in the Austrian PV sector. The transfer of the latest scientific results to the industry by innovation workshops, trainee programmes and conferences, joint national and international research projects, and other similar activities are part of the work programme, besides the needed increasing awareness, aiming at further improving the frame conditions for manufacturing, research and innovation in Austria for the relevant decision makers. In 2017, an "Innovation Award" was launched for the first time in the field of PV integration. The target of "integration" covers two aspects: integration from the point of architecture into the built environment, as well as integration energetically, into the local energy system by optimally providing energy on the site. More than 50 national BIPV projects were submitted.

The research organisations and industrial companies are participating in various national and European projects, as well as in the different IEA PVPS Technology Collaboration Programme's Tasks. The national Energy Research Programme by the Austrian Climate and Energy Fund, as well as the "City of Tomorrow" programme by the Ministry of Transport, Innovation and Technology cover quite broad research items on energy technologies, including PV.

The total expenditures of the public sector for energy research in Austria was about 141 MEUR in 2016; out of that, about 30,5 MEUR was dedicated to Renewable Energy with a share of 11,5 MEUR for photovoltaics.

Within IEA PVPS, Austria is leading the Task 14 on "High penetration of Photovoltaics in Electricity Networks" as well as actively participating in Task 1, 12, 13, 15 and 16.

The national RTD in photovoltaics is focusing on materials research, system integration, as well as more and more on building integration; where integration is seen not only from architectural aspects but from systemic aspects including the local electricity generation for mobility. On the European level, the on-going initiative to increase the coherence of European PV RTD programming (SOLAR-ERA.NET) is actively supported by the Austrian Ministry of Transport, Innovation and Technology.

"Smart Grid" activities in Austria are more and more focusing on business models for new applications, where PV together with storage, heat pumps, electric-vehicles and other technologies offer a wide spectrum for new activities. PV is seen as an important cornerstone in a new, and more and more digital energy world. Moreover, there is a clear tendency of private consumers to achieve a high degree of energy autonomy. PV in combination with storage systems, where both technologies have shown significant cost digression in recent years, offers this opportunity. Out of that trend, discussions about further financing the public grid are emerging.

IMPLEMENTATION & MARKET DEVELOPMENT

Self-consumption is generally more and more an additional driver of PV development. However, a self-consumption tax was introduced in 2014, for annual production, which exceeds 25 000 kWh. Since this is far beyond the typical production by private PV systems, which are dominating the Austrian market traditionally, this tax does not influence the development of private PV storage systems. Nevertheless, it has an effect on larger systems in industry as well as small and medium enterprises. Self-consumption is mainly seen as the decisive factor for amortisation of larger PV systems in Austria. In late 2017, the new government published plans to abolish this self-consumption tax for PV systems completely.

The main applications for PV in Austria are grid connected distributed systems, representing much more than 99 % of the total capacity. Grid-connected centralised systems in the form of PV power plants play a minor role. Building integration is an important issue and a cornerstone of the public implementation strategy.

The Austrian electricity statistic regulation, which was negotiated and decided at the end of 2015, obliges the network operators, since 2016, to report at the end of each year all new installed wind and PV systems to the regulator. This might become the basis of a national PV register, which could also serve as important tool to improve PV power forecasting.

MARKET DEVELOPMENT

The Federal Association Photovoltaic Austria is a non-governmental interest group of the solar energy and storage industry. The association promotes solar PV at the national and international levels and acts as an informant and intermediary between business and the political and public sectors. Its focus lies on improving the general conditions for photovoltaic and storage systems in Austria and on securing suitable framework conditions for stable growth and investment security. Benefiting from its strong public relations experience, PV-Austria builds networks, disseminates key information on the PV industry to the broader public, and organizes press conferences and workshops. By the end of 2017, the association counted 245 companies and persons involved in the PV and storage industry as its members.

The 15th annual National Photovoltaic Conference took place in Vienna, in 2017; again a two and a half days event, which was organised by the Technology Platform Photovoltaic and supported by the Ministry



Fig. 2 - Sphere Expo 2017 Astana, Kasachstan (Photo: © ertex solar, Dieter Moor).

of Transport, Innovation and Technology. This strategic conference was established as THE annual come together of the innovative Austrian PV community, bringing together about 220 PV stakeholders in industry, research and administration. This time, the city of Vienna acted as the conference's host.

Many specific conferences and workshops were organised by the "PV-Austria" association. Renewable energy fairs and congresses in Austria are more and more focussing on PV.

Larger PV power plants, ranging from some 10 kWp to a few MW systems have been successfully installed by the utilities as well as by municipalities as "citizen's solar power plants". Several ways to finance these systems are in place, from crowdfunding models to "sale and lease back" models. As previous projects have shown, the demand is very high, e.g. in the province of Lower Austria, more than 50 municipalities have already realized such PV systems. Usually, it only takes a few hours until a new power plant is sold out. One part of this success is the current, relatively low interest rate on bank savings accounts.

FUTURE OUTLOOK

"Photovoltaic Integration" in the sense of aesthetic architectural integration, as well as integration from the system point of view, into the local energy system, needs to stay in the focus of further PV deployment. Meanwhile, the much lower cost of PV systems and the ambition to optimise systems for self-consumption purposes might open new opportunities for private, as well as for small and medium-size enterprises and for the industry.

In 2017, a revision of the Austrian ELWOG-law (electricity economy and organisation law) has opened the possibility for multi-family houses to jointly use and distribute PV electricity. The enlargement of these self-consumption possibilities to neighbourhoods is under discussion.

The Austrian PV industry is strengthening its efforts to compete on the global market, mainly through close collaboration with the public research sector, in order to boost innovation in specific niches of the PV market. International collaboration is very important.

Storage systems will enable increased energy autonomy and might become a main driver in the sector. Currently, they are mainly driven by private consumers.

Electric cars are subsidised since March 2017 with up to 5 000 EUR; which has led to an increase of 64 % in 2017. About 15 000 fully electric cars are currently registered in Austria; a further strong growing E-vehicle sector might have a significant influence on PV development. Moreover, since the decision for obtaining E-vehicle subsidy depends on the proof of using 100 % electricity from renewable energy (e.g. a supply contract with a 100 % green electricity provider).

PV research and development will be further concentrated on international projects and networks, following the dynamic expertise and learning process of the worldwide PV development progress. Mainly within IEA PVPS Task 14 on "High Penetration Photovoltaics in Electricity Networks", commenced in 2010 and lead by Austria, is a focal point of the international research activities in the topic of smart electricity systems. However, the national energy research programmes are also dedicated to PV issues, with many larger projects just in operation.

Smart city projects are supported by the Ministry of Transport, Innovation and Technology as well as by the Austrian Climate and Energy Fund. Within the broad range of city relevant research, PV plays more and more a significant role and a visible sign of a sustainable energy future in urban areas; frequently also in combination with the use of electric vehicles. As an example, PV roof gardens have the potential to improve the city-micro climate, can create convenient living areas on roofs, store rainwater, etc., besides the main purpose which is renewable energy generation.

Several renewable energy education courses and trainings are already implemented, some new classes are currently under development. All of them include PV as essential part of the future energy strategy. The importance of proper education for PV system installers and planners will increase depending on the market situation. Such training is already available and can be extended easily. At several universities, Bachelor and Master degree courses in renewable energy, energy efficient building technologies with solar, and specifically, PV systems as one core element, are offered.

BELGIUM

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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GENERAL FRAMEWORK

Belgium reached approximately 3,8 GWp of cumulative installed PV capacity at the end of December 2017, according to the latest figures of the three regional regulators. The country added more than 271 MWp in 2017, a strong growth compared to 2016 (179 MW). The Belgian PV park is also characterized by its amount of small systems. Almost 1 household out of 10 owns a PV system.

In Flanders, the small systems (<10 kWp) market was very active despite the "prosumer fee" (approx. 85 EUR/KW). This fee enables DSOs to charge for the cost of grid use by PV owners, without changing the system of net metering. It gives a simple payback time around 12 years for a new PV installation.

This astonishing success is mainly due to the positive communication action made in Flanders to promote PV with a simple message: "You earn more money if you put your savings into PV than to leave it in your bank account."

In 2017, the market of big systems (>10 kW) was on the contrary not very active in Flanders. They have no net-metering or prosumer fee but benefit from a self-consumption scheme and from an additional green certificate (GC) support scheme to ensure that investors have an IRR of 5 % after 15 years. The support is recalculated every 6 months.

In terms of installed capacity, Flanders installed about 206 MWp in 2017, reaching 2,8 GWp. The installation of small systems (<10 kW) represents 57 % of the installed capacity. The big plants (>250 kW) and the commercial segments (10-250 kW) represent respectively 24 % and 19 % of the total installed capacity.

In Wallonia, the Quali watt support plan for small systems (≤ 10 kW) introduced in 2014 was relatively successful; that is, better than 2015 but not yet reaching the maximum amount of supported installations (approx. 5 600/12 000). Quali watt is a premium spread over five years and is calculated to obtain a simple payback time of 8 years (5 % IRR

for a 3 kWp installation after 20 years). End of 2017, it was decided that the Quali watt premium is not needed anymore and will be stopped in July 2018.

For big systems in Wallonia, 2017 will most probably be one of the best years. Since 2015, there is a system of GC reservation that controls the market development. At the end of 2017, the government decided to accept that unused GC from other technologies could be used for PV projects. The amount of GC/MWh depends on the system size and varies between 1,19 (77 EUR) if the system is smaller than 250 MWp and 0,4 (26 EUR) if the system is bigger than 750 MWp.

In terms of installed capacity, Wallonia installed about 59 MWp in 2017, reaching 0,9 GWp. The installation of small systems (<10 kW) represents 82 % of the installed capacity. The big plants (>250 kW) and the commercial segments (10-250 kW) represent respectively 4 % and 14 % of the total installed capacity.

Brussels is the first Belgian region where the yearly net-metering system that has benefited small systems (< 5 kW) is planned to be removed. It will be replaced by a self-consumption scheme in 2020. The green certificates support remains operational and has remained stable since 2016. It guarantees a 7-year payback time.

In terms of installed capacity, Brussels installed about 5 MWp in 2017, reaching 62 MWp. The installation of small systems (<10 kW) represents 18 % of the installed capacity. The big plants (>250 kW) and the commercial segments (10-250 kW) represent respectively 57 % and 25 % of the total installed capacity.

NATIONAL PROGRAM

The Belgian National Renewable Energy Action Plan fixed a target of 1,34 GWp installed in 2020 in order to reach the national target of 13 % renewables in 2020 set by the European directive. This objective had already been reached in 2011.

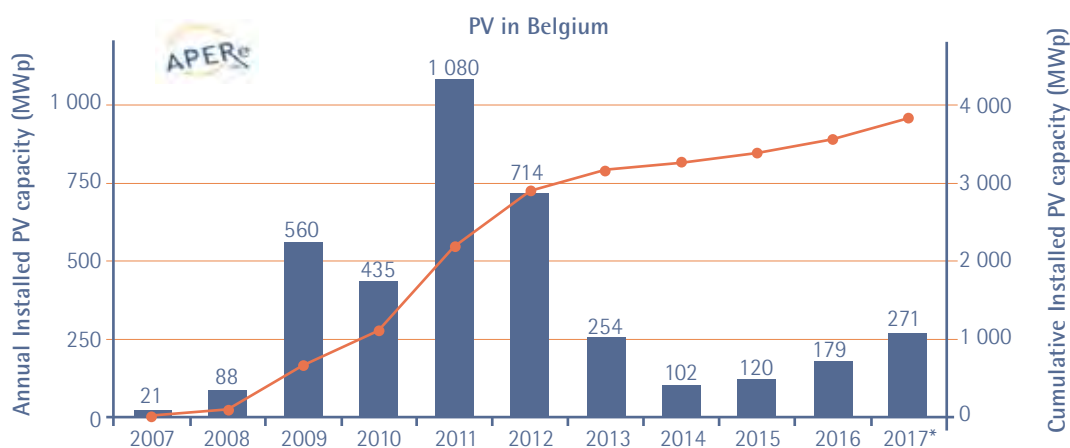


Fig. 1 – Belgium's Annual Installed PV Capacity and Cumulative Installed PV Capacity (MWp).



Fig. 2 - Energiris PV project in Brussels: Cooperatives are increasingly active to allow schools or other public buildings to install PV on their roofs and citizens to invest in projects.

In November 2015, and after long negotiations, this national objective was translated into regional targets. In 2016, each region adapted their existing roadmaps to reach these objectives.

In Flanders, the government defined indicative production objectives for each renewable energy source with the overall objective to reach a share of 10,5 % renewable energy in the total final energy consumption by 2020. For PV, the target in 2020 is a production of 2 670 GWh which translates into about 3 GWp installed. In 2017, about 2 328 GWh were produced by the Flemish PV park. Annual growth should be around 114 GWh/year (138 MWp) to reach the objective of 2020.

In Wallonia, the government wants to produce 13 % of the region energy consumption from renewable energy sources by 2020. End of 2015, the government planned a mean annual growth of 73 GWh (81 MWp) until the end of 2020. This annual objective is split between small systems (43 GWh – 48 MWp) and big systems (30 GWh – 33 MWp).

In Brussels, the objective is to produce 91 GWh of solar electricity by the end of 2020; that means a growth of approximately 17 GWh a year (18 MWp), which is more than tripling the installation rhythm of 2017.

RESEARCH AND DEVELOPMENT

R&D efforts are concentrated on highly efficient crystalline silicon solar-cells, thin film (including perovskite) and organic solar-cells (for example by imec, AGC, etc.). More and more research is also done on smart PV modules that would embed additional functionalities, such as micro-inverters (mainly Imec Research Center), on smart grids that include decentralized production in their models (Energyville) and on recycling (PVSEMA and SOLARCYCLE projects).

INDUSTRY

There are two producers of classical modules in Belgium : Issol and Final24, although Issol mainly develops BIPV activities. With Soltech

and Reynaers, they are the three main companies focusing on BIPV applications. Derbigum is specialized in amorphous silicon.

Next to these five big companies, a lot of companies work in all parts of the value chain of PV, making the Belgian PV market a very dynamic sector. (<http://en.rewallonia.be/les-cartographies/solar-photovoltaic>)

MARKET DEVELOPMENT

Small-scales projects (< 10 KW) account for 61 % of the installed capacity with almost 453 000 installations which represent approximately 1 household out of 10. The other 40 % include about 7 800 large-scale projects.

TABLE 1 – BELGIUM'S ANNUAL GROWTH INSTALLED PV AND CUMULATIVE INSTALLED PV (MWp)

YEAR	ANNUAL GROWTH (MWp)	CUMULATIVE (MWp)
2007	20,5	25
2008	87,8	112
2009	560,5	673
2010	435,3	1 108
2011	1 080,2	2 188
2012	714,3	2 903
2013	254,1	3 157
2014	102,0	3 259
2015	119,8	3 379
2016	178,9	3 557
2017*	270,9	3 828

CANADA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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GENERAL FRAMEWORK

Canada's Department of Natural Resources (NRCan) supports priorities to promote the sustainable and economic development of the country's natural resources, while improving the quality of life of Canadians. CanmetENERGY [1], reporting to the Innovation and Energy Technology Sector of NRCan, is the largest federal energy science and technology organization working on clean energy research, development, demonstration and deployment. Its goal is to ensure that Canada is at the leading edge of clean energy technologies to reduce greenhouse gas emissions and improve the health of Canadians.

The Canadian Solar Industries Association (CanSIA) is a member of the International Energy Agency Photovoltaic Power Systems Program (PVPS) and the national trade association for the solar energy industry working to make solar energy a mainstream and widespread energy option throughout Canada.

The Pan-Canadian Framework on Clean Growth and Climate Change [2] established in December 2016 charts a course for Canada to meet its obligations under the Paris Agreement including a national greenhouse gas emissions reduction of 30 % below 2005 levels by 2030. In support of these policy objectives, Canada's Federal Government have committed the country to a target of 90 % non-emitting electricity by 2030. Increasing the level to which Canada's vast renewable energy resources are harnessed (above the 65 % of total national electricity demand in 2016 [3]) is central to meeting both the national emissions and electricity targets, as emissions reductions through fuel-switching in the transportation, industrial processes and buildings sectors are accelerated.

The continued decline in the cost of generating solar electricity has resulted in it approaching "grid-parity" throughout Canada. In response, consumer demand is also dramatically increasing. Many provincial and territorial governments are now examining how to best manage and accelerate deployment in their jurisdiction. The province of Ontario, Canada's most populous (13,6 million residents) and second largest province (more than 1 million km²), leads the country in solar electricity generation with a cumulative installed capacity of 2,818 MW_p as of October 1st 2017 (representing more than 99 % of the national total). In 2017, Alberta in Western Canada became the first province or territory outside of Ontario to install more than 5 MW_p in a single year (with more than 25 MW_p of new facilities brought in-service in 2017).

NATIONAL PROGRAMME

Research and Demonstration

NRCan's CanmetENERGY is responsible for conducting PV R&D activities in Canada that facilitate the deployment of PV energy technologies throughout the country. The PV program coordinates national research projects, contributes to international committees on the establishment of PV standards, produces information that will support domestic capacity-building and organizes technical meetings and workshops to provide stakeholders with the necessary information to make informed decisions. In 2017, research on the performance,

Utility Interconnected PV Systems 2016



Fig. 1 - Map showing the Canadian provinces, the capacity (in megawatt), and the number of utility interconnected PV systems as of December 31st, 2016. All power capacities are reported in DC (Watt peak, W_p).

cost and durability of PV systems in the arctic was identified as a priority to support the clean electricity program in Canadian northern territories. In addition, research is also led to study the integration of PV in remote grids such as Colville Lake (Northwest Territories), Jean-Marie River (Northwest Territories), Cambridge Bay (Nunavut), and Destruction Bay (Yukon).

A Business-led Network of Centres of Excellence was established in 2014 [4]. The Refined Manufacturing Acceleration Process (ReMAP), headquartered at Toronto-based Celestica, is developing an ecosystem for commercialization that links academics, companies and customers. With access to 38 labs and manufacturing lines across the country, the ReMAP network will work with participating companies from the information and communications technologies, healthcare, aerospace, defence and renewable energy sectors to quickly identify innovations that are most likely to succeed, and then accelerate the product commercialization and global product launch.

IMPLEMENTATION

Ontario: In 2017, the province of Ontario launched its new Long-Term Energy Plan (LTEP) [5], which will set the course for Ontario's energy sector to 2035. The plan emphasizes the role of innovation and technology in modernizing Ontario's electricity sector. The aim is to empower consumers and make electricity more affordable. The province's Feed-in-Tariff (FIT) programs concluded in 2017. Once all contracted facilities are constructed, it is estimated that a total of 3 300 MW_p of solar PV capacity will have been installed. In advance of the conclusion of the FIT, the province's net metering regulations have been enhanced including the removal of the cap on maximum system size and the eligibility of storage technologies. A virtual net metering demonstration pilot program was also announced. The Ontario Government also launched the Market Renewal Program in 2017 [6] which is reshaping the foundation of Ontario's 17 BCAD annual

electricity market. This initiative will address current market design issues and look to find ways to improve the way electricity is priced, scheduled and procured to meet Ontario's current and future energy needs at the lowest cost while striving to align with the Province's climate policies and objectives. Through the 2016 Climate Change Action Plan [7], the Green Ontario Fund was created in 2017 to help fund energy efficiency and renewable technologies that help lower greenhouse gas emissions. As a result, financial incentives are expected for both solar electricity and heating technologies in 2018.

Alberta: In 2017, several new policies and programs were developed and implemented to support the province's Climate Leadership Plan and its commitment to phasing out all coal-fired electricity and tripling its renewable electricity capacity to 30 % by 2030. The first round of the Renewable Electricity Program (REP) auction was launched to support 5 000 MW_{AC} of utility-scale renewable electricity by 2030. Solar electricity facilities were eligible to participate but were not contracted (the first round resulted in 600 MW of wind energy contracts with a weighted average price of 37 CAD/MWh). The Micro-Generation Regulation which provides the regulatory framework for behind-the-meter generation in the province was enhanced including an increase in the maximum system size permissible to 5 MW_{AC}. Several rebate programs were also rolled-out for installations including for residential and commercial consumers by a new agency established by the provincial government called Energy Efficiency Alberta in addition to programs for Indigenous communities and municipalities. The Alberta Utilities Commission (AUC), the province's utility sector and electricity market regulator, undertook an extensive regulatory proceeding to review the status and outlook of generation connected to the distribution system with a focus on projects larger than residential- and commercial-scale but smaller than utility-scale i.e. "community-scale". The year closed with the commissioning of the province's first utility-scale solar facility (15 MW_p) in the city of Brooks.

Rest of Canada: Throughout 2017, several other provinces and territories begun to accelerate their solar electricity activities. Funding from the Federal Government initiated several projects to displace the consumption of diesel fuel for electricity generation in northern and remote communities and it was announced that Nova Scotia would be launching a residential rebate program funded in part by the Federal Government's Low Carbon Economy Leadership Fund. The province of Quebec announced that they would pursue the development of a 100 MW solar facility. The province of Saskatchewan held their first competitive procurement for a 10 MW solar facility in support of their efforts to double their renewable electricity capacity to 50 % by 2030. Prince Edward Island commissioned one of Canada's largest solar-plus-storage facilities. The province of New Brunswick explored a solar leasing program in their rate case. The province of Manitoba introduced a rebate program for their consumers.

INDUSTRY STATUS

Canada's solar sector has experienced a continued significant increase in investments since 2009 when the province of Ontario's Green



Fig. 2 - Credit Union Place Smart Solar Storage System – 494 kW_p, Summerside, PEI.

Energy and Economy Act kick-started activity in Canada. Employment in PV-related areas in Canada has grown to a labour force approaching 10 000 in some years from an estimated 2 700 jobs in 2009. Annual capital investments have exceeded 1 BCAD.

MARKET

Total cumulative installed solar electricity generation capacity in Canada is approaching 3 000 MW_p. To date, more than 99 % has been in the province of Ontario. Outside Ontario, provinces phasing-out coal-fired electricity are expected to sharply increase demand for solar electricity.

FUTURE OUTLOOK

Closing the gap to 90 % non-emitting electricity by 2030 presents a significant opportunity for solar electricity to capture an increasing proportion of total electricity market share. A combination of falling costs, climate policy and consumer demand point to solar electricity continuing to grow in importance in Canada's electricity supply-mix year-on-year.

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CHILE

PV TECHNOLOGY STATUS AND PROSPECTS

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GENERAL FRAMEWORK AND IMPLEMENTATION

The Energy Policy of Chile [1] was built through a participatory process and published in December 2015. Its vision of the energy sector by 2050 is to be reliable, sustainable, inclusive, and competitive, in order to move towards sustainable energy in all its dimensions. In addition, it is built on four pillars: security and quality of supply (which aims for blackouts to not exceed one hour anywhere in the country); sustainable development (models of social participation in projects and lower average electricity prices that allow Chile to be among the five OECD countries with the lowest prices); having energy that is compatible with the environment (by 2050, it is expected that 70 % of electric power will come from renewable sources); and energy efficiency and education (energy culture at all levels of society).

Chile ratified the Paris Agreement in 2017 and it undertook to reduce its CO₂ emissions per GDP unit by 30 % below their 2007 levels by 2030. Additionally, and subject to the grant of international funds, the country is committed to reducing its CO₂ emissions up to a 35 % to 45 % reduction in relation to the 2007 levels. In both cases, future economic growth must allow for the implementation of adequate measures to fulfil this commitment.

The total installed power of photovoltaic solar plants as of December 2017 was 2 101 MW. During 2017, PV plants generated 2 441 GWh in the Central Interconnected Power System and 1 452 GWh in the North Interconnected Power System: a total of 5 % of the annual energy of both systems. Additionally, as of December 2017, 281 MW of photovoltaic plants are under construction and 13 400 MW with environmental impact studies approved in December 2017. See Figure 1.

PV distributed generation facilities declared in the last 13 months reached 7,98 MW with a concentration of more than 50 % of the facilities in the Atacama, Metropolitan, and Valparaíso regions. See Figure 2.

Total net installed capacity by technology

System	Power Capacity (MW)	%
SING	5 288	23.4%
SIC	17 115	75.8%
SEA	62	0.3%
SEM	104	0.4%
Subtotal	22 569	100%

Legend:

- Wind
- Diesel
- Coal
- Biomass
- Natural Gas
- Solar PV
- Run of the river
- Conventional dam hydro
- Mini run of the river
- Geothermal

Notes: SIC: Sistema Interconectado Central; SING: Sistema Interconectado Norte Grande; SEA: Sistema Eléctrico Aysén; SEM: Sistema Eléctrico Magallanes. Source: CDEC-SIC (Centro de Despacho Económico de Carga – Sistema Interconectado Central), CDEC-SING (Centro de Despacho Económico de Carga – Sistema Interconectado Norte Grande), CNE (National Energy Commission).

Fig. 1 – Total net installed capacity by technology, 2017 (Source: Ministry of Energy).

Evolution of installed and declared distributed generation power over the last 13 months

Month	Total declared power (kW)	Total accumulated last 13 months (kW)
Dec 2016	21	~100
Jan 2017	367	~200
Feb 2017	686	~300
Mar 2017	862	~400
Apr 2017	1 363	~500
May 2017	471	~600
Jun 2017	372	~700
Jul 2017	358	~800
Aug 2017	291	~900
Sept 2017	732	~1000
Oct 2017	713	~1100
Nov 2017	838	~1200
Dec 2017	391	7 984

Fig. 2 – Evolution of installed and declared distributed generation power over the last 13 months. Source: Superintendency of Electricity and Fuels (Source: Superintendency of Electricity and Fuels).

[1] <http://www.energia2050.cl/en/>



Fig. 3 - Large PV Plant. 141 MW Luz del Norte PV Plant (First Solar) located at Copiapó, Atacama Region, Chile.

NATIONAL PROGRAMME

The Ministry of Energy is responsible for developing and coordinating the different plans, policies, and rules for the development of the country's energy sector in a transparent and participatory manner, in order to ensure that all citizens have access to safe energy at a reasonable price. Created recently in 2010, today it is an autonomous body.

The Renewable Energy Division of the Ministry of Energy develops policies, plans, programmes, and standards of the national energy sector and its continuous improvement, with the purpose of promoting and incorporating different technologies and innovations regarding Non-Conventional Renewable Energies into the country's energy matrix.

The Prospective and Energy Policy Division focuses on generating energy information and intelligence to develop prospective capabilities that anticipate problems and solutions in the energy area, and is also responsible for developing a "Long-Term Energy Planning" process. This is reviewed every five years for the different energy scenarios of expansion of generation and consumption projected for thirty years, so that these scenarios are considered in the planning of the electric transmission systems carried out by the National Energy Commission. The results of the Long-Term Energy Planning delivered in December 2017 project a massive entry of solar generation systems, up to 13 GW of photovoltaic systems, and 8 GW of solar power concentration systems by 2046.

The National Energy Commission (CNE), under the Ministry of Energy, is the technical body responsible for analysing prices, tariffs, and standards the energy companies must achieve. Likewise, the CNE designs, coordinates and directs the bidding processes to provide energy to regulated customers. Utility companies have been making lower offers to this tender in recent years, from offers for a block of 1 200 GWh/year in 2015, with an average price of 79,3 USD/MWh, up to those observed in 2017, in which the block of 2 200 GWh/year was tendered to supply power in 2024, with an average price of 32,5 USD/MWh. It should be noted that in 2017, offers were submitted for 20,700 GWh, which is nine times more than what was requested.

R&D, D

The Solar Energy Research Centre (SERC Chile [2]) and Fraunhofer Chile Research Centre for Solar Energy Technologies (Fraunhofer CSET [3]) are the most relevant solar R&D organisations in Chile.

The SERC Chile, integrated by five Chilean universities, has gone to phase two following five years of execution, and brings together the largest scientific production in solar energy in the country.

Fraunhofer CSET aims to support a solar economy in Chile. It provides consultancy for industry and public stakeholders, and together with the industry, develops innovative technical solutions to achieve large-scale implementation of solar energy in the main industrial, commercial, and residential sectors in Chile.

Nevertheless, the innovation ecosystem in Chile has very limited capacities for technological development and industrial scaling in relevant technological areas for the productive development of the country. Most of the public resources are preferably allocated to fundamental science and advanced human capital formation with an orientation towards scientific research. Private investment in R&D is 0,13 % of the GDP (representing 1/3 of the total), the lowest among OECD countries, while university-industry collaboration is weak, making it also the lowest among OECD countries.

Within the framework of the Productive Transformation Policy, and in coordination with the guidelines for Science, Technology, and Innovation, CORFO is promoting the creation of National Technological Institutes in strategic areas. Its purpose is to strengthen national capacities to carry out applied research, development, transfer, and diffusion of technologies and innovation in specific production areas and services of relevance to Chile, to generate information for public interest, as well as prepare certification standards and systems as a means of promoting innovation, productivity, and competitiveness of the country.

The Solar Mining Technology Institute (SMTI) was designed in 2017 to catalyse the development, scale-up, and adoption of technological solutions based on solar energy in mining and related industries,

[2] <http://sercchile.cl/en/>

[3] <http://www.fraunhofer.cl/es/cset.html>



Fig. 4 – Outdoor PV Testing Facility, Solar Platform of Atacama Desert (PSDA), University of Antofagasta, Antofagasta Please let me know which size is acceptable Region, Chile.

through a dedicated, autonomous, and flexible public-private institution, jointly with national and international networks.

The most advanced research line of SMTI is the Atacama Module System Technology Centre (AtaMoSTeC), which took on the challenge of developing photovoltaic systems for the high radiation conditions of the Atacama Desert at a levelized cost of energy of 25 USD/MWh. AtaMoSTeC is a technological programme with CORFO's co-financing for 12 MUSD and began its execution in December 2017. The consortium is responsible for its execution and contributes 5 MUSD. It is managed by the University of Antofagasta and sees the participation of the companies Colbún, Mondragón, and CINTAC, along with 15 small national companies entering the market of goods and services for the solar industry.

INDUSTRY AND MARKET DEVELOPMENT

The Committee for the Development of the Solar Energy Industry (Solar Committee) was created by the Board of the Chilean Economic Development Agency (CORFO), with the objective of developing the solar industry in Chile. Its main objective is the execution of the Energy Solar Program, which was launched in September 2016. The mission of the Solar Committee is to promote the development of a national solar energy industry through the design and implementation of projects that, in collaboration with a network of national and international actors, increase competitiveness, productivity, technological capabilities, and markets of companies in the sector, by taking advantage of the exceptional solar resource of the Atacama Desert to create new wealth for Chile.

The Roadmap for Solar Energy was built in 2015 through a participatory process with more than 150 people from private companies, the public sector, research centres, academia, and NGOs.



Fig. 5 - PV Cleaning System. 160 MW Finis Terrae PV Plant (ENEL Green Power) located at María Elena, Antofagasta Region, Chile.

In 2017, the Roadmap was expanded, considering the new challenges currently facing the solar industry in Chile.

The Solar Committee is the specialised technical counterpart of the Government of Chile and is in a key position to remove barriers to develop a profound and high quality national solar industry.

CHINA

PV TECHNOLOGY AND PROSPECTS

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LV FANG, INSTITUTE OF ELECTRICAL ENGINEERING, CHINESE ACADEMY OF SCIENCE

WANG SICHENG, ENERGY RESEARCH INSTITUTE, CHINA NATIONAL DEVELOPMENT AND REFORM COMMISSION



Fig. 1 - PV Home Systems, Yudu, Jiangxi.

GENERAL FRAMEWORK

On December 19, 2017, the National Development and Reform Commission issued the new PV Feed-in Tariff for 2018 (NDRC [2017] No. 2196). The details of PV FIT are shown below:

TABLE 1 – NEW FITs FROM 2018

SOLAR RESOURCES	FIT FOR PV PLANTS (CNY/KWH)
I	0,55
II	0,65
III	0,75
SUBSIDY FOR SELF-CONSUMPTION (CNY/KWH)	
Self-consumed	Excess PV electricity Feed-Back to Grid
Grid Retail Price +0,37	Wholesale Coal-Fire Tariff + 0,37

Source: NDRC

NDRC also announced in the Tariff Document, the FIT of PV will be regulated every year and for the projects, the FIT are set by bidding; the tariff level should be never higher than the published level. For self-consumed PV projects, the subsidy level is kept the same as before.

The subsidy money is come from surcharge. The surcharge level is 1,9 USDcents/kWh. By this surcharge, about 60 BCNY (about 10 BUSD) can be collected every year to subsidize PV, wind and biomass power.

NATIONAL PROGRAM

13th Five-Year PV Plan (2016–2020)

On July 19, 2017, the National Energy Administration (NEA) issued the "Implementation Guideline for the 13th Five-year Plan of Renewable Energy" (NEA [2017] No. 31) and issued the PV quota for 2017 – 2020:

- 1) The 2017-2020 total PV quota is 86,5 GW, including 32 GW of the Top Runner Program (8 GW per year);
- 2) There is no quota control for distributed PV, including: PV on buildings, self-consumed PV, home PV systems, etc. 60 GW of distributed PV is estimated by the year 2020;
- 3) For Beijing, Tianjin, Shanghai, Chongqing, Tibet, Hainan and Fujian, there is no quota control for PV installation. There is at least 10 GW for the Seven Cities and Provinces;
- 4) 15 GW for PV Poverty Alleviation before 2020.
- 5) 78 GW of PV already installed before 2017. Thus, the total cumulative PV installation will be about 250 GW by 2020 (78 + 86,5 + 60 + 10 + 15 =249,5 GW).

PV Poverty Alleviation Plan

By the end of 2016, there were 20 million families with 70,17 million people living under the poverty level (annual income is less than 2 300 CNY per person; about \$1 USD per day per person) in China. Three million poor families will be funded by government to build 5 kW PV for each family. Each of these families will then earn at least 3 000 CNY each year by selling PV electricity to grid. In this way, the poor families will earn money and PV market will expand. 15 GW of PV will be installed before 2020 for poverty alleviation.

Subsidy Money Shortage and Curtailment Problems

In China, the PV and wind power market is growing fast with the annual installation standing at number one in the world and huge subsidy funding is required. Every year, the subsidy funding for wind and PV generation is about 100 BCNY, but only 60 BCNY can be collected from surcharge (1,9 USDcents/kWh). By the end of 2017, the total shortage of subsidy funding reached 100 BCNY (recently announced by NEA). To solve this problem, the Renewables Portfolio Standards (RPS) and "Green Certificate" system will be implemented to expand the RE market and to collect enough funds from selling "Green Certificates," to support green electricity and to fulfill the gap of subsidy funding.

For the PV curtailment problem in western China, the Chinese government announced on November 8, 2017 (NEA [2017] No.1942), curtailment of PV in Xinjiang and Gansu will be controlled within 20 % by 2020, and in other western provinces the PV curtailment will be controlled within 10 % and less than 5 % for the whole of China.

RESEARCH & DEVELOPMENT (R&D)

Top Runner Plan

The "PV Top Runner Plan" started in 2015; with the total installed PV capacity for the 1st and 2nd phases at 6,5 GW. The 3rd phase Top Runner Plan was approved on September 22, 2017 and the total capacity is 6,5 GW (5 GW for Top Runner and 1,5 GW for Super Top Runner). The specification requirements are listed below:

TABLE 2 – TOP RUNNER SPECIFICATIONS

TYPE	MULTI-SI	MONO-SI
Size of Cells (mm)	156*156	156*156
Module Cell Number	60	60
MARKET ENTRY SPECIFICATIONS		
Module Efficiency	16,0 %	16,8 %
Module Power (Wp)	265	275
TOP-RUNNER SPECIFICATIONS		
Module Efficiency	17,0 %	17,8 %
Module Power (Wp)	280	295
SUPER TOP RUNNER SPECIFICATIONS		
Module Efficiency	20,0 %	21,50 %
Module Power (Wp)	295	310

Source: NEA

Stimulated by the "Top Runner Plan", PV technologies are making great progress and the module efficiency at the industry level is increasing a lot. Mass production has been achieved for high-efficiency, even super-high-efficiency technologies:

TABLE 3 – CAPACITY FOR HIGH-EFFICIENCY TECHNOLOGY

TECHNOLOGY	MANUFACTURE CAPACITY (MW)
P-PERC	20 000,0
N-PERT	2 000,0
HJT	500,0
IBC	100,0
MWT	1 000,0
Bifacial Modules	10 000,0

Source: CPVS

Highest Cell & Module Efficiencies

Table 4 shows the highest laboratory (Lab.) level cell efficiencies in China for various type of PV cells. In Table 5, the industry level's highest cell and module efficiencies are provided.

TABLE 4 – LAB. LEVEL CELL EFFICIENCY

NO.	TECHNOLOGY	LAB. LEVEL CELL EFFICIENCY (%)	AREA (CM ²)
1	P-PERC	21,3±0,4	242,74
2	N-PERT	22,3±0,5	156,26
3	IBC	25,04	243,2
4	HJT	23,2	242,70
5	GaAs (1-Junction)	28,8±0,9	1,00
6	GaAs (2-Junction)	31,6±1,9	1,00
7	GaAs (3-Junction)	34,5±4	1,002
8	CIGS	21,0	1,00
9	CdTe	17,8	Lab.
10	Perovskite	16,0±0,4	16,29

1. Trina Solar 2. Trina Solar 3. Trina Solar 4. SIMIT
5. Hanergy 6. Hanergy 7. DerongTech 8. Hanergy
9. CNBM 10. Microquanta

Source: CPVS

TABLE 5 – INDUSTRY LEVEL CELL & MODULE EFFICIENCY

NO.	TYPE	TECH.	CELL EFF. (%)	MOD. EFF. (%)
1	P-Poly-Si	PERC	21,25	19,86
2	P-Mono-Si	PERC	23,26	20,41
3	N-Mono-Si	N-PERT	21,50	19,00
4	P-Poly-Si	MWT	19,60	17,50
5	N-Mono	HJT	21,20	19,00
6		CdTe		14,50
7		CIGS		17,52

1. Trina Solar 2. Longi 3. Jolywood 4. Sunport
5. GS Solar 6. CNBM 7. Hanergy

Source: CPVS

INDUSTRY AND MARKET DEVELOPMENT

PV Industry in China

China has been the largest producer of PV modules in the world since 2007. In 2017, China was also the top country in the world for PV production.

TABLE 6 – PRODUCTION OF PV CHAIN (2015-2017)

YEAR	2015	2016	2017
Poly-Silicon (10 ³ Ton)	165,00	194,00	242,00
Silicon Wafer (GW)	48,00	64,80	87,60
PV Cells (GW)	41,00	51,00	68,00
PV Modules (GW)	43,90	53,00	76,00

Source: CPIA

PV Market Development

In 2017, the PV market in China was booming with total installation reaching 53,06 GW! It is also worthwhile to indicate that the distributed PV was growing very fast in 2017, especially the home PV systems, with 500 000 sets being installed.

TABLE 7 – PV INSTALLATION BY SECTORS IN 2017

MARKET SECTOR	ANNUAL (MWP)	CUMULATIVE (MWP)	SHARE (%)
Off-Grid		360	0,28
Distributed	20 000	30 290	23,11
Power Plant	33 000	100 430	76,62
Total	53 000	131 080	100,00

Source: CPIA

During last decade, the cost of PV in China has been reduced sharply. It is estimated that PV priceS will reach grid-parity on the user-side by 2020 and reach grid-parity on the generating-side, at the most, by 2025.

During the last decade, the cost of PV in China has been reduced sharply. It is estimated that the PV price will reach grid-parity on the user-side by 2020 and reach grid-parity on the generating side, at most, by the 2025.

TABLE 8 – PV PRICE AND FIT (2015-2018)

YEAR	2015	2016	2017	2018 (E)
Cumulative (GWp)	43,4	78,1	130,0	180,0
Module Price (CNY/Wp)	3,50	3,10	3,00	2,50
System Price (CNY/Wp)	7,50	7,00	6,80	6,00
PV FEED-IN TARIFF (CNY/KWH) NDRC				
Solar Zone	2015	2016	2017	2018
I	0,90	0,80	0,65	0,55
II	0,95	0,88	0,75	0,65
III	1,00	0,98	0,85	0,75

Source: CPVS and NDRC

Abbreviations used above:

NDRC: National Development and Reform Commission

NEA: National Energy Administration

CPIA: China PV Industry Association

CPVS: China PV Society

COPPER ALLIANCE

THE COPPER ALLIANCE'S ACTIVITIES

FERNANDO NUNO, PROJECT MANAGER, EUROPEAN COPPER INSTITUTE



Fig. 1 - Calama Solar 3. This 1 MW power plant provides electricity to the industrial facilities of División Chuquicamata (the largest open-pit copper mine in the world).



Fig. 2 - Calama Solar 3. The excellent local radiation conditions, in combination with the one-axis tracking systems, makes this 1 MW plant to deliver an outstanding annual generation of 2900 MWh (data April 2012 - March 2013).

Copper Alliance is supported by 43 industry members, active in various stages of the copper value chain. Through its market development program, Copper Alliance promotes copper applications to multiple target audiences. Its policy, advocacy, education and partnership initiatives are designed to translate copper's excellent technical properties into user benefits and added-value. Considering the strong linkages between carbon reduction and copper use, Copper Alliance aims to accelerate the energy transition through its Leonardo ENERGY initiative.

SUSTAINABLE ENERGY

Leonardo ENERGY (LE) actively supports a low carbon economy by facilitating knowledge and technology transfer, as well as promoting good practices in both engineering and policy making. LE runs innovative and targeted campaigns on a broad portfolio of copper-intensive technologies. They are designed to contribute significantly to energy sustainability in key areas such as building automation and controls, high efficiency motor systems, industrial demand-side management, etc.

Since copper is the material that integrates many diverse solutions in electricity systems, LE develops and executes strategic initiatives in the field of renewable energy such as:

- Analysis of how to improve the inherent flexibility of the electricity system and enhance its ability to cope with variable electricity production in preparation for near 100 % renewable electricity;
- Promotion of industrial demand side management (facilitating the integration of massive renewables in the grid);
- Capacity building and knowledge transfer on best practices on renewables through application notes, webinars and e-learning programs;
- Development of strategies for green corporate sourcing for industry.

PV RELATED ACTIVITIES

Copper Alliance supports PV development through various streams:

- Policy advocacy, notably in the context of the Clean Energy reform in Europe, currently going on;
- In-depth market intelligence reports;
- Regular and active involvement in standardization activities at the IEC level;
- Advocacy on new business models for PV. For example, Copper Alliance supports the design of economically sustainable incentive schemes for PV through the grid parity monitor (www.leonardo-energy.org/photovoltaic-grid-parity-monitor), which also contributes to improving public acceptance.
- Training engineers and policy makers on facilitating, designing, installing and operating PV systems.

COPPER ALLIANCE INVOLVEMENT IN IEA PVPS ACTIVITIES

Copper Alliance actively participates in the IEA PVPS ExCo meetings and Task 1 activities. In addition to the publication of IEA PVPS reports and summaries on the Leonardo ENERGY website, Copper Alliance successfully held three webinars (PV technical training, PV module failures in the field and PV financial models) in 2017, reaching an audience of about 600 energy professionals.

ABOUT COPPER ALLIANCE

Headquartered in New York, NY, USA, the organization has divisions in Asia, Europe and Africa, Latin America, and North America. It incorporates a network of regional offices and copper promotion centers in nearly 60 countries, which propagate the Copper Alliance™ brand and are responsible for program development and implementation, in close cooperation with their partners. Through this international network, Copper Alliance has built up a comprehensive resource of approximately 500 program partners from all over the world.

DENMARK

PV TECHNOLOGY STATUS AND PROSPECTS

FLEMMING KRISTENSEN, ENIIG LTD., DENMARK

PETER AHM, PA ENERGY LTD., DENMARK

GENERAL FRAMEWORK

The Danish government launched its energy plan called Our Energy In November 2011 with the vision of a fossil free energy supply by 2050 and interim targets for energy efficiency and renewable energy by 2020 and 2035, e.g. 50 % of the electricity shall come from wind turbines by 2020. The energy plan was finally agreed upon in March 2012 by a broad coalition of parties in- and outside the government. The plan, which reaches up to 2020, was further detailed in the government's energy statements. In the latest PV relevant statements of September - October 2017 a new support model has been agreed upon for the promotion of renewable energy (RE), in particular PV and wind. The model is based on so called technology neutral tenders, initially for the years 2018 and 2019. The tenders will be launched with a defined public economic support ceiling, and interested stakeholders can submit their bids. The bids with the lowest cost per kWh produced and exhibiting a solid base will win. The aim is to get as much RE energy for the public money as possible, leaving the market to decide technology within some framework conditions. With regard to RE, the plan sets a target for the overall contribution from RE by 2050, but the previous in-between targets leading up to 2050 are no longer in the plan. A new energy plan covering 2020 - 2030 is under development by the government and is expected to be politically treated during 2018.

Renewable energy is very much a present and considerable element in the energy supply: by the end of 2017, more than 45 % of the national electricity consumption was generated by renewable energy sources including incineration of waste. Ongoing research, development and demonstration of new energy solutions including renewable energy sources have in principle high priority in the energy plan, however, the amount of R&D funding allocated to RE has been reduced. Renewable energy technologies, in particular wind, play an important role with PV still seen as a minor option suffering from go-stop political interventions; preventing a stable market development despite a proven growing degree of competitiveness.

Regions and municipalities are playing an increasingly more active role in the deployment of PV as an integral element in their respective climate and energy goals and plans, and these organisations are expected to play a key role in the future deployment of PV in the country. However, existing regulations for municipal activities have been found to present serious barriers for municipal PV, and several municipalities have presently reduced or stopped PV deployment.

NATIONAL PROGRAM AND IMPLEMENTATION

Denmark has no unified national PV programme, but during 2017 a number of projects supported mainly by the Danish Energy Authority's EUDP programme, and some additional technology oriented support programmes targeted R&D in the field of green electricity producing technologies, including a few PV projects.

Net-metering for privately owned and institutional PV systems was established in mid-1998 for a pilot-period of four years. In late 2002, the net-metering scheme was extended another four years up to end of 2006. Net-metering has proved to be a cheap, easy to administrate and effective way of stimulating the deployment of PV in Denmark; however the relative short time window of the arrangement was found to prevent it from reaching its full potential. During the political



Fig. 1 - PV/T Energy Day at Stenløse Football Club: The innovative "Hercules energy roof" with efficiency exceeding 50 %, was developed and produced by RACELL A/S for the Stenløse club building. The old worn-out and leaking roof was replaced by the new water-tight solar roof. The 7,5 m² self-bearing light-weight Hercules modules were fixed directly on-top of the wooden battens, thus the installation took 2 days only. The hybrid PVT roof has a capacity of 520 W/m² (electricity 180 W_p/m² and heat energy 340 W_p/m²). The total south roof area is 180 m². The project was supported by the Danish Energy Agency EUDP (Photo: RACELL).

negotiations in the fall of 2005, the net-metering for privately owned PV systems was consequently made permanent, and net-metering - during 2012 at a level of approx. 0,30 EURcents /kWh. This was primarily due to various taxes - combined with dropping PV system prices, which proved in 2012 to be able to stimulate PV deployment seriously, as the installed grid connected capacity during 2012 grew from about 13 MW to approx. 380 MW, a growth rate of about 30 times. For PV systems qualifying to the net-metering scheme, grid-parity was reached in 2012 for the sector of private households.

This dramatic grow gave rise to political debate towards the end of 2012, and the government announced a revision of the net-metering scheme inter alia reducing the net-metering time window from one year to one hour. During the first half of 2013, a series of new regulations were agreed to politically; this because the consequences of the new regulations were not fully clear to the decision makers at time of decision and follow up measures were found to be necessary. By June 2013, the new regulations were finally in place including transitory regulations, effectively putting a cap on future PV installations under the net-metering scheme in terms of an overall maximum installed capacity of 800 MW by 2020. For municipal PV installations the cap was set at an additional 20 MW by 2020. In 2016, PV was summarily excluded from the long existing standard FIT for both wind and PV set at 0,60 DKK/kWh (8,05 EURcents) for the first 10 years and 0,40 DKK/kWh (5,4 EURcents) for the following 10 years.

Since 2016, an additional result of Denmark harmonizing its support mechanisms for RE and PV produced electricity to EU state aid regulations has been shared German-Danish auction schemes for large scale PV, meaning that under certain limitations German developers could enter bids for German located PV plants under the Danish auction and vice versa. Danish developers succeeded in both the

German 2016 auction of 50 MW and the Danish one of 20 MW; the winning bids were around 0,40 DKK/kWh (€c 5,4/kWh) and thus very close to the lowest ever Danish off-shore wind price of 0,375 DKK/kWh at the 600 MW Kriegers Flak. Consequent PV bids have been even a bit lower.

The above mentioned market uncertainties combined with reduced R&D funding has effectively put the PV market on hold in 2017. Only about 60 MW [1] installed capacity was added leading to a total installed capacity of just above 900 MW by end of 2017. The amount of PV installations not applying for the additional support but operating in the economic attractive "self consumption mode" appears to be growing, but no firm data is available yet.

The main potential for deployment of photovoltaics in Denmark has been identified as building applied or integrated systems. However, during 2015 a few ground based centralised PV systems in the range of 50 to 70 MW have been commissioned and later extended.

The Danish Energy Agency commissioned a revision of the national PV Strategy in 2015; the revision, which was carried out in consultation with a broad range of stakeholders including the Danish PV Association, was completed in the first half of 2016 and can be found on the Danish Energy Agency's website; however, the revised strategy has not received any official recognition.

In early 2016, the Danish Energy Agency forecasted PV to reach 1,75 GW by 2020 (5 % of power consumption) and more than 3 GW by 2025 (8 % of power consumption). These figures are part of a periodically revised general energy sector forecast, the so called Energy Catalogue. So far, there seems to be little if any political impact from these forecasts.

RESEARCH AND DEVELOPMENT

R&D efforts are concentrated on silicon processing, crystalline Si cells and modules, polymer cells and modules and power electronics. R&D efforts exhibit commercial results in terms of export, in particular for electronics, but also for other custom made components.

Penetration and high penetration of photovoltaics in grid systems are, as a limited effort, being researched and verified by small demonstrations, and network codes are reported to be under revision to accommodate a high penetration of inverter-based decentral generation and to conform to the EU wide harmonisation under development in Entso-E/EC. The Danish TSO has published a study indicating that up to 7,5 GW PV can be accommodated in the national grid system without serious problems; 7,5 GW PV will correspond to about 20 % of the national electricity consumption.

As mentioned above, R&D funding for renewables and photovoltaics appears to exhibit lower political priority after 2016.

INDUSTRY AND MARKET DEVELOPMENT

A Danish PV Association (Dansk Solcelleforening) was established in late 2008. With some 75 members, the association has provided the emerging PV industry with a single voice and is introducing ethical guidelines for its members. The association has formulated a strategy



Fig. 2 - PV Solar Systems at the Regional Hospital in Viborg: A total of 280 kWh has been installed on 5 roof and area covering app. 10 % of the annual consumption at the hospital (Photo: Kenergy, Kenn H. B. Frederiksen).

aiming at 5 % of the electricity for private households coming from PV by 2020, but is now revising this target, although being hampered in the process by the regulatory uncertainties. The association played a key role in the previously mentioned revision of the national PV Strategy and has initiated a national PV/solar energy conference to be held in January 2018, highlighting the possible role of PV/solar energy in the future energy system.

A few PV companies producing tailor-made modules such as window-integrated PV cells can be found.

There is no significant PV relevant battery manufacturing in Denmark at present although a Li-Ion battery manufacturer has shown interest in the PV market.

A few companies develop and produce power electronics for PVs, mainly for stand-alone systems for the remote-professional market sector such as telecoms, navigational aids, vaccine refrigeration and telemetry.

A number of companies are acting as PV system integrators, designing and supplying PV systems to the home market. With the rapidly expanding market in 2012, the number of market actors increased fast, but since 2013, most start-ups have disappeared again.

Danish investors have entered the PV scene acting as holding companies, e.g. for cell/module manufacturing in China and the EU, as well as acting as international PV developers.

Consultant engineering companies specializing in PV application in emerging markets report a slowly growing business volume.

The total PV business volume in 2017 is very difficult to estimate with any degree of accuracy due to the small market of around 60 MW and to the commercial secrecy of the PV sector both domestically and internationally. The cumulative installed PV capacity in Denmark (including Greenland) by end of 2017 is estimated at a bit more than 900 MW.

FUTURE OUTLOOK

The present liberal government has announced the intention to keep the present level of the annual government funds allocated to R&D into energy and renewable with slight increases indicated, and has shown little interest in PV as such. However, the before mentioned technology neutral auction/tendering scheme to be launched in 2018 may provide new opportunities for PV. The upcoming energy plan covering 2020 – 2030 is hoped to provide new opportunities for PV as well. The emerging market sector of PV installations for own consumption appears to be growing, however there is little firm data on this relative new sub-market.

[1] The official Danish statistics on grid connected PV was transferred from Energinet.dk (the TSO) to the Danish Energy Agency (the government) by end 2017. This left some uncertainties, and the figure of about 60 MW is thus the authors best estimate based on available data.

EUROPEAN COMMISSION

SUPPORT TO RESEARCH, DEVELOPMENT AND DEMONSTRATION ACTIVITIES ON PHOTOVOLTAICS AT EUROPEAN UNION LEVEL
 FABIO BELLONI, EUROPEAN COMMISSION, DIRECTORATE-GENERAL FOR RESEARCH AND INNOVATION
 PIETRO MENNA, EUROPEAN COMMISSION, DIRECTORATE-GENERAL FOR ENERGY

THE EUROPEAN ENERGY POLICY FRAMEWORK

The Energy Union sets out a strategy for making energy more secure, affordable and sustainable in the EU Countries. It facilitates the free flow of energy across borders and improves the secure supply in every EU country. New technologies and renewed infrastructure will contribute to cutting household bills and creating new jobs and skills, as companies expand exports and boost growth. It will lead to a sustainable, low carbon and environmentally friendly economy, putting Europe at the forefront of renewable energy production, clean energy technologies, and the fight against global warming. The Energy Union is made up of five closely related and mutually reinforcing dimensions: security, solidarity and trust: diversifying Europe's sources of energy and ensuring energy security through solidarity and cooperation between EU countries; a fully integrated internal energy market: enabling the free flow of energy through the EU through adequate infrastructure and without technical or regulatory barriers; energy efficiency: improved energy efficiency will reduce dependence on energy imports, lower emissions, and drive jobs and growth; decarbonising the economy; research, innovation and competitiveness: supporting breakthroughs in low-carbon and clean energy technologies by prioritising research and innovation to drive the energy transition and improve competitiveness. Since the Energy Union strategy was launched in February 2015, the Commission has published several packages of measures to ensure the Energy Union is achieved. The Commission also publishes regular reports on the progress of the Energy Union, the most recent in November 2017 [1].

DEPLOYMENT

The annual maximum deployment of PV installations in Europe was reached in the year 2011, when more than 22 GW were installed. After that year, we have observed more of a reduction in annual installations. Different reasons (phasing out of support schemes, restricted access to credit, introduction of caps, and retroactive changes) might have contributed to reduce the demand. The PV power installation of 6,7 GW in 2016 brought the cumulative PV capacity to surpass the symbolic 100 GW threshold. Considering that the total power installed worldwide in 2016 is reported at 76,6 GW, the European market share is less than 9 % of the global market, which represents a dramatic decline from the 72 % market share recorded in the year 2011.

The cumulated PV capacity installed in some EU countries is reported in Figure 1.

Nevertheless, solar is now supplying, on average, nearly 4 % of electricity demand in Europe. Italy, Greece and Germany are producing each more than 7 % of their electricity demand by solar power.

RESEARCH AND DEMONSTRATION PROGRAMME Horizon 2020 – The EU Framework Programme for the years from 2014 to 2020

Horizon 2020, the EU framework programme for research and innovation for the period 2014–2020, is structured along three strategic objectives: 'Excellent science', 'Industrial leadership', and 'Societal challenges' [3].

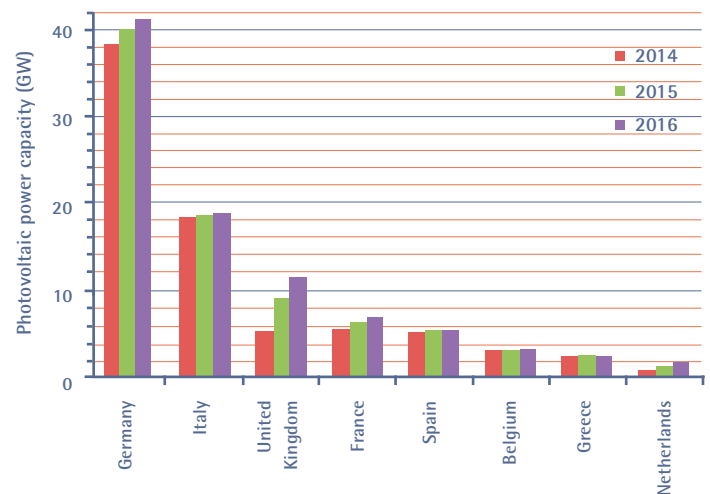


Fig. 1 – Cumulative installed photovoltaic capacity in some EU countries [2].

A view of the budget which is currently being invested overall on photovoltaics, under different Horizon 2020 activities, is provided in Figure 2.

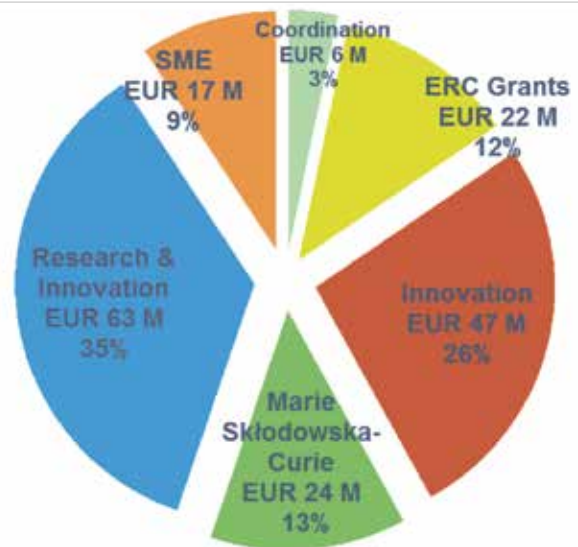


Fig. 2 – Ongoing photovoltaic activities funded under Horizon 2020.

A total EU financial contribution of about EUR 179 million is being invested, under H2020, on activities which are related to photovoltaics. This contribution is mostly spent for research and innovation actions (35%), innovation actions (26%) and grants to researchers provided by the European Research Council (12%). Fellowships, provided under Marie Skłodowska-Curie actions, absorb 13 % while actions for SME are at 9 % of the overall investment. Coordination actions, such as ERA-NET, represent 3 % of the budget.

SET-PLAN ACTIONS AND INITIATIVES

From January until November 2017, an intense collaborative process took place between 11 SET Plan countries (Cyprus, Belgium – Walloon region, Belgium – Flemish region, Estonia, France, Germany, Italy, Norway, the Netherlands, Turkey and Spain), that led to the drafting of the PV Implementation Plan (IP) [4], concerning actions needed to achieve the ambitious targets set out in the Declaration of Intent (DoI) on PV [5]. Discussions were held within an ad hoc Temporary Working Group (TWG), co-chaired by Germany and the European Technology and Innovation Platform for Photovoltaics (ETIP PV) [6]. Fifteen representatives of the ETIP PV, industry and research institutions were also part of the TWG. The European Commission, represented by the Directorate-General for Research and Innovation, the Directorate-General for Energy and the Joint Research Centre, participated throughout this process as a facilitator, also providing guidance. The PV IP was officially endorsed by the SET-Plan Steering Group on 16 November.

The PV IP addresses the research and innovation (R&I) activities required to deliver the agreed targets listed under the DoI, that is: to advance the efficiency of established technologies (crystalline silicon and thin films) and new concepts; to reduce the cost of key technologies; to enhance lifetime, quality and sustainability, hence improving environmental performance, of PV modules; to enable mass realization of "(near) Zero Energy Buildings" (NZEB) by Building-Integrated PV (BIPV), through the establishment of structural collaborative innovation efforts between the PV sector and key sectors from the building industry; to advance manufacturing, installation and maintenance of PV modules.

The TWG elaborated a set of 6 technology-related priority activities for the future development of PV technologies and applications in Europe:

- 1) PV for BIPV and similar applications,
- 2) Technologies for silicon solar cells and modules with higher quality,
- 3) New technologies and materials,
- 4) Development of PV power plants and diagnostics,
- 5) Manufacturing technologies (for cSi and thin films),
- 6) Cross-sectoral research at lower TRL.

For each priority, ongoing R&I actions (conducted at national and/or at European level and/or by industry) have been identified which already support the DoI strategic targets. Additional R&I actions are considered important as the global PV industry is developing rapidly, on both the grounds of technology and economics. The IP also identifies Flagship activities. Actions are envisaged to be mainly supported at national level (national, public and private funding). For those actions or elements of actions where EU added value is justified, funding at the EU level is considered/identified.

Across the proposed actions, the overall volume of investment to be mobilised has so far been identified as broadly EUR 530 million, with the main contribution expected from the SET Plan countries involved,

then from industry, and finally from the H2020 Framework Programme. Some of the actions are already running.

With the production of the IP and after its endorsement by the SET Plan Steering Group, the mission of the PV TWG is completed. A new structure needed for the effective execution of the IP is expected to be put in place. The European Commission intends to facilitate this process through a Coordination and Support Action (CSA) [7].

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FINLAND

PV TECHNOLOGY STATUS AND PROSPECTS

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Fig. 1 - The head office of PAF Oy in Mariehamn in Åland (Photo: Naps Solar Systems Oy).



Fig. 2 - LUT two-axis solar PV tracker (Photo: Lappeenranta University of Technology).

GENERAL FRAMEWORK AND IMPLEMENTATION

A long-term objective of Finland is to be a carbon-neutral society. In 2014, a national roadmap was published with the aim of finding means to achieve 80–95 % greenhouse gas reductions from the 1990 level by 2050. In the energy sector, the challenge of transformation is particularly great. Approximately three-quarters of all greenhouse gas emissions in Finland come from power generation and direct energy consumption, when energy use of transportation is included.

NATIONAL PROGRAMME

So far there is no specific national strategy nor objectives for photovoltaic power generation in Finland. Instead, the solar PV is mainly considered an energy technology that can be used to enhance the energy efficiency of buildings by producing electricity for self-consumption. However, it is becoming widely accepted that PV will be one of the least-cost power generation technologies also in Finland. To support PV installations, the Ministry of Economic Affairs and Employment has granted investment subsidies to renewable energy production. The support is only intended for companies, communities and public organizations, and it will be provisioned based on applications. Thus far, the subsidy level has been 25 % of the total project costs. Agricultural companies are also eligible to apply an investment subsidy of 40 % for PV installations from the Agency of Rural Affairs. Individual persons are able to get a tax credit for the work cost component of the PV system installation. The sum is 45 % of the total work cost including taxes resulting up about 10–15 % of total system costs.

R&D

In Finland, the R&D activities on solar PV are spread out over a wide array of universities. Academic applied research related to solar systems, grid integration, power electronics and condition monitoring is conducted at Aalto University, Lappeenranta University of Technology and Tampere University of Technology as well as at Metropolia, Satakunta and Turku Universities of Applied Sciences. There is also active research on silicon solar cells at Aalto

University, on high-efficiency multi-junction solar cells based on III-V semiconductors at Tampere University of Technology, and on roll-to-roll printing or coating processes for photovoltaics at VTT Technical Research Centre of Finland. In addition, there are research groups working on dye-sensitized solar cell (DSSC), organic photovoltaic (OPV) and atomic layer deposition (ALD) technologies at Aalto University and the Universities of Helsinki and Jyväskylä.

The research work in universities is mainly funded by the Academy of Finland and Tekes (today: Business Finland), which also finances company-driven development and demonstration projects. In Finland, there are no specific budget lines, allocations or programs for solar energy R&D&I, but PV is funded as part of open energy research programs. In 2017, Tekes' public research and development funding for solar energy was round 4 MEUR.

INDUSTRY AND MARKET DEVELOPMENT

For a long time, the Finnish PV market has been dominated by small off-grid systems. There are more than half a million holiday homes in Finland, a significant proportion of which are powered by off-grid PV systems capable of providing energy for lighting, refrigeration and consumer electronics. Since 2010, the number of grid-connected PV systems has gradually increased. Presently, the market of grid-connected systems heavily outnumbers the market of off-grid systems. The grid-connected PV systems are mainly roof-mounted installations on public and commercial premises and in private dwellings. The first multi-megawatt utility PV plant, with the total power of 6 MW, will be built in Finland during years 2017–2018 in Nurmo. By the end of 2017, the installed grid-connected solar PV capacity was estimated to be approximately 50 MW.

FRANCE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

CELINE MEHL AND PAUL KAAIJK, FRENCH ENVIRONMENT AND ENERGY MANAGEMENT AGENCY (ADEME)

MELODIE DELEPINE, HESPUL



Fig. 1 - 1,8 MW on Eaux de Paris reservoirs at L'Hay-les-Roses that supply the city of Paris with drinking water (Photo: Studio VU - SOPREMA Entreprises).

GENERAL FRAMEWORK AND IMPLEMENTATION

Opinion polls in 2017 showed French citizens have an overwhelming preference for self-consumption when contemplating investing in photovoltaics, a preference that was mirrored by the increasingly high proportion of grid requests including self-consumption in the residential market for systems under 3 kW (more than 80 % of grid connection requests under 3 kW in the 4th quarter). It was also reflected in the active participation of industry actors in the public consultation held by the Energy Regulation Commission (CRE) regarding the place and framework of self-consumption in the national energy policy. Fiscal rules and grid access costs were focal points.

The year saw several modifications to the national photovoltaics framework, including the publication of new Feed-in tariffs and conditions for systems under 100 kW, signalling a move away from the "all BIPV" previous FiT conditions, although ground-based systems continue to be excluded. Specific and separate texts were published for continental France and overseas territories, with tariffs adapted to local irradiance and system costs. The much-anticipated application decree concerning grid access and regulatory considerations for individual and collective self-consumption was published, as well as commissioning certification requirements and minimal installer qualifications for all RES systems. A reduction in the direct cost of grid connection for RES systems under 5 MW was announced in February and implemented in December, with part of the upfront connection costs being integrated into annual access charges, thus improving the economic accessibility of grid connection.

With reduced volumes being commissioned through 2017, and a risk that France would not meet its own Energy Programme Decree (PPE) target for photovoltaics, the Call for Tenders capacity was increased to 2,5 GW (up from 1,5 GW) in December, coming into force in 2018, with proportionally more volume for the largest systems. At the same time, the Tender specifications were made more stringent with regards to citizen and public authority investment tariff bonuses, reflecting the high value placed on mobilising citizen and public capital investment by the government.

In 2018 more experimental collective self-consumption systems are expected and clarification of fiscal rules and grid charges for self-consumption. A Working Group, initiated by the government, on simplifying administrative procedures for solar will run through 2018, and revised Energy Programme Decree (PPE) targets may be published as part of the revised National Low Carbon Strategy.

National photovoltaic capacity grew by 875 MW, compared to less than 600 MW in 2016, for a cumulative capacity of 8 044 MW.

NATIONAL PROGRAMME

The new French government, formed in May 2017, further reinforced the national strategy for meeting the Energy Programme Decree (PPE) photovoltaics targets through large or centralised systems, with continued support for competitive Tenders via an increase in Tender volumes—and no corresponding increase in the expected FiT volumes (500 MW/year).

The Regional Energy Programme (PPE) photovoltaics targets were set in 2017 for most overseas departments or regions, with a combined new additional capacity target of 130 MW in 2018 and 1,7 GW in 2023, compared to 2015.

The results of seven Tenders were announced, three new Tenders were launched (self-consumption, innovation and wind energy/ground-based solar energy), as well as the substantial increases to the volume of existing calls, announced in December and shown in

Table 1. The Innovation Tender is giving scope to industrial innovation, whilst the wind energy/ground-based solar energy tender reflects the continued reduction in costs for solar, mirroring other countries "technology neutral" tenders.

The rules governing the additional tariff/feed-in premium of 3 EUR/MWh for citizen and local authority capital investment were modified, with the addition of a smaller 1 EUR/MWh bonus for citizen and local authority participation in debt financing.

TABLE 1 - COMPETITIVE TENDERS – VOLUMES, CALENDAR AND RECENT AVERAGE BID LEVELS

System type and size	Building mounted systems and parking canopies	Building mounted systems	Ground-based systems and parking canopies	Systems with storage in ZNI*	Building mounted systems for self-consumption		Innovative solar systems	Wind and/or ground-based photovoltaic systems
Individual system size limits	100 kW to 500 kW	500 kW to 8 MW	Ground: 500 kW to 30 MW (raised from 17 MW in 2017) Canopies: 500 kW to 10 MW	100 kW to 5 MW	100 kW to 500 kW	100 kW to 500 kW	100 kW to 3 MW	5 MW to 18 MW
Support Mechanism	Call for Tenders 2017–2019	Call for Tenders 2017–2019	Call for Tenders 2017–2019	Call for Tenders 2017	Call for Tenders** 2016–2017	Call for Tenders** 2017–2020	Call for Tenders 2017–2019	Call for Tenders 2018
Volume	825 MW in 9 calls of 75 MW to 100 MW (up from 675 MW)	1050 MW in 9 calls of 75 MW to 150 MW (up from 675 MW)	3,92 GW in 6 calls of 500 MW to 850 MW (up from 3 GW)	50 MW in 1 call	40 MW in 2 calls of 20 MW (continental) 20 MW in 1 call (ZNI*)	450 MW in 9 calls of 50 MW	210 MW in 3 calls of 70 MW	200 MW in 1 call
Remuneration type	PPA***	FIP****	FIP	PPA	Self-consumption + bonus on self-consumption + FIP	Self-consumption + bonus on self-consumption + FIP	PPA (5 MW) FIP (65 MW)	FIP
Average tendered price (or bonus for self-consumption)	3 rd call: 89,9 EUR/MWh	2 nd call: 88,4 EUR/MWh	2 nd call: 63,9 EUR/MWh	113,6 EUR/MWh	Mainland 2 nd call: 19,35 EUR/MWh ZNI 2 nd call: 34,19 EUR/MWh	1 st call: 7,9 EUR/MWh (note: 36 candidates tendered at 0 EUR/MWh)		

Note: Call for Tenders limited to mainland France unless otherwise specified

* ZNI: non-interconnected territories (Corsica and French overseas departments)

** Call for Tender is not limited to photovoltaics systems; other RES technologies are eligible

*** PPA = Power Purchase Agreement at tendered rate

**** FIP = Market sales + Additional Remuneration (Feed in premium) Contract at tendered rate

In parallel, a revised Feed-in Tariff scheme was published in May 2017, phasing out the historical support for full-building integration (BIPV) by late 2018 whilst retaining the obligation to install on buildings. Tariffs are segmented based on system size and the chosen remuneration model (FiT only or partial self-consumption). The creation of specific tariffs for partial self-consumption reflects government strategy and the public appetite for self-consumption: For residential systems up

to 3 kW, by last quarter 2017 four out of every five grid connection requests were for self-consumption systems. However, the model seems less attractive for larger systems, as take-up falls to less than 5 % of new grid connection requests for systems between 36 kW and 100 kW. New opportunities have been created, with 75 MW installed in the 36 kW to 100 kW segment in the last quarter of 2017, more than for any other quarter since 2011.

TABLE 2 – PV FEED-IN-TARIFFS FOR THE 4TH QUARTER OF 2017 (EUR/KWH)

TARIFF CATEGORY AND PV SYSTEM TYPE	POWER OF PV INSTALLATION (KW)	TARIFF Q4 2017
Ta (no self-consumption)	≤3 kW	0,1848 (+ 0,03 for full BIPV)
Ta (no self-consumption)	3 kW to 9 kW	0,1571 (+ 0,03 for full BIPV)
Tb (no self-consumption)	9 kW to 36 kW	0,1207
Tb (no self-consumption)	36 kW to 100 kW	0,1136
Pa (partial self-consumption)	≤3 kW	0,10 (+ 0,39 EUR/W installed)
Pa (partial self-consumption)	3 kW to 9 kW	0,10 (+ 0,29 EUR/W installed)
Pb (partial self-consumption)	9 kW to 36 kW	0,06 (+ 0,19 EUR/W installed)
Pb (partial self-consumption)	36 kW to 100 kW	0,06 (+ 0,09 EUR/W installed)
Call for Tenders	100 kW to 500 kW	Average selling price (EUR/AveraMWh) 89,9 (3 rd Call)

Source: CRE, Ministry of Environment, Energy and Sea.

R&D

Research and Development in France ranges from fundamental materials science to pre-market development and process optimisation. The two major centres for collaboration on photovoltaics, the Institut Photovoltaïque d'Ile-de-France (IPVf) and the Institut National de l'Energie Solaire (INES2) are both ITEs (Institutes for Energy Transition) and include significant industrial research platforms, working with a number of laboratories and industrials across France.

The IPVf, an industry-academic partnership with an experimental research platform also performs research advancing performance and competitiveness of cells in conjunction with a number of specialised laboratories, also across a variety of cell technologies: silicon, thin film and very high performance multi-junction cells.

INES2 has a wide range of actions covering photovoltaics, building integration components, grid integration and storage technologies, as well as fundamental research on improving cell stability and efficiency across multiple technologies (heterojunction, organic, etc.). It is active in the AMPERE project, working towards automated process lines scalable to a GW factory.

The 2017 National Budget has an account dedicated to Energy Research, with a specific mention for the CEA (Atomic Energy and Alternative Energies Commission) working on developing very-high-yield PV cells (heterojunction and backside contact). The CEA has teams working in over 100 joint research units, laboratories and facilities, including INES2.

The principal state agencies financing research are:

- **the National Research Agency (ANR)**, which finances projects through topic-specific and generic calls and also through tax credits for in-company research. Projects awarded or begun in 2017 through ANR calls include 2 aimed at creating international networks, an industrial research Chair and both fundamental materials research and photovoltaics-specific research (organic, Perovskite...). Twenty laboratories are involved, several private partners and a dozen foreign universities. Ongoing research subjects outside of these recent calls include passivating contacts for silicon solar cells, carrier-selective contacts for silicon solar cells, tandem cells, low temperature or standard atmospheric pressure silicon cell manufacturing for cost reductions, etc.

- the French Environment and Energy Management Agency (ADEME) runs its own Calls for R&D on RES and has an active policy supporting PhD students with topics related to PV, as well as being the French relay for the IEA PVPS and SOLAR-ERA.NET pan-European network. ADEME also manages the State's "Investing in the Future" programme (Investissements d'Avenir) that is financing innovative pre-industrial technologies. At the end of 2017, a review of the previous "Investissements d'Avenir" programmes (2010–2017) was published, highlighting over 1 100 M EUR in subsidies, repayable advances and capital investment being dedicated to renewables, storage and smart grid subjects. The great majority of this amount went to large businesses, and predominantly for renewable energies. Financing for photovoltaics was "contributing to industrial competitiveness through innovation, and national and international development of market players" [1]. The overall programme financing was made available through 28 calls, including five specifically targeting SMEs. A 3rd Investissements d'Avenir programme was announced late 2016 and ADEME will continue to manage the fund, that will include a priority of getting technologies developed within previous programmes to commercialisation. In 2017, ADEME had two main calls relative to photovoltaics: a call for Renewable Energy projects within the Investissements d'Avenir programme, targeting the development of advanced PV technologies, industrial trials of innovative PV systems and building integration products, and a Call for Research projects, with a focus on Balance of System component performance and cost optimisation, innovative electric architectures and valorisation of cell and module recycling outputs.
- Bpifrance (a French public investment bank) that provides, amongst others, low-cost financing and subsidies for research-to-enterprise technology transfers and technology innovation-to-market deployment, feasibility studies and accompaniments.

A national Call for Tenders specifically targeting the deployment of innovative solar systems, with a capacity of 70 MW for systems between 500 kW and 3 MW, will finance systems through Power Purchase Agreements or Feed in Premium contracts and competitive tender rates. Innovation in system components (including building interfaces), and composition is eligible, as well as innovative system services ranging from operations optimisation to virtual power plants and agricultural photovoltaic systems that can prove their synergy with agricultural use.

The major show-cases for photovoltaics research in France are the PVTC (PhotoVoltaic Technical Conference) in April with a focus on materials and advanced processes to innovative applications, and the National PV Days (JNPV) in late December at the initiative of the Fed-PV, (CNRS PV research federation) and IPVf.

INDUSTRY AND MARKET DEVELOPMENT

Once again market interest in 2017 was focused on self-consumption schemes, with a significant number of conferences and working groups on the subjects, organised both by market players, government or administrative bodies and local authorities. Much discussion was generated on collective self-consumption, with France's first project inaugurated in December. Market players have worked on providing collective and individual self-consumption turn-key solutions, although continuing work on framework conditions hampered development, and doubts remain as to the economic viability of collective self-consumption systems for fiscal reasons.

Analysis of the national Call for Tenders has shown major market players concentrate on specific calls – for the 1st and 2nd Calls for systems on buildings, the top three winning bidders in each Call had very small volumes in the other call, demonstrating both a sharing of market volumes but also the importance for developers of grouping projects timewise to achieve competitive material prices. This is also true, to a smaller degree, for some operators in the Call for ground-based systems.

Photovoltaic energy production is a concentrated market in France, with over 25 % of the commissioned capacity in the hands of 10 companies [2]. These companies both develop and operate systems, for themselves or clients. No major variations are expected in the near future, considering Tender winning bids.

Industrial sites and supermarkets have been the preferred consumers in the Self-Consumption Competitive Tenders, with half of all projects in the last 2017 call awarded on supermarkets, and 30 % for a single company. The Tender's obligatory high self-consumption rates require concomitant on-site electricity demand and solar production, and the competitive nature of the Tenders requires large surface that can be economically equipped, favouring these types of sites.

For ground-based Tenders, both the carbon footprint of modules and previous land use are weighted selection criteria, giving a greater chance of selection to systems with a lower environmental impact. National industry does not seem to have benefited with only 3 % to 10 % of modules in winning bids assembled in France, although the majority of wafers were manufactured in Europe. The carbon footprint of modules has been effectively lowered through the calls, dropping by 9 % between Tenders to an average of 329 kg CO_{2e}/kW for 2nd call winners. Systems on degraded or polluted land received extra points that were instrumental in retaining 29 projects in the 1st call and 10 in the 2nd. The over-subscribed Tenders have resulted in a high rate of resubmission, with 75 % of repeat candidates in the 2nd call, more than 90 % having adjusted the price and/or carbon footprint of their bids.

[1] Bilan 2010–2017 Programme d'investissements d'avenir, ADEME 2017.

[2] Analyse Finergreen December 2017

Overall, it appears that the environmental criteria in the Tenders for ground-based systems have successfully promoted improved environmental performance for a significant number of systems, influencing manufacturers and developers in site, material selection and processes improvement.

Some local industry suffered through 2017, with the definitive closure of the Sillia (ex-Bosch Solar) module assembly site close to Lyon, and the acquisition of the Brittany Lannion site by an established European manufacturer. Others have had a more positive year—Photowatt, (EDF ENR PWT) announced plans to change its long standing "vertically integrated" industrial model, with the creation of a joint venture to exclusively manufacture advanced technology silicon ingots and wafers with a low carbon footprint on the French site, with a gradual increase in annual ingot production to 500 MW, up from the current 50 MW. Modules will no longer be assembled in France. Conjointly, EDF announced their intention of installing 30 GW of photovoltaics in France from 2020 to 2035, notably in the national competitive tenders that include module carbon footprint as selection criteria.

France has, for the past 10 years, strongly encouraged fully building integrated PV, with preferential feed-in tariffs and access to Tenders, currently being phased out. However, fire damages (especially the SCHEUTEN case) and leakages in agricultural roofs has led insurers to take a close look at the photovoltaics industry. After reflection, the insurer representative body Agence Qualité Construction (AQC) took the unprecedented move of announcing, in March, that as of January

1st, 2018, most BIPV systems would be placed under observation. This means that for professionals installing building integrated photovoltaics systems, decennial building liability insurance will be hard to find, more expensive and more restrictive, as insurers add surcharges to cover probable losses or move out of the photovoltaics sector to avoid potential risks. However, manufacturers of BIPV products may present their products to the AQC Product Prevention Commission (C2P), and be added to the Green List of products, that are considered by insurers to be "normal risk level" building products. This decision, added to the May revision and announced phase-out of full BIPV bonuses for feed-in tariffs was responsible for increasing insurance and commercial difficulties for professionals, both on the manufacturing and installation side.

The 1st quarter in 2017 had the lowest capacity connected since 2012—but larger volumes of previous Calls for Tender were connected in the 2nd and 4th quarters (respectively 213 MW and 394 MW), though below the expected 1,5 GW from Tenders awarded in late 2015 and early 2016. A November 2017 partial analysis indicated that only roughly 1/3 of bids awarded in these Tenders were in service, with a further approximately 40 % under construction, and 20 % suspended due to procurement difficulties (such as the closure of Sillia).

Overall grid connected volumes grew by an estimated 875 MW in 2017 as compared to 587 MW in 2016 and 894 MW in 2015. Commercial and industrial systems dominated the grid connections, with 70 % of new capacity for 621 MW.

TABLE 3 – GRID CONNECTED CAPACITY AT THE END OF DECEMBER 2017 (PROVISIONAL)

POWER CATEGORY	CUMULATIVE POWER (MW)	CUMULATIVE NUMBER OF SYSTEMS (NUMBER)
Up to 9 kW (T1/Ta FIT)	1 246 (15 %)	362 718 (90 %)
9 kW to 100 kW (T4/Tb FIT)	1 508 (19 %)	30 735 (8 %)
Above 100 kW	5 291 (66 %)	7 486 (2 %)
Total (provisional)	8 045	400 939 installations

Source: SDES (Department for data and statistical studies, Ministry for the Ecological and Inclusive Transition).

GERMANY

PHOTOVOLTAIC BUSINESS IN GERMANY – STATUS AND PROSPECTS

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GENERAL FRAMEWORK AND IMPLEMENTATION

The expansion of renewable energies is one of the central pillars in Germany's energy transition. The overall objective is an environmental friendly, reliable and economical feasible energy supply. Thus, a more climate-friendly electricity supply is necessary. Germany's electricity supply is becoming "greener" every year as the contribution made by renewable sources is constantly growing. In 2017, roughly 39 % of gross electricity generation is covered by renewable energy. This makes renewables an important source of electricity in Germany. Thereof 7 % are generated by Photovoltaic (PV) systems. At the same time there is a reduction of the net installed electricity generation capacity of fossil (-2,7 GW) and nuclear (-1,3 GW) power plants [1, 2].

In 2017, a capacity of 1,75 GW PV power (as a first estimate) has been newly installed in Germany (see Figure 2) which is a slight increase compared to the previous years. This results into a total installed PV capacity of 43 GW connected to the German electricity grid [3]. Differences compared to numbers published previously are related to differences between the data collection of the Bundesnetzagentur (Federal Network Agency) and the transmission system operators (TSOs).

NATIONAL PROGRAMME

The responsibility for all energy related activities is concentrated within the Federal Ministry for Economic Affairs and Energy (BMWi). Up to now the main driving force for the PV market in Germany is the Renewable Energy Sources Act. The 2017 revision of the Renewable Energy Sources Act is the key instrument to achieve effective annual quantitative steering and to bring renewable energies closer to the market. It rings in the next phase of the energy transition: from 2017 onwards, funding rates for renewable electricity systems with more than 750 kW installed power will no longer be fixed by government, but will be determined via a market-based auction scheme –



Fig. 1 - CIGS thin film solar façade system (Photo: © ZSW Stuttgart / www.zsw-bw.de).

a fundamental change in funding renewable energy. This will permit the further expansion of renewables in a controlled manner, synchronize their expansion with the upgrading of the grid, and set the level of subsidies for them in market-based auctions [4]. For photovoltaic systems, a total volume of 600 MW is planned to be released in three auctions per year.

Accordingly, in 2017 three auctions with a total volume of 600 MW installation capacity have taken place for ground-mounted photovoltaic installations. The calls were characterized by a high degree of competition. The proposed capacity was significantly over-subscribed and the price level decreased from call to call down to 4,91 EURcents / kWh which shows a good efficiency of the process [5].

Medium size photovoltaic systems below 750 kW are still eligible with a guaranteed Feed-in-Tariff (FiT) for a period of 20 years. Systems with more than 100 kW power capacity are obliged to direct marketing of the generated electricity. A feed-in premium is paid on top of the electricity market price through the so-called "market integration model".

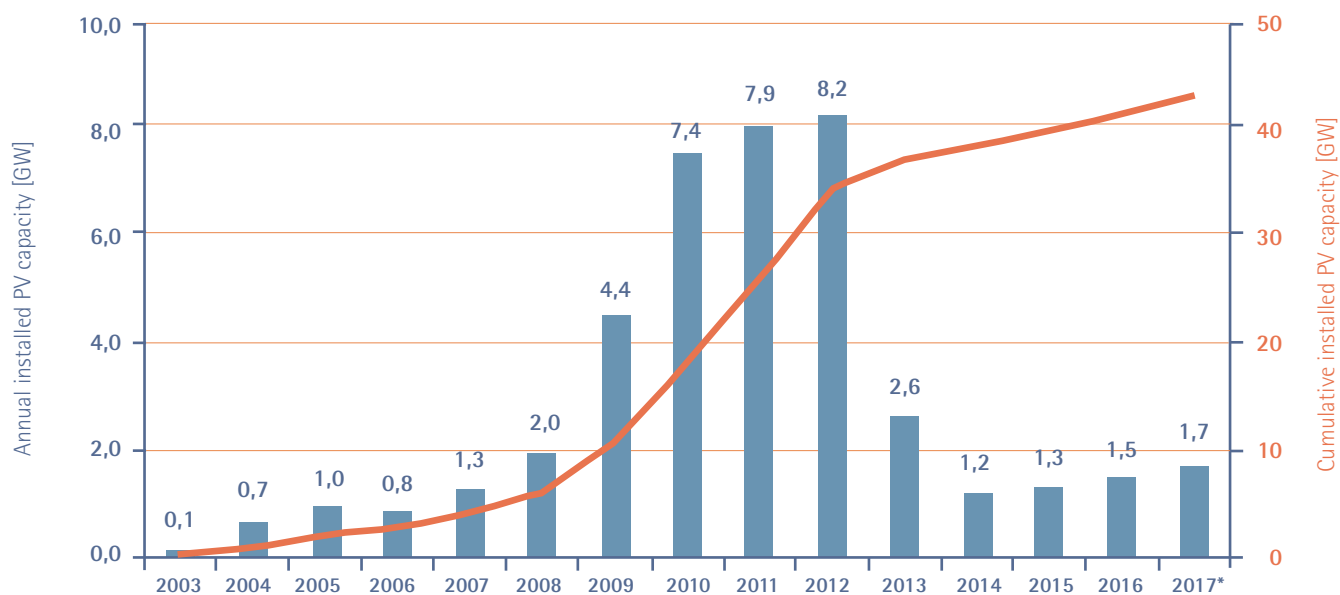


Fig. 2 - Development of grid connected PV capacity in Germany, *first estimate as of January 2018.

TABLE 1 – DEVELOPMENT OF THE FEED-IN TARIFF (FIT) FOR SMALL ROOFTOP SYSTEMS (< 10KW)

YEAR	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012*	2013*	2014*	2015*	2016*	2017*	2018*
EURcents/ kWh	50,6	48,1	45,7	57,4	54,5	51,8	49,2	46,75	43,01	39,14	28,74	24,43	17,02	13,68	12,56	12,31	12,31	12,20

* adjusted by a flexible monthly degression rate between 0 – 2,8 % throughout the year

For small PV systems < 100 kWp, a fixed FIT is paid which depends mainly on the system size and the date of the system installation. The FIT is adapted on a regular basis, depending on the total installed PV capacity of the last twelve months. Details on the development of the FIT can be found in [6]. Table 1 shows the development of the FIT for small rooftop systems (< 10 kW) installed since 2001.

Moreover, investments in residential PV installations are getting attractive even without financial support by a Feed-in-Tariff. Offers for PV rooftop system of 10 kW with a price of 10.000 EUR are accessible. The Levelized Costs of Energy (LCOE) for these systems are around 13 EURcents / kWh whereas the average electricity price for a private household is around 29 EURcents / kWh [7]. Therefore, private homeowners have an interest in maximizing the self-consumption from their PV systems. Nearly every second new residential PV system is now installed with a battery storage system, too.

This development is fostered by the continuation of a market stimulation program for local stationary storage systems in conjunction with small PV systems (< 30 kWp) [8]. The program is equipped with a sum of 30 MEUR and is designed to run from March 2016 until end of 2018.

RESEARCH AND DEVELOPMENT

Research and Development (R&D) is still conducted under the 6th Programme on Energy Research "Research for an environmental friendly, reliable and economical feasible energy supply" [9] which came into force in 2011. Despite the success of this programme a new Programme on Energy Research is under preparation to incorporate the recent developments and tremendous changes in the energy sector. An effective consultation process is conducted to include stimulations from the main stakeholders from industry, research institutes, Federal States and associations.

Within the framework of the running Energy Research Programme, the BMWi as well as the BMBF (Federal Ministry of Education and Research) support R&D on different aspects of PV. The main parts of the programme are administrated by the Project Management Organisation (PtJ) in Jülich.

Funding Activities of the BMWi

In December 2014, the BMWi released a call for tender which reflects the targets of the energy research program. Concerning PV, the call addresses specific focal points which are all connected to applied research:

- Efficient process technologies to increase performance and reduce costs for Silicon wafer and thin film technologies

- Quality and reliability issues of PV-systems
- System technology for both, grid-connection and island PV plants,
- Cross-cutting issues like Building Integrated PV (BIPV) or recycling of PV systems.

In 2017, the BMWi support for R&D projects on PV amounted to about 80,9 MEUR shared by 424 projects in total. That year, 106 new grants were contracted. The funding for these projects amounts to 91,5 MEUR in total. The development of funding activities is summarized in Figure 3. The German contributions to most of the PVPS Tasks are part of the programme. Details on running R&D projects can be found via a web-based database of the Federal Ministries [10].

Network on Research and Innovation in the field of Photovoltaics
The energy transition will only succeed if all stakeholders work together especially in the field of research and innovation. Therefore, the BMWi coordinates the close and ongoing dialogue between the relevant stakeholders by initiating high-level energy transition platforms. This also creates a high level of transparency, contributing to greater public acceptance of the energy transition. The Research and Innovation Platform acts as an advisory body for the BMWi, hosting a dialogue on the strategic direction of energy research with the national stakeholders in the Federal Government and the business and scientific communities [11].

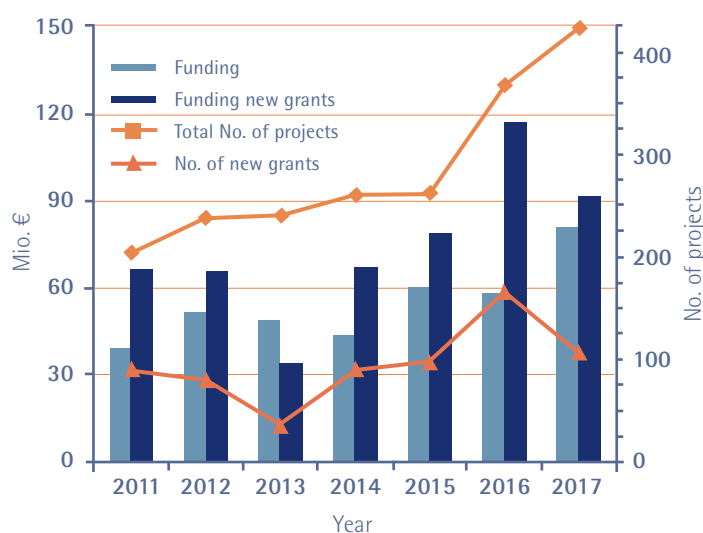


Fig. 3 – R&D support and quantity of PV projects funded by BMWi (BMU) in the 6th EFP.



Fig. 4 - mc-PERC and ZEBRA-solar cell at the exit of an annealing furnace (Photo: © RCT Solutions and ISC Konstanz).

Underpinning the Research and Innovation Platform the Network on Research and Innovation in the field of Renewable Energies was founded in 2016. PV and wind power are the two pillars of this network. The network serves as an information and discussion platform for players from industry, universities, research institutes and politics. It is a source of inspiration for the future focus of research on renewable energies to the BMWi and gives concrete ideas for the implementation of thematic topics or support concepts. Two recent major outcomes are the expert recommendations for the consultation process towards the 7th Programme on Energy Research mentioned above and a position paper on PV production technologies [12]. The Research Network is an open expert forum for all interested stakeholders.

Funding Activities of the BMBF

From September 2015 on, the BMBF relaunched its energy related funding under the "Kopernikus" initiative. Under this scheme cooperative research on four central topics of the German Energy Transition are addressed: storage of excess renewable energy, development of flexible grids, adaption of industrial processes to fluctuating energy supply, and the interaction of conventional and renewable energies.

The research initiative "FuE for Photovoltaic", a joint activity of BMWi and BMBF, was summarized and concluded at its final workshop that was held in September 2017. The aim of this activity has been the support of R&D activities of the German PV industry in the fields of economical operation of grid-connected and off-grid PV system solutions, efficient and cost effective production concepts for PV cells and modules and the introduction of new PV module concepts with a special focus on quality, reliability and life time. At the workshop, significant progress was reported on new coating processes, efficient metallisation of silicon solar cells with less consumption of Silver and new generations of inverters using innovative SiC power semiconductors. A total of 13 joint projects have been funded by the ministries BMWi (8 projects, 43 MEUR) and BMBF (4 projects, 6 MEUR) [13].

INDUSTRY AND MARKET DEVELOPMENT

2017 was once again an ambivalent year for the German PV industry. Again a significant drop in module prices was observed. This required additional cost savings and put the global PV industry under pressure again.

In Germany, SolarWorld AG, the last big manufacturer of Silicon wafers, cells and modules had to register for insolvency in May 2017. But the innovative production of cells and modules is continued by the new SolarWorld Industries. At the same time and based on the advantages of solar technologies from Germany – namely a high

quality of products as well as technically advanced and innovative production processes – first signs of a turnaround have recently been seen even among other German PV module manufacturers. And German manufacturers of components, machines and plants still benefit from a continued global investment of the solar industry in photovoltaic-equipment. The VDMA (Verband Deutscher Maschinen- und Anlagenbau, Mechanical Engineering Industry Association) specialist group on PV reported a significant increase of orders at 328 %, in the first quarter of 2017, in the equipment market [14]. German photovoltaic industry reported two-digit growth rates for the installation of new PV systems [15]. Together with a strong research community and a high number of system installers, a workforce of approx. 45 200 people were employed in the solar industry in 2015 [16].

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ISRAEL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS: AN UPDATE
Yael Harman, Technologies & Renewable Energy Section Manager
Ministry of Energy

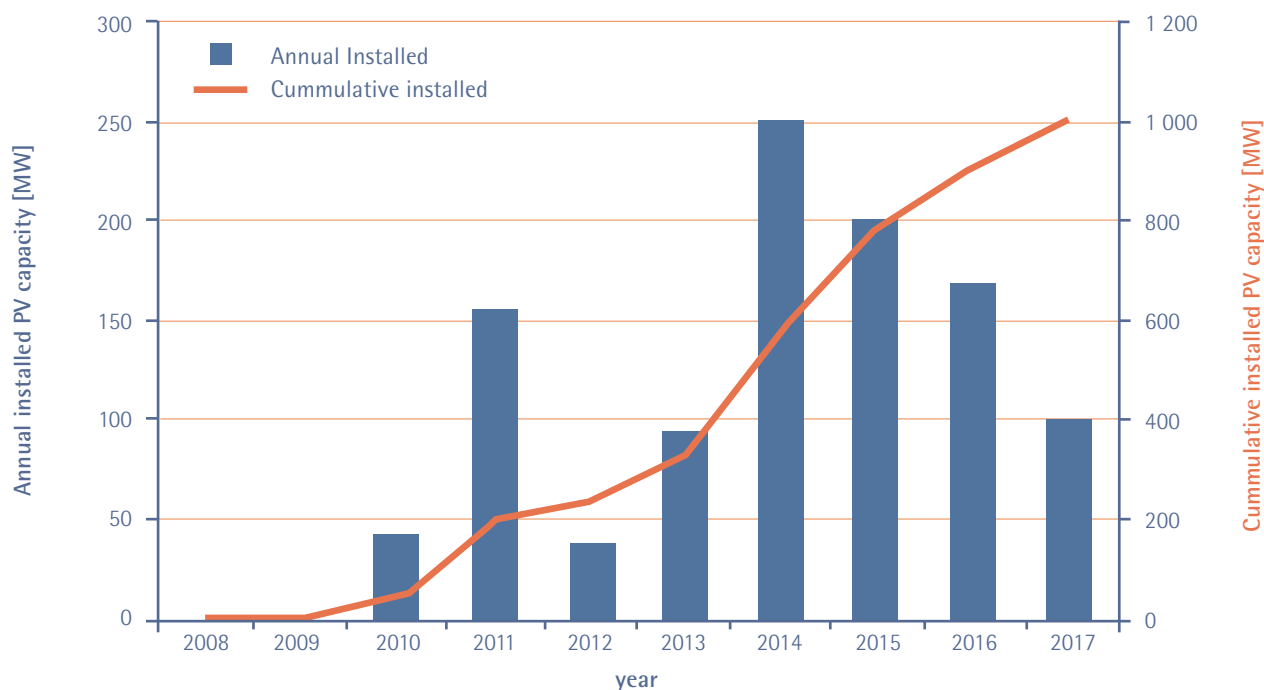


Fig. 1 - Development of grid connected PV capacity in Israel until 2017.

GENERAL FRAMEWORK

In 2016, the Israeli government decided on a series of steps designed to ensure that Israel meets its target of 17 % Renewable Energy (RE) electricity production (in energy terms) by 2030, with interim targets of 13 % in 2025 and 10 % in 2020. This included funds allocated to encourage energy efficiency projects for which a target of 17 % energy efficiency improvement was previously set, and a long series of procedural steps to promote RE and energy efficiency. In 2017 the PUA (Public Utility Authority) published several tenders for over 500 MW of PV.

In 2017 capacity of only 100 MW PV power was installed in Israel (Figure 1). This resulted in a total installed capacity of 1 005 MW of PV with total RE capacity of 1 075 MW. PV systems are the most abundant RE in Israel accounting for over 90 % of the total renewable energy sources in Israel.

PV installations in 2017 were lower than in previous years, due to a halt in quotas allocation during 2014-2016.

As the promise for new policy finally materialized, the Ministry of Energy allocated, during 2016 and 2017, a number of new quotas for PV projects, at a total of 1 600 MW. These quotas will make the market practically unlimited, and in case these quotas will be connected before 2020, Israel will be able to reach close to its target of 10 % RE by 2020. The overall electricity production from renewables in 2017 remained

almost the same as for year 2016 with only 2,5 % of total electricity consumption of approximately 63 TWh.

Two big projects of PV started construction in 2017, these are 60 MW and 120 MW in Mashabei Sadeh and Tze'elim respectively and are expected to be grid-connected in 2018. Furthermore, the large project at Ashalim of 240 MW is also expected to be connected in 2018. These alone will guarantee an expected installations of 460 MW, and with other projects in development, total installation might reach 700 MW. In order to reduce the costs of RE installations, Israel started, in 2017, a new bidding system in medium to large PV projects, in which all winning bidders pay the amount of the highest non-winning bid. The first and the second bidding rounds for a total of 34 MW took place, and a price of 0,2 ILS per kWh (0,06 USD) was set.

2015 has seen a dramatic decline in the electricity cost in Israel (around 15 %), which stayed stable during 2016 and increased by 5 % during 2017 to 0,47 ILS (0,13 USD) per kWh (without VAT), yet it is still considered low compared to the prices of 2006. Although renewable energy is more competitive than ever, competition with other sources of energy, mainly natural gas, is tough. Gas prices continued to decline – down to about 4 USD per MMBTU, with the entrance of a new player, Energean, owner of Karish and Tanin gas fields. It now looks quite probable that electricity production from gas will increase up to 80 % within 4-5 years. At the same time, the Ministry of Energy took

a historic decision to close a major coal power station, Orot Rabin in Hadera, with a total capacity of 1 600 MW, within 4-5 years. This is part of the Energy Minister's vision for reducing Israel's dependence on coal to the minimum level by 2030. Thus, it is clear that PV systems must play an important role in the electricity production supply mix. This can certainly be done as PV electricity costs are around grid parity, even considering additional costs required for backup and balancing. For example, the estimated cost, without externalities, of an open cycle gas turbine in Israel is about 0,25 ILS per KWh, which is higher than the closing price of 2017 PV auction of 0,06 USD per KWh.

NATIONAL PROGRAMME

2017 marked a significant change in Israel's energy policy, which shifted towards cleaner energy especially in the field of PV. A strong effort is being made to meet the 10 % RE goal by year 2020. Several steps are being taken to simplify new construction of PV. In addition strong incentives are given to rooftop installations, as they are perceived as the easiest and quickest to install.

At the same time, it became clear that in order to support a high percentage of electricity production from variable RE, Smart Grid is essential. Initial steps in this direction have been taken with the support of the Office of the Chief Scientist at the Ministry of Energy.

RESEARCH AND DEVELOPMENT

The Ministry of National Infrastructure, Energy and water supports R&D under three main programs, which are operated by the Office of the Chief at the Ministry:

- Direct support for academic research- support is 100 % for research projects.
- Support for startup companies. Support is 62,5 % for projects with technology innovation.
- Support for Demonstration and Pilot programs- support is 50 % for commercial deployment of novel technologies. Projects can also be supported under a special dedicated cap for electricity production, through the FIT over 20 years.

To facilitate higher penetration of PV systems, high priority research topics include improved efficiency of PV systems, and storage.

In 2017 the Office of the Chief supported nine projects related to solar and PV with total investment of approximately 1,6 MUSD out of total budget of 10,7 MUSD.

Among the current supported projects are:

Solight develops Solar Lighting systems, to illuminate buildings during daytime. The Solight system collects sunlight throughout the day and effectively channels it into desired spaces as natural, healthy, full spectrum, interior lighting. Thanks to its simple design, it is a cost-effective solution for various installations. Typical applications would include residential, offices, retail, workshops and other light roofed structures. www.solight-energy.com



Fig. 2 - Solight installing its lighting system.

Synvertec developed innovative control algorithm called Synchronverter. The algorithm in the grid inverters transforms their behavior to that of a synchronous generator. The grid becomes more stable, as it recognizes the inertia produced by the algorithm-supplemented inverters. This process will allow good grids to include more RES – without increasing fossil power generation for stability
www.synvertec.com

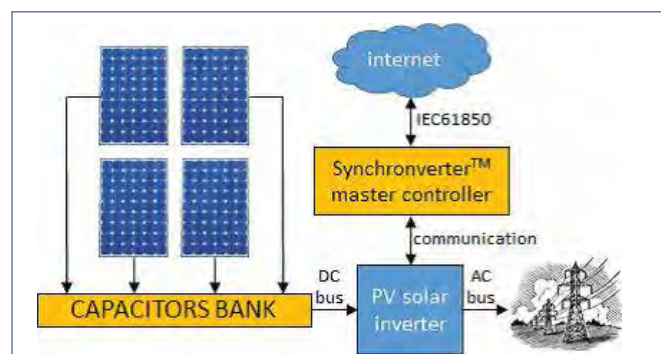


Fig. 3 - Regulation of real and reactive power in a synchronverter.

Vigdu Technologies has developed a unique technology for treating Potential-Induced Degradation (PID) in PV systems. A PV plant is planned for a maximum possible production yield, which results as revenues. In many cases this expected production level is not met due to accelerated degradation (PID), and results in lower income. The Vigdu device applies voltage against the PV modules and be doing so recovers power degradation in the PV modules, by installing it the PV is protected. The new system targets small systems, at low cost.
www.vigdu.com



Fig. 4 - The Vigdu device.

ITALY

PV TECHNOLOGY STATUS AND PERSPECTIVES

SALVATORE CASTELLO, ENEA

SALVATORE GUASTELLA, RSE



Fig. 1 - Bifacial Module produced in the new line of 3SUN (Photo: 3SUN ENEA).

GENERAL FRAMEWORK AND IMPLEMENTATION

In Italy, 2017 was marked by a growth of PV installations slightly higher than last year. Nevertheless, the PV market's context in Italy is rather lively, due to the Italian government's 10-year energy plan (National Energy Strategy) which has been adopted to anticipate and manage the change in the energy system and, in particular, to enhance the electricity production from RES, with the target of reaching a PV installed power of 50 GW in 2030.

In this framework, a preliminary data of the photovoltaic installations in Italy in 2017 is 409 MW, while in the past year the installations amounted to 382 MW.

According to preliminary data, PV grid connected production units have been slightly diminished (-0,5 %) yearly; residential systems (up to 20 kW) make up 50 % of the new installed capacity in 2017 thanks to tax deductions, while the installations of medium and large plants is still low, even if for the first time an utility scale plant (63 MW) was installed without any incentives, these are demonstrating that the "market parity" has been reached.

The PV off-grid sector for domestic and not-domestic applications confirmed the unchanged cumulative installed power of about 14 MW, remaining as a marginal sector.

On the whole, it can be estimated that a total cumulative PV capacity of around 19,7 GW was reached at the end of 2017

In 2017, the estimated photovoltaic production was 24,811 GWh, up 14 % more than 2016 and covering 6,9 % of the national demand. Also during the year, all the other RES decreased their electricity production: Geothermal -1,4 %, Hydroelectric -14,3 % and Wind -0,2 %.

NATIONAL PROGRAMME

Some mechanisms are presently applied in Italy that support the PV installation:

(1) "Scambio Sul Posto" (SSP) and "Ritiro Dedicato" (RID)

This mechanism consists in two schemes:

- net billing system, so-called "Scambio Sul Posto" (SSP), which deals with the value of energy exchanged with the grid, given the real time self-consumption allowed for all PV system sizes);

this mechanism is valid for existing plants with a power below 200 kW and from 2015 for new plants up to 500 kW; under the SSP scheme, electricity fed into the grid is remunerated through an "energy quota" (based on grid prices) and a "service quota" (depending on some grid services costs);

- electricity sales, indirectly by entering into a "Ritiro Dedicato" (RID), through which GSE [1] retires the electricity according to a dedicated withdrawal agreement, or directly, through sales of electricity on the power exchange or to a wholesaler.

(2) Tax breaks and white certificates

The tax breaks' scheme allows that some or all expenses associated with small PV installations (power less than 20 kW) are to be deducted from taxable income streams.

Moreover, companies and public institutions could benefit from white certificates, a mechanism which rewards all initiatives for the energy savings and, in this frame, also the PV installations.

(3) "Sistemi Efficienti di Utenza" (SEU)

The so-called "Sistemi Efficienti di Utenza" (SEU) consist in a scheme in which one or more power production plants operated by a single producer are connected through a private transmission line to a single end user. This scheme is becoming widespread, especially among existing medium size plants.

The experience so far has outlined (as confirmed already in 2016) that SSP plus tax breaks are the most effective mechanisms in boosting new PV installations, especially in the residential sector.

RESEARCH, DEVELOPMENT AND DEMONSTRATION

In Italy, research, development and demonstration activities in the field of PV technology are mainly led by ENEA (the Italian Agency for New Technology, Energy and Sustainable Economic Development), RSE (a research company owned by GSE), CNR (the National Council for Scientific Research), EURAC, several universities and other research institutes, including company's organizations.

ENEA is the most relevant research organization in the photovoltaic technology sector in Italy. In the field of material and devices, its activities are focused on crystalline, microcrystalline and heterojunction (a-Si/c-Si) cells, CZTS single junction and CZTS/silicon tandem cells, perovskite single junction and perovskite-silicon tandem cells and micromorph tandem cells.

In the systems sector, ENEA activities are focused on: study and experimentation of grid integration of photovoltaic and cogenerative hybrid systems with storage and implementation of techniques and models for generation predictability; development of methodologies and solutions for the use of photovoltaics in residential buildings, also in the context of NZEBs; and modelling of grid and microgrid, which integrates distributed PV generation and storage, for the development of smart grids linked to clusters/energy districts and implementation of operational strategies, through multi-objective approaches.

[1] GSE (Gestore dei Servizi Energetici, www.gse.it) is the state-owned company which promotes and supports renewable energy sources (RES) in Italy.

RSE is the main research organization carrying out activities on high efficiency solar cells in Italy, developing multi-junction solar cells based on III-V-IV elements and nano-structured coating for high concentration applications (CPV) in the frame of the Italian electric system research programme RdS (Ricerca di Sistema) and European projects (i.e. CPV Match). In this field, RSE is also involved in the development of a new SiGeSn ternary material for the realization of monolithic four junction solar cells, in the design of new optics, in the set-up of new methodologies for outdoor and indoor CPV module characterization and in the development of advanced solar tracking control. Moreover, RSE is engaged in the development of new quaternary calcogenides PV thin film cells made of chemical elements abundant on the earth's crust to ensure a potential large penetration of PV technology. Furthermore, RSE carries out performance evaluation of innovative flat modules and plants, as well as in research and demonstration activities for electrification of remote communities and for enhancing the RES penetration into the microgrids of small islands not connected to the national electric grid, jointly with the adoption of energy storage and demand response.

The "PV Energy Systems Group of the Institute for Renewable Energy" of EURAC is active in three core areas. In the first area "Performance and Reliability", the activities are focused on the definition of various methodologies for the calculation of degradation rates in PV performance using data from PV systems from different climates worldwide. In the second area of "BIPV field", EURAC is creating a database for BIPV products and BIPV case studies. The strong focus of the group is on giving support to early design of BIPV projects. In the frame of the third area "PV grid integration", EURAC has access to large amount of data coming from more than 2 000 PV plants located in the area and it is investigating the impact of PV in the distribution grid. Finally, EURAC is a point of reference for O&M operators developing methodologies to assess the failure rate in the field and the relevant economic impact.

Enel has launched the Enel Innovation Hub in 2017, in its site of Catania (Sicily), with the aim of stimulating research and innovation in the PV and RES sectors, through the creation of a 100 000 m² technology campus and an accelerator for start-ups. Also in 2017, a call for collaboration with national and international start-ups and research centers was started to develop innovative projects and the first ones have just been started.

INDUSTRY AND MARKET DEVELOPMENT

The production of photovoltaic modules in Italy is characterized by a limited quantity, even if several manufactures have been producing new modules, which already reached relevant quality and efficiency values comparable with those obtained by the best worldwide producers. An important industrial initiative is constituted by 3SUN, a company of ENEL Group, located in Catania, which is presently the main Italian PV factory and one of the biggest in Europe. 3SUN has started the process to convert its production lines from the double junction thin-film modules, with annual capacity of 200 MW/y, to a new bifacial PV technology based on silicon Hetero-Junction



Fig. 2 - Bifacial modules Installed by EGP on one-axis sun trackers manufactured in Italy (Photo: ENEL Green Power).

(HJT, amorphous silicon deposited on crystalline silicon wafers) and glass-glass architecture. The first phase of the project (starting in April 2018) consists in implementing a module assembly line with nominal capacity of 80 MW/year to manufacture innovative bifacial modules, by assembling PV cells purchased from external suppliers: the 2m² modules will have an efficiency of 18,4 % and the ability of producing additional energy thanks to the bifacial characteristic. The second phase will start in January 2019 producing both high efficiency HJT solar cells and bifacial modules with a nominal capacity of 110 MW/year. The third phase, in September 2019, will allow the manufacturing capacity to be increased to 240 MW/year.

In the power conditioning systems sector (mainly inverter), the Italian manufacturers confirmed their wide production and their ability to remain among the leading manufacturers around the world. In fact, the Italian inverter manufactures, taking into account their capacity and the low national market, realized that the internationalization is their obliged path.

New initiatives on energy storage have been implemented and others have been announced. They consist mainly on hybrid storage systems to be used in micro-grids, in electrification of rural areas and in balancing services in the field of on and off-grid applications.

Italian EPC contractors and system integrators are mainly involved in PV installations in emerging market areas of South and Central America, South Africa and India. Among them, the biggest company is Enel Green Power, which is active especially in the field of utility scale plants.

Moreover, several Italian PV operators, are focused on large size plant management and maintenance services in Italy. Generally, they aim at optimizing performances and reducing costs through integrating management, control and maintenance of big ground plants into single platforms.

In the field of CPV, several Italian operators are active (Solergy, Beghelli Bechar and SUNGEN), with prototypes developed in EU funded projects, and are implementing systems both mirror and lens based, passively or actively cooled.



Fig. 3 - CPV plant installed at Monteveglio (BO) in the frame of the EU funded Ecosole project (Photo: Beghelli Becar).

FUTURE OUTLOOK

The National Energy Strategy adopted in 2017 represents an important step in the development of photovoltaics in Italy as it foresees that PV cumulative installed power will become three times higher than the present value by 2030. This means that the annual installation capacity should increase from the current one of almost 400 MW to over 3 GW. To achieve this goal, it will be necessary for the legislator to operate for the simplification of authorizations, to create the conditions for the real opening of the markets, but above all to enhance the regulatory framework of the PV integration to the grid.

Among the various proposals of the PV operators are highlighted:

- the authorization of installation of large PV plants in less relevant areas (not usable for agricultures, tourism, residential, etc.)
- the possibility for aggregators to participate in the dispatching services market and to implement closed distribution systems with collective self-consumption;
- the creation of conditions to facilitate investments in electric storage systems;
- the reform of electricity tariffs to benefit self-consumption;
- the introduction of reward mechanisms for those who consume when photovoltaic production is higher;
- the possibility of implementing energy efficiency measures through the realization of photovoltaic systems.

JAPAN

PV TECHNOLOGY STATUS AND PROSPECTS

HIROYUKI YAMADA, NEW ENERGY AND INDUSTRIAL TECHNOLOGY DEVELOPMENT ORGANIZATION (NEDO)

OSAMU IKKI, RTS CORPORATION



Fig. 1 - Ground-mounted PV System arranged in the east-west direction with an M shape (F Nagara PV Power Plant) (Nagara-machi, Chosei-gun, Chiba Prefecture). 1,905. 1 kW Multicrystalline silicon PV module (by Suntech) (315 W).

GENERAL FRAMEWORK

The Ministry of Economy, Trade and Industry (METI) started reviewing the fourth Strategic Energy Plan which was established in 2014 as the national energy policy. METI aims to achieve the energy mix for 2030, by identifying the issues of each energy source. Regarding renewable energy, METI positions it as a main power source and plans to formulate the fifth Strategic Energy Plan in 2018, toward taking measures for proper cost reduction, enhancement of industry and large-volume introduction.

For the purpose of achieving balanced introduction of renewable energy while curbing the nation's burden, METI revised the Act on Special Measures Concerning Procurement of Renewable Energy Sourced Electricity by Electric Utilities (Renewable Energy Act, so-called FIT Act) and enacted it in April 2017. As a result, the Feed-in Tariff Program (FIT Program) was drastically reviewed and the approval scheme was shifted from facility approval to approval of the PV project business plan. As to the change of setting purchase prices, a tender scheme was introduced for PV systems with a capacity of 2 MW or more.

Toward sound development and expansion of introduction of PV power generation for the future, METI sorted out "issues of policy in the era of large-volume introduction of renewable energy" and presented the following as a focused direction: 1) enhancement of cost competitiveness; 2) measures to be independent from the FIT program and 3) measures to integrate PV electricity smoothly with the grid. Furthermore, METI started working on establishing a dissemination environment for renewable energy-based electricity to achieve a large-volume introduction of renewable energy and to create the next-generation electricity network.

The national government held a meeting of the Ministerial Council on Renewable Energy, Hydrogen and Related Issues and decided the "Action Plan on Ministry and Agency Collaboration Towards the Expansion of Renewable Energy". This Action Plan consists of 12 collaboration projects covering the issues of deregulation and establishment of dissemination environment. It is planned that, over the next five years, the issues will be overcome to realize an independent introduction of renewable energy, which will lead to creation of industry and regional revitalization.

Regarding the approved and the installed capacities of PV systems under the FIT program which took effect in July 2012, a total of 84,5 GWAC (as of the end of March 2017, including cancelled and revoked projects) of PV systems have been approved, of which 33,5 GWAC started operation. Japan's annual PV installed capacity in 2017 is estimated to be 7 GWDC, and its cumulative PV installed capacity is expected to reach 45 GWDC level.

NATIONAL PROGRAM

(1) Feed-in Tariff (FIT) program for renewable energy power generation facilities

METI is taking initiative in supporting the introduction of PV systems under the FIT program. In FY 2017, the FIT levels for PV systems were set lower than those of the previous fiscal year. The tariffs and periods of purchase were set. The tariff for PV systems with a capacity of 10 kW or more was set at 21 JPY/kWh (excl. tax) for the period of 20 years. For PV systems with a capacity of below 10 kW, the tariffs were set on a mid- to long-term basis as follows, for the period of 10 years: 1) 30 JPY/kWh for FY 2017 (28 JPY/kWh for PV systems which are not required to be equipped with devices to respond to output curtailment); 2) 28 JPY/kWh for FY 2018 (26 JPY/kWh for PV systems which are not required to be equipped with devices to respond to output curtailment) and 3) 26 JPY/kWh for FY 2019 (24 JPY/kWh for PV systems which are not required to be equipped with devices to respond to output curtailment). In the period from July 2012 when the FIT program started, to the end of March 2017, total capacity of approved PV systems with a capacity of below 10 kW, between 10 kW and below 1 MW and 1 MW and more are 5,5 GWAC, 38,3 GWAC and 40,7 GWAC, respectively, amounting to 84,5 GWAC in total. Around 3 GWAC of PV systems were approved in February and March 2017 approaching the end of FY 2016, and the cumulative approved capacity of PV systems increased by 5,8 % year on year. However, since it takes time for many PV projects to start operation after they obtained approval due to the issues of permission and electric grids, only 33,5 GWAC of FIT-approved PV systems started operation, of which approximately 1,5 GWAC started operation between January and March 2017, a 28,9 % decrease year on year. METI's data on commissioned capacity as of the end of March 2017 are the latest data available.

METI revised the Renewable Energy Act and enforced it from April 2017. Major points of the revision are drastic changes in the approval scheme, including a requirement to sign a connection contract with a relevant electric utility and introduction of a tender scheme for PV systems with a capacity of 2 MW or more.

The approval scheme has shifted from facility approval to approval of PV project business plan, which examines business plans of PV projects. PV projects for which connection contracts are signed with relevant electric utilities by April 1, 2017 will obtain deemed approval. They are required to obtain approval of a PV project business plan by submitting the plan by a fixed deadline. Meanwhile, PV projects for which connection contracts were not signed by the fixed deadline lost their approval. It was reported that, among the PV projects with a capacity of 10 kW or more approved by June 30, 2016, around 260 000 projects totaling 14,6 GWAC lost their approval. Cancellation of approval of PV systems with a capacity of below 10 kW has not been investigated. In and after April 2017, information on approval of a PV project business plan for PV systems with a capacity of 20 kW or more has been released. Although it takes time for examination, approval has steadily been on the rise. As of November 30, 2017, capacity of approval of a PV project business plan for PV systems with a capacity of 20 kW or more reached about 270 000 projects totaling 44,3 GWAC, including commissioned projects.

As for the tender scheme, the first tender was held. The tender capacity and ceiling price were 500 MWAC and 21 JPY/kWh, respectively. The pay-as-bid scheme, under which the bidding price is set as the purchase price, was adopted. For the examination of tender qualification, PV project business plans for 29 PV projects with a total capacity of 490 MWAC were submitted, of which 23 projects totaling 388 MWAC were qualified to participate in the tender. According to the tender results released, 9 projects totaling 141 MWAC were selected. The lowest bidding price was 17,2 JPY/kWh and the highest bidding prices was 21 JPY/kWh, the same as the ceiling price. Additional tender or passing of the remaining tender capacity to the next tender will not be conducted. Of all the winning tenders, 5 projects totaling 100 MWAC were withdrawn, by not paying the deposit after winning the tender. The remaining 4 projects totaling 41 MWAC which paid the deposit are required to obtain approval of PV project business plan by the deadline for approval. The first to third tenders are positioned as trial tenders and discussions on the upcoming tenders are underway based on the results of the first tender.

Following the increase in installations of naturally variable renewable power sources such as PV and wind power generation systems, output curtailment was conducted on the dates and the hours when the power generation amount was forecasted to exceed the demand. So far, output curtailment was conducted in remote islands with isolated electric grids, and it has been indicated that output curtailment is likely to be conducted in the electric grids of the mainland Kyushu region and the Shikoku region. After output curtailment was conducted, the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) verified it by following the guidelines and the results of verification were released.

It was decided to establish the "non-fossil value exchange market" in FY 2018 in order to actualize the environmental value of renewable energy and the like. Non-fossil value will be securitized and traded separately from kWh value of electricity. The detailed design of the scheme is making progress and trading of all the non-fossil power sources owning the environmental value is expected to start in FY 2019. Trading of non-fossil value of electricity generated by renewable energy power generation facilities approved under the FIT program (FIT electricity) is scheduled to start in FY 2018 ahead of others. Revenues gained from the trading of non-fossil certificates of FIT electricity will be used for reducing the nation's financial burden. The first auction was conducted for non-fossil certificates equivalent to FIT electricity generated between April and December 2017, with the lowest tender price of 1,3 JPY/kWh and the highest of 4 JPY/kWh. The non-fossil certificates bidden by and awarded to electricity retailers are available for achieving the target of the Act on the Promotion of the Use of Nonfossil Energy Sources and Effective Use of Fossil Energy Source Materials by Energy Suppliers and the Act on Promotion of Global Warming Countermeasures (ratio of non-fossil power source by 2030: 44 %, equivalent to 0,37 kg-CO₂/kWh), as well as to appeal to customers.

(2) METI's budget related to the dissemination of PV power generation

Following the revision of the Feed-in Tariff (FIT) program and other movements, METI's budget for the dissemination of PV power generation has been allocated towards sustainable and large-volume introduction of renewable energy, including implementation of a tender scheme, promotion of renewable energy introduction in Fukushima Prefecture as a pillar of reconstruction, responses to grid restrictions and rationalization of safety regulations. In order to introduce the tender scheme from April 2017, a new budget item "Subsidy for expenses for management of the tender program under the FIT program" was established with the allocation of 0,18 BJPY, designed to support a part of expenses required to implement tenders by a designated tender institution. Aiming to make Fukushima Prefecture a pioneer prefecture of renewable energy, METI will newly allocate 2,5 BJPY for "Subsidy for projects to support promotion of renewable energy introduction in Fukushima Prefecture." For promoting ingenuity of business entities regarding electrical safety, METI will newly allocate 0,16 BJPY for "Consignment expenses for investigation for discussion on rationalization of safety regulations of electric facilities, etc." Meanwhile, the budget amount of "Subsidy for expenses of projects to implement special measures for the surcharge scheme under the FIT program," which is designed to reduce the surcharge for energy-intensive industries, was decreased from 48,3 BJPY to 29,2 BJPY, since a measure was introduced to curb their surcharge reduction rate through energy-saving efforts.

(3) Efforts by other ministries and local governments related to the dissemination of PV power generation

The Ministry of the Environment (MoE) has been continuously promoting projects in partnership with other ministries. Among the projects in partnership with METI, MoE increased the budget amount for the "Project to promote self-sustainable dissemination



Fig. 2 - Smart Town with PV systems installed on all houses as standard (Sma x Eco Town Hidamari no Oka) (Kuwana City, Mie Prefecture). Houses: 66 residential PV systems (ca. 330 kW in total), Ground-mounted PV system: 100 kW, Multicrystalline silicon PV modules (by Sharp).

of renewable energy-based electricity and thermal energy" from 6,0 BJPY to 8,0 BJPY. This project received 432 applications in FY 2017, of which 87 applications were made by local and public organizations. Approximately 150 projects were selected and MW-scale PV systems for self-consumption were introduced. Among the projects in partnership with the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), MoE increased the budget amount for the "Model project to promote CO₂ saving in rental housing" from 2,0 BJPY to 3,5 BJPY. Toward renewing and advancing Japan's FY 2030 target of 26 % reduction of greenhouse gas emissions, 0,552 BJPY was newly allocated for "Expenses for investigation to discuss mid- to long-term measures to reduce greenhouse gas emissions in response to the Paris Agreement." MoE also newly started the "Project to establish a model to concentrate urban functions in local communities and to enhance resilience" (0,1 BJPY), aiming to promote concentration of urban functions.

The **Ministry of Land, Infrastructure, Transport and Tourism (MLIT)** obliges the buildings to conform to the energy conservation standards, in response to the "Act on Improvement of Energy Consumption Performance of Buildings", the "Revised Act Concerning the Rational Use of Energy (Energy Saving Act)" and so on. As a budget item to realize these efforts, the budget was continuously allocated to the "Green housing in local community" (11,4 BJPY), etc. Moreover, 9,068 BJPY was allocated for the "Enhancement of disaster prevention functions of governmental facilities which act as disaster prevention bases," and 5,4 BJPY was allocated for "Expenses related to sewage projects" which is designed to promote disaster prevention and reduction measures for sewage facilities. In these efforts, the introduction of renewable energy is also a significant issue. In order to secure safety of maritime transportation routes in case of disaster, the budget amount for "Disaster prevention measures for aids to navigation" was increased from 2,42 BJPY in FY 2016 to 4,91 BJPY.

The **Ministry of Agriculture, Forestry and Fisheries (MAFF)** is continuously implementing a subsidy program to introduce PV systems in facilities for agriculture, forestry and fisheries, in order to promote introduction of renewable energy to these industries. MAFF is promoting the introduction of renewable energy with the initiative of local communities, and allocated 0,146 BJPY, about the same amount as FY 2016 for "Measures to promote introduction of renewable energy in agricultural, forestry and fishing villages," which is designed to promote development of local agriculture, forestry and fishing industries.

The **Ministry of Education, Culture, Sports, Science and Technology (MEXT)** has been actively promoting the introduction of renewable energy in relation to promoting measures to improve quake resistance of educational facilities and measures against aging facilities. MEXT has been continuously committed to "Realization of clean and economically efficient energy system," which aims to promote R&D to overcome energy and environmental issues. MEXT will newly allocate 0,4 BJPY for the "Project to create future society (promotion of high risk and high impact R&D)," which is designed to promote R&D on highly innovative energy technology.

Among **local authorities**, a large number of municipalities formulated visions and action plans to expand the introduction of renewable energy such as PV power generation. Through partnerships with private enterprises, local production and local consumption of electricity have been increasingly promoted. Meanwhile, amid the rapid expansion of PV dissemination, co-existence with community and long-term stable operation have become significant subjects, which has led to formulating ordinances and guidelines for appropriate installation of PV systems nationwide.

R&D, D

R&D

As for R&D activities of PV technology, the New Energy and Industrial Technology Development Organization (NEDO) conducts technology development towards commercialization, which is administered by METI, and the Japan Science and Technology Agency (JST) conducts fundamental R&D, which is administered by MEXT.

NEDO advances "Development of high performance and reliable PV modules to reduce levelized cost of energy" (FY 2015 to FY 2019), which is designed to develop mainly PV device technology and technology to evaluate the reliability of PV modules, as a five-year project based on the NEDO PV Challenges, a guidance for technology development that was formulated in September 2014. As accomplishments of this project, the world's highest level conversion efficiencies were achieved on crystalline silicon (c-Si), CIGS thin-film, perovskite and III-V thin-film solar cells or modules. In 2017, Kaneka achieved 26,7 % conversion efficiency on a heterojunction back-contact type solar cell and 24,5 % on module, while Solar Frontier achieved 22,9 % on a CIS thin-film solar cell (around 1 m²) and 19,2 % on a Cd-free submodule (30 cm x 30 cm). From a consortium on perovskite PV led by The University of Tokyo, Toshiba achieved 10,5 % on a film substrate (10 cm x 10 cm) and Panasonic achieved 12,6 % on a glass substrate module (20 cm x 20 cm, 35 cells in series). NEDO also conducts "Technological development project for improvement of PV system efficiency and operation and maintenance (O&M) (FY 2014 to FY 2018)" and "Development of Solar Power Recycling Technology" project (FY 2014 to FY 2018). For technology development to reduce BOS cost and to improve system efficiency, four projects were newly selected in 2017, which are designed to develop technology to lower cost and improve efficiency of PV systems by using building-integrated PV (BIPV) modules and bifacial PV modules.

Under the "Strategic Creation Research Promotion Program" promoted by JST, research themes on fabricating smart silicon ingot for solar cells by utilizing machine learning of data and on exploring innovative materials for solar cells were selected as new research themes for FY 2017. Also, as one of the technological fields "PV cells /modules and solar energy utilization system" under the "Advanced Low Carbon Technology Research and Development Program (ALCA)", development on PV-related technology is continued, focusing on high quality silicon quantum dot PV, organic thin-film PV (OPV) and perovskite PV technology. Under the ALCA project, R&D on the next-generation storage batteries is also underway as a specially-prioritized technology field. From FY 2017, JST started the "Future Society Creation Project" based on the Fifth Science and Technology Basic Plan (FY 2016 to FY 2020). Under this project, "Realization of low-carbon society with 'game-changing technology'" was set forth as one of the prioritized themes for projects to be selected in FY 2017, and PV was set as an energy creation technology. Two R&D projects, one on the Pb-free perovskite solar cell and the other on the ultra-thin type crystalline silicon (c-Si) triple junction solar cell were selected. For these projects, the research facilities within FREA, Fukushima Renewable Energy

Institute of AIST, National Institute of Advanced Industrial Science and Technology will be utilized. Under the "Future Society Creation Project", collaboration is made with ALCA projects as well as the "Unexplored challenge 2050" which started in FY 2017 as one of the leading programs on energy and environment by NEDO. This collaboration is expected to create synergies for facilitating the projects.

Demonstration

Demonstration research related to PV technology is mainly promoted by NEDO. Under the "Technological development project for improvement of system efficiency and operation and maintenance (O&M) (FY 2014 to FY 2018)", development and demonstration are being conducted on technologies to increase the power generation amount by improving functions of BOS, technologies to reduce BOS cost including installation cost, snow load test, experiment on wind pressure resistance as well as sink test, in order to secure safety of PV power generation facilities. NEDO also conducts "Program to support technology innovation of new energy by venture capital firms (formerly called New Energy Venture Business Technology Innovation Program) (from FY 2007)", aiming to commercialize developed technologies in four phases; a feasibility study, fundamental research, R&D for commercialization and large-scale demonstration research. In FY 2017, a demonstration started on a system to collect energy from tracking type concentrating PV system, which generates power and collects heat at the same time. As new research themes, 10 projects related to PV power generation mainly for R&D on commercialization, and a demonstration project on MW-scale large-capacity storage system were newly selected.

Demonstration activities on technologies for the utilization of PV system are conducted mainly abroad by METI and NEDO in demonstration projects aiming at realizing smart communities and improving storage technology of PV electricity as well as technology to optimize electric consumption (automatic demand response (ADR), ICT technology). These projects are aiming at global market development by the localization of technologies to meet the diverse needs of different countries and regions. Under the "International demonstration project on technology and system to improve efficiency of energy consumption", NEDO conducted PV-related demonstration projects in other countries including Indonesia, Germany, India, Canada, the USA and Portugal in FY 2017.

NEDO also conducted a demonstration project on technology to address global warming from FY 2011 to FY 2017 under the Joint Crediting Mechanism (JCM). Under the JCM, an investigation on the formation of demonstration projects was also conducted. In FY 2017, a project on a floating PV system (Vietnam) and a project on the introduction of a solar panel cleaning robot (Saudi Arabia) were selected.

Furthermore, in Japan, demonstration projects on large-capacity storage systems are being conducted by electric utilities as part of support programs by METI and MoE, aiming to expand possible grid connection capacity of renewable energy and to control the grid.



Fig. 3 - PV System for a Parking Lot (Spa Resort Hawaiians) (Iwaki City, Fukushima Prefecture). 2.1 MW Multicrystalline silicon PV module (by Yingli, 275 W x 7,627 modules).

Supported by METI, a technical demonstration project on a virtual power plant (VPP) is also conducted in the form of a large-scale consortium. In addition to VPP demonstration in combination with a forecast of PV power generation amount, demonstration on utilization of electric vehicles (EVs) with the participation of auto manufacturers, as well as demonstration on utilization of frequency control system using residential storage batteries started in 2017. METI and MoE also conduct a demonstration project on net zero energy building (ZEB) and a large number of PV technologies were selected for energy creation facilities. NEDO also started a demonstration test on CO₂-free hydrogen using PV and other renewable energy sources. Electric utilities and energy service companies started discussion or demonstration to develop an electricity trading service by using block chain technology.

INDUSTRY STATUS AND MARKET DEVELOPMENT

In the PV cell/ module and PV system business, while the PV module shipments in the Japanese market are stabilizing, annual demand has continued declining. In addition to the declining demand mainly for industrial applications, price reduction both home and abroad as well as impacts of yen's appreciation resulted in the decrease in revenue and profit for businesses, or a tendency to go into the red. Manufacturers are aiming to improve their business performances by reviewing their cost structure through cultivation of overseas emerging markets, launch of high performance and high quality products, production adjustment, reorganization of production framework and so on. In order to improve competitiveness of the PV business, some are reorganizing their manufacturing bases. Panasonic plans to terminate production of PV modules at its Shiga Factory at the end of FY 2017 then ending March 2018 and to start to sell HIT solar cells as a single product. Solar Frontier will concentrate its manufacturing bases of the current CIS PV modules and promote shifting to manufacturing the next-generation products. Sharp plans to transfer its PV business units, except for the manufacturing unit to its sales subsidiary.

Overseas manufacturers are enhancing business development, aiming to increase their market share in Japan. They launched high value-added PV modules, packaged systems and storage systems for zero energy housed (ZEH), while continuing efforts on cost reduction. Domestic manufacturers also launched new products, mainly for residential applications. They proposed high efficiency and high output PV modules using PERC technology, bifacial PV modules, high durability PV modules, product lineup applicable to various types of roofs, as well as packaged products consisting of a PV module, storage battery and HEMS for ZEH and self-consumption.

In the PV inverter business, major manufacturers launched new products one after another. They are working on reducing the cost of installation by introducing a variety of products to meet the needs of customers such as smaller and lighter products, products for residential and distributed systems and for outdoor installation, products for salt-damaged areas, products without limitation on the number of interconnected units, products for power supply from EVs, products for which storage batteries can be installed afterwards, products applicable to 1,000/ 1,500 VDC, as well as products responding to output curtailment. Cultivation of overseas markets is further expanding. The inverter manufacturers are aiming to expand their business in North America, Southeast Asia, South America, the Middle East and Europe, in the form of the energy solution business. Their overseas factories are starting operation one after another.

In the supporting structure and foundation industry, some manufacturers developed new products realizing total cost reductions through reduction in the number of components and improvement of installability, while others heightened their cost competitiveness through purchasing components from Asia.

In the storage battery industry, manufacturers are launching lithium-ion storage batteries for residential applications one after another. New products using storage batteries made by overseas manufacturers were launched and production of storage batteries also started in Japan. Mergers and acquisitions (M&As) of manufacturers have advanced. Panasonic started mass production of lithium-ion batteries at a Tesla factory (USA). Murata Manufacturing acquired the battery business from Sony, while NEC is reportedly considering withdrawing from the lithium-ion battery business. Furthermore, announcements were made on development of low-cost storage battery systems to mitigate output fluctuations for MW-scale PV power plants, multi-functional applications at virtual power plants (VPPs) taking advantage of communication function, as well as development of ceramic all-solid-state battery. In overseas markets, trading companies and manufacturers are expanding sales of large-sized storage systems and developing the storage service.

Among manufacturers of manufacturing equipment, Mitsubishi Diamond Industrial and Toshiba Mitsubishi-Electric Industrial Systems Corporation (TMEIC) received an order from a Chinese CIGS thin-film PV module manufacturer.

In the housing and construction industry, activities on zero energy houses (ZEH) are growing, mainly among major housing companies and housing equipment manufacturers. LIXIL TEPCO Smart Partners,

a joint venture company between LIXIL and TEPCO Energy Partner, started a new service to realize no PV installation cost and enable reduction in electricity bills. Sekisui House started the sales of a condominium which realized ZEH for all the dwelling units, while Kyocera and Daito Trust Construction completed a rental housing which satisfies ZEH standards. Also, announcements on business partnerships and enhancement targeting the existing residential market and proposals were made by trading companies on residential PV systems made by overseas manufacturers which offer a variety of combinations.

In the EPC and PV power generation business sectors, development of large-scale PV projects has advanced in Japan and PV projects with a capacity of several dozen MW were continuously constructed and started operation. Plans for PV projects with a capacity of over 100 MW were also announced. New plans were also announced on the installation of PV systems with storage batteries, floating PV systems, as well as large-scale solar sharing (installation of PV systems on farmland while continuing farming activities). Trading of MW-scale PV projects in operation has been expanding mainly among major business operators. Overseas deployment has also been accelerating and announcements were made also on the development of large-scale PV power plants, PV-wind hybrid power plants and distributed PV projects, as well as plans to supply electricity from natural energy using green electricity certificates. Targeting the markets with high growth potential such as Asia, Africa and South America, companies are cultivating markets through setting up local operation bases. Among them, Marubeni Corporation entered into a long-term power purchase agreement (PPA) with Abu Dhabi Water and Electricity Company (ADWEC) for a 1 177-MW PV project. Such activities are significantly contributing to reducing the cost of PV power generation.

In the area of PPS (power producer and supplier), electricity supply service with a high ratio of renewable energy (even 100 % in some cases) has started, in expectation for the start of a non-fossil value trading market. In order to promote local production and local consumption of energy, collaboration and support activities toward the establishment of regional PPS are gaining momentum. Business partnerships toward the aggregation business have also started. Demonstration tests on virtual power plant (VPP) have started across Japan, which are expected to apply to PV power plants and EVs. Development of large-scale hydrogen systems utilizing renewable energy has also started.

In the area of the PV power generation business support service, O&M service for PV systems has advanced. Activities include expansion and partnerships in the monitoring and maintenance business, improvement of efficiency of inspection service using drones, machine cleaning service and anti-stain coating service, one-stop contracting covering from construction of power plants to O&M, as well as differentiation of service by improving warranty service such as an extension of free-of-charge warranty period. O&M service providers have broadened their scope of business to cover low-voltage and

residential PV systems, in addition to MW-scale PV power plants. Among proposals of new services, a packaged service combining maintenance and damage insurance, risk diagnosis service and a service to evaluate future values started. Furthermore, some companies entered into overseas markets such as Southeast Asian countries. In the PV module recycling business, partnerships home and abroad and enhancement of processing capabilities made progress.

As for the finance-related business, investment in and loans for MW-scale PV projects home and abroad increased. In Japan, regional banks have strengthened their activities, planning to revitalize the regional economy through establishment of investment fund for renewable energy projects, syndicate loans for MW-scale PV projects as well as loans for solar sharing. In the secondary market, a fund to invest in operating PV power plants was established. In the asset management business for PV power generation, businesses are increasingly acquiring the needs for selling projects and contracting management. As a new insurance scheme, an insurance plan to guarantee failures of operating MW-scale PV projects was released. Also, infrastructure funds for supporting renewal of facilities including energy facilities were created one after another.

For supporting overseas deployment, efforts have been made on syndicate loan for large-scale PV power plants, support for introduction of PV systems utilizing JCM, as well as project finance for large-scale PV projects. Some projects are supported by Nippon Export and Investment Insurance (NEXI) through guaranteeing of losses and undertaking trade insurance, aiming to boost infrastructure export to developing countries.

REPUBLIC OF KOREA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

DONGGUN LIM, KOREA NATIONAL UNIVERSITY OF TRANSPORTATION



Fig. 1 - 1 638,48 kW PV system installed at Incheon Airport Terminal 2, Incheon, Korea.



Fig. 2 - Combined PV and solar thermal system, Samcheok-si, Gangwon-do, Korea.

GENERAL FRAMEWORK AND IMPLEMENTATION

Korea has to rely on imports for almost its entire energy demand due to its poor indigenous energy resources. In 2016, the dependency rate on imported energy, including nuclear energy, was 94,7 %. The Ministry of Trade, Industry and Energy (MOTIE) announced "The Implementation Plan for Renewable Energy 2030" on 20 December 2017, which aims to increase the proportion of renewable energy generation from 7 % to 20 % by 2030. Its goal is to establish 63,8 GW of renewable source capacity by 2030. Currently renewables can generate 15,1 GW. About 63 % of the new facilities will be in solar power and 34 % in wind. According to the plan, the Korean government will invest 110 trillion KRW (Korean Won, 1,070 KRW/USD) over the next decade to expand renewable energy infrastructure to ensure stable power supply instead of nuclear and coal-fired power generators.

The Korean government set "the 8th Basic Plan for Long-term Electricity Supply and Demand" in 2017 that is based on an estimated forecast for power generation over the next 15 years until 2031. Under the new energy roadmap, natural gas and renewable energy sources will have a greater share in the generation mix in terms of installed capacity. Renewable energy would account for 33,7 % of the installed capacity in 2030 compared with the current 9,7 %.

In Korea, FIT was terminated at the end of 2011. RPS replaced the FIT scheme from 2012. Under the RPS scheme, Korea's PV installation marked a tremendous jump to 1 121 MW in 2017. At the end of 2016, the total installed capacity was 4 502 MW.

NATIONAL PROGRAMME

Korea has been making an effort to increase the renewable energy portion of "national energy mix". The new goal was announced in 2014. In the target scenario, Korea's renewable energy share of primary energy supply will account for 11 % in 2035. That is same as the target of the first energy plan which was announced in 2008. Currently renewable energy is estimated to account for 4,7 % of total primary energy supply in 2016.

(1) RPS Programme

The RPS is a system that enforces power producers to supply a certain amount of the total power generation by NRE. The RPS replaced the FIT Scheme from 2012. In Korea, 18 (in 2017) obligators (electricity utility companies with electricity generation capacity exceeding the 500 MW) are required to supply 10 % of their electricity from NRE (New and Renewable Energy) sources by 2023; up from 2 % in 2012. In 2017, 1 121 MW was installed under this programme. The RPS is expected to be the major driving force for PV installations in the next few years in Korea with improved details such as boosting the small scale installations (less than 100 kW) by adjusting the REC and multipliers, and unifying the PV and non-PV markets.

(2) Home Subsidy Programme

This programme was launched in 2004 that merged the existing 100 000 Solar-Roof Installation Programme. Although the 100 000 solar-roof deployment project was to install PV system in residential houses, the One Million Green Homes Plan focuses on a variety of resources such as PV, solar thermal, geo-thermal, and small wind. In general, detached and apartment houses can benefit from this programme. The Government provides 60 % of the initial PV system cost for single-family and private multi-family houses, and 100 % for public multi-family rent houses. The maximum PV capacity allowed is 3 kW. In 2017, 23,3 MW was installed under this programme.

(3) Building Subsidy Programme

The Government supports a certain portion (depending on the building type) of installation cost for PV systems (below 50 kW) in buildings excluding homes. Various grid-connected PV systems were installed in schools, public facilities, welfare facilities, as well as at universities. In 2017, 6,5 MW was installed under this programme.

(3) Regional Deployment Subsidy Programme

In an effort to improve the energy supply & demand condition and to promote the development of regional economies by supplying



Fig. 3 - 142 kW roof mounted PV system installed by PV rental programme, Seoul, Korea.

region-specific PV system that are friendly to the environment, the government has been promoting a regional deployment subsidy programme designed to support various projects carried out by local government. The government supports up to 50 % of installation cost for NRE (including PV) systems owned and operated by local authorities. In 2017, 12,1 MW was installed under this programme.

(4) Convergence and Integration Subsidy Programme for NRE

A consortium led by either local authority or public enterprise with NRE manufacturing companies and private owners can apply for this subsidy programme. This programme is designed to help diffuse the NRE into socially disadvantaged and vulnerable regions and classes such as islands, remote areas (not connected to the grid), long-term rental housing districts, etc. Local adaptability is one of the most important criteria, thus the convergence between various NRE resources (PV, wind, electricity and heat) and the complex between areas (home, business and public) are primarily considered to benefit from this programme. In 2017, 5,6 MW was installed under this programme.

(5) Public Building Obligation Programme

The new buildings of public institutions, the floor area which exceeds 1 000 square meters, are obliged by law to use more than 21 % (in 2017) of their total expected energy usage from newly installed NRE resource systems. Public institutions include state administrative bodies, local autonomous entities, and state-run companies. The building energy obligation share will increase up to 30 % by 2020. In 2017, 39,9 MW was installed under this programme.

(6) PV Rental Programme

Household owners who use more than 350 kWh of electricity can apply for this programme. Owners pay PV system rental fee (maximum monthly 70 000 KRW which, on the average, is less than 80 % of the electricity bill) for a minimum of seven years and can use the PV system with no initial investment and no maintenance cost for the rental period. PV rental companies recover the investment by earning PV rental fee and selling REP (Renewable Energy Point) having no multiplier. In 2017, 15,9 MW was installed under this programme.

R&D, D

The KETEP (Korea Institute of Energy Technology Evaluation and Planning) controls the biggest portion of the MOTIE-led national PV R&D budget and managed total 57 BKRW in 2017. It has four main directions for the revitalization of the PV industry. (1) Development of Low Cost PV Cell and Module for Securing Economic Efficiency (2) Development of PV Materials and Components for Improving Industrial Competitiveness (3) Demonstration of Large-scale PV System (4) Development of High PV Penetration Models.

INDUSTRY AND MARKET DEVELOPMENT

The supply chain of crystalline silicon PV in Korea is complete, from feedstock materials to system installation.

TABLE 1 - CAPACITY OF PV PRODUCTION CHAIN IN 2017

POLY-SI (TON)	INGOT (MW)	WAFERS (MW)	CELLS (MW)	MODULES (MW)
82 000	3 250	3 250	6 300	8 290

Production of Feedstock and Wafer: OCI achieved its total production capacity of poly-silicon feedstock up to 52 000 ton. Woongjin Energy is operating a 1,5 GW silicon ingot capacity plant. Nexolon has a capacity of 1,75 GW in silicon wafers.

Production of Photovoltaic Cells and Modules: Hanwha Q CELLS Korea built a 3,5 GW photovoltaic cell plant and a 1,5 GW module plant. LG Electronics has a capacity of 1,5 GW in both c-Si solar cells and modules. Hyundai Heavy Industry has a capacity of 600 MW in both c-Si solar cells and modules. Shinsung E&G has a capacity of 600 MW and 200 MW in the c-Si solar cells and modules, respectively.

The RPS scheme was the main driver for PV installation in 2017, and a remarkable size of 1 121 MW was recorded. At the end of 2016, the total installed PV capacity was about 4 502 MW, among them, the PV installations that were made under RPS scheme accounted for 73 % of the total cumulative amount.

MALAYSIA

PV TECHNOLOGY STATUS AND PROSPECTS

DATUK BADRIYAH BINTI ABDUL MALEK, MINISTRY OF ENERGY, GREEN TECHNOLOGY & WATER (KETHA)

CATHERINE RIDU, SUSTAINABLE ENERGY DEVELOPMENT AUTHORITY MALAYSIA



Fig. 1 - Floating PV System 270 kW, Rembau, Negeri Sembilan Darul Khusus (Photo: Sterling Fiesta Sdn Bhd).

GENERAL FRAMEWORK AND IMPLEMENTATION

In 2017, PV market growth was driven by the feed-in tariff (FiT), Large Scale Solar (LSS) and Net Energy Metering (NEM) programmes. The FiT and NEM are implemented by the Sustainable Energy Development Authority (SEDA) Malaysia and LSS by the Energy Commission (EC) of Malaysia. As of the end of 2017, the cumulative PV market from the FiT, LSS and NEM was 373,74 MW. In 2017 alone, the PV market grew by 159,05 MW of which the FiT contributed 139,37 MW, LSS 14,43 MW and NEM 5,25 MW. The main actors involved in the FiT, LSS and NEM are the Ministry of Energy, Green Technology and Water, SEDA, the EC, the distribution licensees, RE developers, and the PV service providers.

NATIONAL PROGRAMME & MARKET DEVELOPMENT

In Peninsular Malaysia, the electrification rate is almost 100 % while in East Malaysia, the electrification rate is just slightly above 90 %. In this respect, the PV market in Malaysia is dominated by grid-connected PV systems whilst off-grid PV applications are miniscule compared to grid-connected ones. This report only focuses on the grid-connected PV market in the country of Malaysia save for the state of Sarawak. This is because the three prevailing PV programmes (i.e. FiT, LSS and NEM) are not applicable to Sarawak as the state is governed by its own electricity supply ordinance.

FiT Update: The FiT scheme began in December 2011 and is funded by a surcharge imposed on electricity bills of 1,6 %. By 2017, the available quota for PV under FiT was reduced due to constraint in the Renewable Energy (RE) Fund. In 2017 alone, a total of 798 applications for PV were approved with a total capacity of 13,77 MW. The breakdown of approved applications is as follows: individuals (753 applications 5,90 MW), community (75 applications 1,95 MW), and non-individuals (20 applications 6,07 MW). As of 31 December 2017, a cumulative installed capacity of 354,03 MW of PV projects were operational of which the 75,89 MW was for the individuals, 5,28 MW was for the community and 272,86 MW was for the non-individual PV projects.

This translated to 8 222 individuals, 264 communities, and 507 non-individuals feed-in approval holders. The installed PV capacity in 2017 alone was 139,37 MW; 17,33 MW from individuals, 1,81 MW from communities, and 50,55 MW from non-individuals. More information on PV quota, FiT rates and operational capacity can be viewed at www.seda.gov.my.

LSS Update: The LSS was implemented in 2016 as an organic progression of the FiT scheme. The cumulative quota awarded under the LSS as of the end of 2017 was 1 207,88 MW_{ac} [1], of which 250 MW_{ac} was granted direct awarded under fast track programme and the rest was based on competitive bidding held in two tranches; 400,90 MW in 2016 and 556,98 MW in 2017. As of the end of 2017, the total capacity achieving commercial operation was 12 MW_{ac} (or 14,43 MW). The remaining capacity is expected to achieve commercial operation between 2018 and 2020.

NEM Update: The NEM has been implemented since November 2016. The NEM permits an eligible electricity consumer to install a PV system primarily for his own use and the excess energy to be exported to the grid. The credit on the excess energy is based on prevailing Displaced Cost and credit can be rolled over for a maximum of 24 months. While the FiT and LSS have faced much success in terms of application submission, the NEM take-up rate has been slow. The key reasons for the low take-up rate are due to low electricity tariff rates (at the point of self-consumption) as the tariffs are still being subsidized and the low prevailing Displaced Cost (at the point of sale to the grid as a result of surplus). A total of 100 MW per year has been allocated from 2010 – 2016, making a total of 500 MW. As at end of 2017, the cumulative total number of applications approved was 131 of which 93 were from domestic, 29 from commercial and 9 from industrial sector. The cumulative capacity approved was only 5,28 MW of which 0,60 MW was from domestic, 1,96 MW from commercial and 2,72 MW from industrial sector.

[1] Unless specified, all PV capacities in this report are dc-rated.

RESEARCH & DEVELOPMENT

Research and development activities in PV are largely under the purview of the Ministry of Science, Technology and Innovation. Universities and research institutes in Malaysia undertake the main R&D areas.

INDUSTRY DEVELOPMENT

On the PV manufacturing front, Malaysia remains a significant PV producer (after China and Taiwan). It was estimated that over 90 % of the PV products were exported to Europe, the USA and Asia. The USA reported that the largest import of solar modules is from Malaysia (36 %).

In 2017, the total metallurgical grade silicon (MGS) and polysilicon manufacturing nameplate capacity remained at 9,8 kilotons with employment of **507**. For ingot, wafer, solar cells and PV modules manufacturing, the total estimated nameplate capacity was 15 365,4 MW with employment of 17 361. Figure 2 shows the major PV manufacturing statistics in Malaysia classified under four categories for 2017 and 2018 (estimate): Metallurgical and Poly Silicon, Ingot and Wafer, Solar Cells, and PV Modules.

Within the PV industry, there were 124 PV service providers active in the market in 2017. The list of these registered PV service providers for 2018 can be found in www.seda.gov.my.

METAL SI & POLY SI		2017		2018 (ESTIMATE)	
No.	Company Name	Capacity (kilo ton)	Employment	Capacity (kilo ton)	Employment
1	OCIM Sdn Bhd (Poly-Si)	9,8	507	14	520
	Total	9,8	507	14	520
INGOT/WAFER		2017		2018 (ESTIMATE)	
No.	Company Name	Capacity (MW)	Employment	Capacity (MW)	Employment
1	LONGI (ingot)	1 000	2 113	1 000	2 851
2	LONGI (wafer, P-type mono)	1 000		1 000	
	Total	2 000	2 113	2 000	2 851
CELL		2017		2018 (ESTIMATE)	
No.	Company Name	Capacity (MW)	Employment	Capacity (MW)	Employment
1	SunPower (N-type Mono-Si)	826,4	1597	764,4	1 400
2	Hanwha Q-Cells (P-type Multi-Si)	1 600	2 000	1 800	2 260
3	TS Solartech (Mono & Multi-Si)	240	200	240	200
4	Jinko Solar (Multi-Si)	1 500	4 300	1 500	4 300
5	LONGI	600	Incl. above	650	Incl. above
6	JA Solar (Multi-Si)	1 000	1 500	1 000	1 500
	Total	5 766,4	9 597	5 954,4	9 660
MODULE		2017		2018 (ESTIMATE)	
No.	Company Name	Capacity (MW)	Employment	Capacity (MW)	Employment
1	First Solar (CdTe thin film)	2 071	2 800	2 344	2 800
2	Flextronics (OEM for crystalline)	513	600	473	600
3	Panasonic (HIT N-type mono crystalline)	469	1 167	370	1 165
4	MSR (Mono & Multi-crystalline)	100	71	120	110
5	Solartif (Multi-crystalline)	0,7	27	1	130
6	PV HiTech (Multi-crystalline)	0	8	3	15
7	LONGI	600	Incl. above	900	Incl. above
8	Hanwha Q-Cells	1 600	Incl. above	1 800	Incl. above
9	Jinko Solar (Multi-crystalline)	1 300	Incl. above	1 300	Incl. above
11	Promelight (Mono & Multi-crystalline)	100	33	100	30
	Total	6 753,7	4 706	7 411	4 850

Fig. 2 - Major PV Manufacturing Statistics in Malaysia.

MEXICO

PV TECHNOLOGY: STATUS AND PROSPECTS IN MEXICO

AARON SANCHEZ-JUAREZ & ANTONIO DEL RIO PORTILLA – SPECIAL COLLABORATION FROM: O. RUIZ SOLORIO, J. ORTEGA CRUZ & E. O. ANGEL RUIZ – INSTITUTO ENERGIAS RENOVABLES, UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

GENERAL FRAMEWORK AND IMPLEMENTATION

The Energy Reform approved by the Mexican Congress (2013) is a step towards the modernization of the energy sector in Mexico. One of its purposes is to promote the use of clean energies in the electrical sector. The Law for the Electrical Industry (LIE VIII-11-2014) and the Law for Energy Transition (LTE XII-24-2015) are both the regulatory frame to promote and accelerate the transition towards the use of more environmentally friendly energies, the reduction on fossil fuels and the efficient use of energy.

The Energy Ministry (SENER), under the Energy Reform, has set as a specific goal that a minimum contribution of clean energy in the generation of electric power must be 25 % by 2018, 30 % by 2021 and 35 % by 2024 [1]. To fulfill this goal, some of the objectives that the Energy Reform seeks to achieve are the following [2]:

- Modernize and strengthen PEMEX and the Federal Electricity Commission (CFE) as 100 % Mexican Productive Enterprises of the State.
- Allow the nation to exercise, exclusively, the planning and control of the National Electric System (SEN), in benefit of a competitive system that allows the reduction of the prices of electricity.
- Attract more investment to the Mexican energy sector to boost the country's development.
- Have a greater supply of energy at lower prices.
- Guarantee international standards of efficiency, quality and reliability of supply, transparency and accountability.
- Promote development including social responsibility and protect the environment.

One of the most important results of the Energy Reform was the establishment of long-term electricity auctions, with which generators enter into contracts with large consumers, either CFE or other companies. To date there have been three long-term public auctions with an investment of about 8 600 MUSD, 65 new power plants, mainly solar and wind power will be installed in 17 states of the country. Thus, by 2020, there will be four times the wind and solar installed capacity that was before the Energy Reform [3].

Another mechanism that created the Energy Reform is the Clean Energy Certificates (CEC) as financial instruments, which establish that a minimum of 5 % of the total energy consumption of large users must come from less polluting sources, increasing this percentage to 13,9 % by 2022.

During the first auction, the price per package of MegaWatt-hour energy and CEC was 41,80 USD, and for the third auction in November 2017, they were sold at 20,57 USD [4]. Table 1 present the amount of the contracted capacity and the average price for the MWh as a result of the three auctions carried out in México in the last three years. The third auction, which began in April 2017 and ended in November 2017, aimed at the construction of 15 power plants in the country, nine solar farms out of a total of 1 323 MW, five wind farms with a combined capacity of 689 MW, and a 550 MW gas plant. The winning



Fig. 1 - Camargo Solar Plant: Granja Solar Fotovoltaica Camargo, Chihuahua, Mexico; 35,5 MW (Photo: balamfund.com).



Fig. 2 - Parque Solar Coahuila in Matamoros, Coahuila, Mexico; 22,7 MW (Photo: <https://www.elsiglodetorreon.com.mx/noticia/fotos.php?nota=1441166>).



Fig. 3 - Solar plant Jalisco I; Zacoalco de Torres, Jalisco. Mexico; 8,0 MW (Photo: <https://www.fortius.com.mx/node/50>).

TABLE 1 - CAPACITY CONTRACTED IN THE LONG-TERM AUCTIONS [5]

CONTRACTED CAPACITY	FIRST AUCTION	SECOND AUCTION	THIRD AUCTION
Solar	1 691 MW	1 853 MW	1 323 MW
Average Price per MWh	41,80 USD	33,47 USD	20,57 USD

[1] SENER, *Reporte de Avance de Energías Limpias*, 2017

[2] SENER, *Reforma Energética*, 2013

[3] SENER, *Boletín Volumen 4 No 32*, 2018

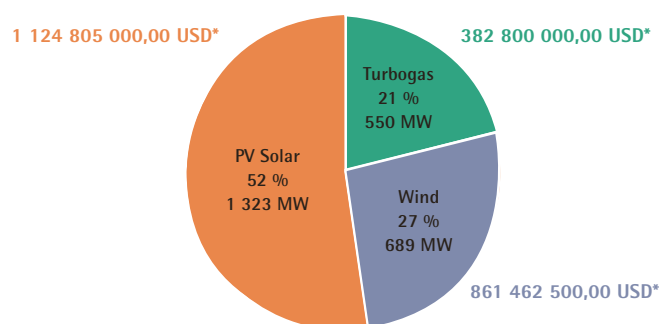
[4] SENER: *In the third Mexican Electric Auction, one of the lowest prices was obtained internationally said Pedro Joaquin Colwell*, Energy Minister 2017.

[5] CENACE, *third Mexican Electric Auction*, 2017

energy purchase agreements will provide 5 492 575 MWh per year, the energy that will be acquired by Spain's Iberdrola and Cemex Mexico companies, which participated together with CFE as buyers. The results of the third long-term auction are presented in Table 2, and the investment for them in Figure 4.

TABLE 2: WINNERS OF THE THIRD LONG-TERM AUCTION

	COMPANY	CEL/YEAR	ENERGY (MWH/YEAR)	GUARANTEED CAPACITY (MW)
1	Enel Rinnovabile S.A. DE C.V. (Enel)	2 089 610,00	2 089 611,65	-
2	Consortios Engie Solar-Eólico (Engie)	1 653 620,00	1 508 906,05	30,62
3	Neon International S.A.S. (NEON SAS)	770 864,00	616 692,00	-
4	Canadian Solar Energy Mexico, S. de R.L. de C.V. (Canadian Solar)	764 826,00	652 083,00	-
5	X-ELIO ENERGY, S.L. (Gestamp - KKR & Co)	483 727,00	435 354,48	10,00
6	Mitsui & Co., Ltd. and Trina Solar (Netherlands) Holdings B.V	189 928,00	189 928,00	-
7	Compañía de Electricidad los Ramones S.A.P.I. DE C.V. (Invenergy Investment Company LLC)	-	-	499,95
8	Energía Renovable del Istmo II S.A. DE C.V. (Acciona)	-	-	52,04



*Millions of USD

Fig. 4 – New capacity and investment for technology (CENACE, 2017).

NATIONAL PROGRAMME

The new laws enacted within the Mexican Energy Reform contemplate the inclusion of renewable energy in the electricity sector to achieve a penetration of 35 % of electricity produced with clean energy. In December 2016, the Energy Regulatory Commission (CRE) approved the new distributed generation regulation through operation schemes that allow the electric power generated to be used to satisfy the consumption requirements of an end user or to be sold through a supplier (CRE, 2017).

Before the Energy Reform, the development of distributed generation was limited, since the electrical energy generated by solar panels was destined to self-consumption, without the possibility of selling it. The regulation approved by the CRE includes compensation schemes for net metering, net billing, and total sales, which will allow customers to generate their own electricity and obtain income from marketing their surpluses. It should be noted that similar schemes are used successfully in many states of the United States, Canada, and various European countries.

Likewise, a legal instrument called the Contract Model for the interconnection of distributed generation plants has been approved, which includes the terms for the sale of energy as well as the methodology to determine the amounts associated with the sale of power and the general technical specifications applicable to distributed generation power plants.

This regulation, together with the Manual of Interconnection of Generation Plants with a capacity of less than 0,5 MW (published by the Energy Ministry in December 2016) will allow open access. However, this is not unduly discriminatory to the electricity grid, the simplification of procedures, the ease of generating and selling small-scale electric power according to the preferred scheme, and the incorporation of clean energies in the Mexican electricity system.

R&D

The Mexican Center for Innovation in Solar Energy, CeMIESol continues to be at the forefront of research in the development of new materials for photovoltaic applications. One of the main strategic projects is the consolidation of the project "National Laboratory for the Evaluation of Modules and Photovoltaic Systems, LANEV", as a third-party Test Laboratory, which provides the services of certification of photovoltaic modules to the national photovoltaic industry.

To expand the CeMIESol project and create a portfolio of projects oriented to the commercialization of products, patents, and services, a new call for projects was opened. One of the approved projects was the *Study of the Degradation in Modules and Photovoltaic Systems*, whose main objective is to offer the diagnostic service for the analysis of degradation phenomena in photovoltaic technology, and to consolidate the offer of services that are developed in the testing lab LANEV.

At the beginning of 2017, 13 patent applications, 188 scientific publications, three business plans and 79 new professionals have been

trained as a specialized human resource, derived from the results of each of the 22 CeMIESol projects.

Although the current photovoltaic projects related to the research and technological development on solar cells within this initiative are in the middle phase, there are very satisfying results in the development of solar cells with conventional semiconductors and new materials.

INDUSTRY AND MARKET DEVELOPMENT

From the Electric Reform, the photovoltaic market in Mexico, both in the manufacturing of modules and in the installations, has grown exponentially. With respect to photovoltaic systems, considering a power installed in the low range (less than 50,0 kW) and medium scale (up to 500,0 kW), there has been an increment on the demand and growth of photovoltaic installations. This growth has been not only in systems interconnected to the network for domestic residences, buildings, factories, hospitals; but also in off-grid systems for domestic use funded with the SENER Universal Electric Service Fund project (SENER-UESF), and for agricultural production projects. Table 3 shows a condensate of the projects in both low and medium scale, which have been installed or started on the 2017 year.

TABLE 3 – PROJECTS OF PHOTOVOLTAIC SYSTEMS INITIATED AND INSTALLED DURING 2017

STATE	POWER PEAK / SQUARE METERS / OTHER UNIT	BUILDING / INDUSTRY
Estado de Mexico	63,80 kWp	Offices
San Luis Potosi	71 000 m ²	Car Industry
Baja California	90,0 kWp	Hospitals
Oaxaca: SENER-UESF	7 500 Houses (130 Wp per house)	Rural communities
Baja California	10,0 kW	Orphanage
Yucatán: SENER-UESF	2 967 Houses (130 Wp per house)	Rural communities
Chiapas, Nuevo León and Tamaulipas: SENER-UESF	10 000 Houses (130 Wp per house)	Rural communities
CDMX	3,7 MW/h	Offices
Yucatán	5 Plants	Sewage treatment
Jalisco	499,0 kWp	Guadalajara University (UdeG)

In the range of large scales, high-power photovoltaic plants are playing a very important role in the development of this technology not only because of the attractiveness of the sale of energy through the PPA, but also as an opportunity towards the strengthening of the Mexican photovoltaic industry and its value chain. To date, there are nine Mexican companies manufacturing photovoltaic modules with a global annual estimated production of 220 MW. Table 4 presents the name of these companies as well as their power installed capacity.

TABLE 4 – MEXICAN PV MANUFACTURERS

NAME	ADDRESS	POWER CAPACITY (MW)
SOLARSOL: Producciones solares	Calle 73 No Ext 218E No Int 1 entre Av. Maquiladoras y Carretera a Dzitya, Col. Poligono Chuburna 97302, Merida Yuc, México; (+52) 999 941 2293; RFC: PSM1409036M6; contacto@solarsol.mx	20
SOLARVATIO	Calzada del Panteón #911; San Felipe del Agua; Oaxaca, Oaxaca. México; Email: contacto@ solarvatio.com; LADA: 01 800 212 0535; (+52) 951 205 7564; (+52) 951 516 7389	12
ERDM SOLAR	Mangana 1 Fraccionamiento El Rodeo; San Andres Tuxtla, Ver.; CP. 95765; Tel. (+52) 294 942 7520	165
SOLAREVER	Autopista México-Querétaro km 71.9, Noxtongo 2da Sección, Tepeji del Río de Ocampo; Tel. (+52) 773 733 3707; 733 0389; 733 0406, servicio@solarever.com.mx	12
SYDEMEX SOLAR	Av. Benito Juárez #358 B-Altos Colonia Juan José Ríos 1; Villa de Álvarez, Colima C. P. 28984; Tel Villa de Álvarez (+52) 312 308 7530, 308 7651 / Manzanillo: (+52) 314 335 3489; Email: ventas@sydemexsolar. com	12
SAYA: Fabricante de Paneles Solare	Moscatel 305, Col. Paso Blanco. Jesús María, Aguascalientes, México. 20905; (+52) 449 235-4516	12
SOLARNORTE	Isidoro Sepulveda #550, Bodega 15; Col. Titán, C.P. 66633, Apodaca, N.L.; Tel (+52) 811 505-0933 y 811 505-0920; info@solarnortesadecv.com	12
IUSASOL	Paseo de la Reforma No. 2608 Piso 7; Col. Lomas Altas, CP. 11950; México, D.F. (+52) 55 4170-7350y (+52) 55 5261-8800; contacto@iusasol.mx	125
SOLARTEC	Libramiento Querétaro-León Km. 4.6, Parque Apolo, Irapuato, Guanajuato, 36826; Teléfono: 01800 83 76527 ext. 3183. 01800 83-SOLAR; www.solartec.mx, info@solartec.mx	172,5

The great solar resource of Mexico and the decrease in the prices of photovoltaic technology have been factors of change in the paradigm concerning the initial cost of the use of such technology on a large scale. A project such as the New International Airport of Mexico City (NAICM) is an example of that. It is expected that NAICM has a solar plant to feed the energy to its installations. This amazing construction on 4 770 hectares will have almost four LEED (Leader in Energy and Environmental Design) buildings with low energy consumption (Secretaría de Comunicaciones y Transportes 2015). According to the enterprise Proyectos Mexico 2018, the dimension of this plant is over 40 MWp and represents an investment of 20 MUSD just for PV plant. Cemex, the national cement company, is another example. This company will build a photovoltaic plant in Huichapan, in the state of Hidalgo, as part of its plan to install a total of seven clean energy projects in the country. The project is called Cemex Huichapan Photovoltaic Plant, with a peak power of 15,4 MW.

Table 5 presents the PV projects that were installed and completed in 2017 or will be completed in 2018 (Gaceta Ecológica 2018)

TABLE 5 - PV PROJECTS THAT WERE INSTALLED AND COMPLETED IN 2017 OR WILL BE COMPLETED IN 2018 (GACETA ECOLÓGICA 2018)

NAME & COMPANY	POWER PEAK (MW)	STATE	DATE
Puerto Libertad and Tuto Energy a Acciona	404	Sonora	Due to 2018
La Trinidad I	283	Durango	In construction
Las Animas / Eosol	16,8	Durango	2014
Coahuila/ Macquarie	22,5	Coahuila	Project
Pachamama II, Enr NL S. A. DE C. V	330	Puebla	Project
San Pedro Enr NL S. A. DE C. V	99,9	Chihuahua	Project
La Barca; Vega Solar 10	200	Jalisco	Project
Palo Fierro Solar, Palo Fierro Solar S.R.L. DE C.V	80	Sonora	Project
Rumorosa Solar / Sierra de Suarez Holding S. DE R.L. DE C.V.	53,7	Baja California	Project
Framor Solar Plant 2, S.A. de C.V Guadalupe Saravia	315	Puebla	Project
Peñas Prietas Sonora Proyectos Transparentes S. de R.L. de C.V	133	Sonora	Project
General Cepeda, México Lindo Solar PV II, S.A. De C.V	153	Coahuila	Project

NAME & COMPANY	POWER PEAK (MW)	STATE	DATE
Central Fotovoltaica Ranchitos. Desarrollos Solares PV de México II, S.A. de C.V	301,5	Jalisco	Project
Alten Energías Renovables	400	Aguascalientes	Project
Alten Energías Renovables	350	Aguascalientes	Construction.
Tastiota, Canadian Solar	100	Sonora	Project
El Mayo, Canadian Solar	99	Sonora	Project
FV Bacabachi I, X-Elio	200	Sonora	Project
Abril 99, Engie Solar I	99	Sonora	Project
Pachamama, Neon	300	Aguascalientes	
Horus AG	95	Aguascalientes	
Others presented in the Agency of environmental and Natural Sources	754		Project

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THE NETHERLANDS

PV TECHNOLOGY STATUS AND PROSPECTS
OTTO BERNSEN, RVO, ENERGY INNOVATION



Fig. 1 - Renovation social housing in Goes, Province Zeeland, courtesy of Marsaki (Photo: Marsaki & RWS partner in wonen).

GENERAL FRAMEWORK

The Dutch PV market grew in 2017 with an estimated 853 MWp (National Solar Trend Rapport 2018) which is over 300 MWp more than in the previous year. The main ingredients for this steady acceleration are relatively low financing costs, low installation costs and certainty about the net metering scheme for the coming years, at least until 2020 for smaller systems. The market for larger solar systems (over 15 kWp) continues to grow and the main limiting factors in the near future will be grid integration and the availability of suitable surfaces in this densely populated country. The development of new solar systems and the integration of solar modules is supported by the national tenders.

The national Climate Goals are set on 16 % renewable energy sources (RES) in 2023 and no emissions in 2050. Notable in 2017 is the intended accelerated pace to replace natural gas as the main energy source in the Netherlands. Increased electrification of the energy system will be a major part of this trajectory.

NATIONAL PROGRAMMES

The national effort on energy innovation is led by the Top consortium for Knowledge and Innovation (TKI) for Solar under the flag of Urban Energy (see <http://topsectorenergie.nl/urban-energy>). The TKI Urban Energy is a public-private partnership and its goal is to further accelerate the development and application of solar power in the Netherlands, as well as to ensure that the added value to the Dutch economy is maximized. Supporting national schemes for exploitation of solar power are varied and complementary. For small systems a national net metering scheme exists and for larger systems over 15 kWp, the SDE plus scheme is available; which is basically a

reversed auction system. The total budget in 2017 for all renewable technologies amounted to 12 BEUR divided over two calls in spring and autumn.

For collective PV systems, a tax reduction system is in place called the "Postcoderoos", covering members that live nearby with a similar postal code. The number of local cooperative initiatives has risen with 100 new projects in 2017, accounting for 12,7 MWp installed capacity (Lokale Energie Monitor 2017). Several schemes are in place to stimulate investments by private companies and SMEs. An energy label is mandatory (the EPC) for newly built houses coming on the market, which stimulates the installation of roof top PV panels. As of 2020, all new buildings will need to be almost "energy neutral".

The "HE" or renewable energy subsidy, with 50 MEUR budget a year, is a generic innovation scheme for all renewable energy sources, including combinations with storage, targeting the Dutch Climate goals for 2030 and technologies that save on the SDEplus expenses in future years. The objective is the accelerated introduction of new products to the market in order to reach the national climate goals with lower expenses.

RESEARCH AND DEVELOPMENT ACTIVITIES

In 2017, much as in previous years, there exists a R&D budget for solar of 12 MEUR divided over the two program lines of the TKI "solar technologies" and "multifunctional building parts". In addition, there are separate programs for fundamental research (NWO and STW), for renewable energy, technical innovation in general and specific programs for SMEs.



Fig. 2 - Installation of ice/water storage tank Goes, Province Zeeland, courtesy of Marsaki (Photo: Marsaki & RWS partner in wonen).

The key research partnerships in these main focus areas are:

- SEAC (Solar Energy Application Centre; an initiative of ECN, TU-e, TNO and University of Utrecht) for systems & applications;
- Silicon Competence Centre (ECN, FOM-Amolf, TUD-Dimes and Tempres, Levitech en Eurotron) for wafer-based silicon PV technologies;
- Solliance (TNO, ECN, TU/e, Holst Centre, IMEC and FZ Jülich and DSM, VDL, DyeSol, Rexroth, Nano-C, SolarTek) for thin-film technologies.

Several academies have bachelor and master courses on solar technologies and the TUDelft has a very successful free massive online course (MOOC) "Solar Energy" by prof. Arno Smets.

Research into solar technologies, production and applications is regionally dispersed in the Netherlands over various universities including Utrecht, Leiden, Amsterdam, Delft, Nijmegen, Groningen, Eindhoven and at AMOLF in various groups like Nanoscale Solar Cells, Photonic Materials and Hybrid Solar Cells, see their website <http://www.amolf.nl/research/nanoscale-solar-cells/> and DIFFER <https://www.differ.nl/research/solar-fuels>.

INDUSTRY STATUS

In 2017, the manufacturing industry of machinery (led by Tempres, Eurotron, Levitech and VDL) has maintained their international market position. For encapsulation, DSM is a worldwide market leader; specifically with antireflective and anti-soiling coatings.

All parties in the Dutch Solar sector can be found for matchmaking activities on the mobile App Dutch solar sector. The App is available for IO (iPhone and iPad), see <http://nederlandseapp.nl/iphone-ipad/zakelijk-financien/tki-urban-energy-app-dvawpgf.html>

DEMONSTRATION PROJECTS

New market segments are being explored notably the integration of solar panels in buildings, infrastructure, including floating, and vehicles. In addition, the combination with storage technologies is a priority. In one of the demonstration project (IPIN Proseco project GOES) the storage of solar energy in ice (summer) and warm water (winter) provides a remarkably flat energy profile during the year for an average family; see Figure 2.

IMPLEMENTATION AND MARKET DEVELOPMENT

The PV market showed sustained growth and a continued acceleration in 2017 with an estimated added amount of 853 MWp.

Dutch Installed Capacity MWp/y and Accumulated

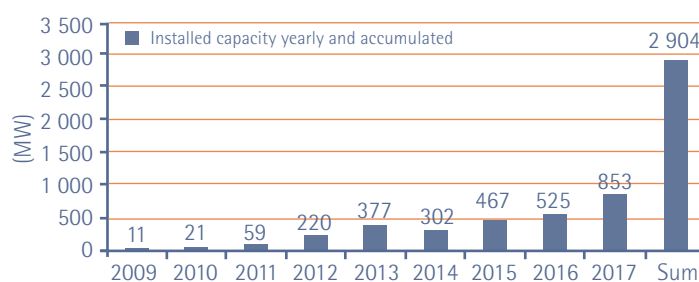


Fig. 3 - Preliminary estimation for the installed capacity in 2017 and the accumulated/sum based on the National Solar Trend Report, 2018. Definite figures follow in May 2018 by the CBS Statline.

NORWAY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS
TROND INGE WESTGAARD, THE RESEARCH COUNCIL OF NORWAY

GENERAL FRAMEWORK

Norway's electricity production is already based on renewable energy due to the availability of hydropower. In normal years the electricity production from hydropower exceeds the domestic electricity consumption by a significant margin. In 2017 hydropower generated 96 % of the total electricity production of 149 TWh, while the gross domestic electricity consumption was 134 TWh. The generation from wind power is increasing from year to year due to increased installed capacity, and is now approximately 2 % of the total electricity generation. The hydropower generator capacity can under normal circumstances satisfy peak demand at any time.

Norway and Sweden operate a common electricity certificate market to stimulate new electricity generation from renewable energy sources. This market-based support scheme is in practice not accessible for small scale producers due to the registration fees.

In this situation where electricity already is provided from renewable energy sources, PV systems are predominantly installed on residential and commercial buildings for self-consumption of the electricity produced by the systems.

NATIONAL PROGRAMME

Norway has no defined goals when it comes to implementation of PV technology. The electricity certificate market is technology neutral, and it is only relevant for hydropower, wind power, and large commercial rooftop PV installations. To compensate for this Enova SF subsidizes up to 35 % of the installation costs for grid connected residential PV systems at a rate of 10 000 NOK per installation and 1250 NOK per installed kW maximum capacity up to 15 kW. Enova SF is a public agency that supports new power generation and energy saving technologies.

Mandatory rules for access to the grid for sale of surplus electricity from privately operated PV systems were implemented in 2017. These rules exempt small suppliers of surplus electricity for some specific grid connection fees, and they facilitate sale of surplus electricity at net electricity rates.

Enova SF has programs that support energy efficiency projects for commercial buildings and residential apartment buildings, but these programs have had little impact on PV installation projects.

The municipality of Oslo had a capped support scheme for PV systems with a higher level of support (40 %) than the level that was available from Enova SF. This local support scheme was terminated when the available funds were fully allocated in September 2017, and it will not be renewed for 2018 and later. Only the Enova support will be available in the future.

RESEARCH AND DEVELOPMENT

The Research Council of Norway (RCN) is the main agency for public funding of research in Norway. Within the energy field it funds industry oriented research, basic research, and socio-economic research.



Fig. 1 - Efficient production of silicon feedstock is an important part of The Research Center for Sustainable Solar Cell Technology. Parts of this research are done with this prototype reactor for high rate pyrolysis of gaseous precursors (Photo: Jarle Nytingnes, Dynatec AS).

The total RCN funds for solar related R&D projects, mostly in PV, were approximately 110 MNOK (14 MUSD) for 2017. Most of the R&D projects are focused on the silicon chain from feedstock to solar cells research, but also related to fundamental material research and production processes.

The Norwegian Research Centre for Solar Cell Technology (www.solarunited.no) was replaced by The Research Center for Sustainable Solar Cell Technology (www.sosultech.no) in the first half of 2017. Leading national research groups and industrial partners in PV technology participate in the new center. The research activities are within silicon production, mono- and multi-crystalline silicon, solar cell and solar panel technology, and use of PV systems in northern European climate conditions. The total center budget is 240 MNOK (31 MUSD) over its duration (2017–2025).

There are six main R&D groups in the university and research institute sector of Norway:

- Institute for Energy Technology (IFE): Focuses on polysilicon production, silicon solar cell design, production, characterization, and investigations of the effect of material quality upon solar cell performance. A solar cell laboratory at IFE contains a dedicated line for producing silicon-based solar cells. Additionally, there are a characterization laboratory and a polysilicon production lab, featuring three different reactor types.
- University of Oslo (UiO), Faculty of Mathematics and Natural Sciences: The Centre for Materials Science and Nanotechnology (SMN) is coordinating the activities within materials science, micro- and nanotechnology.
- Norwegian University of Science and Technology (NTNU) Trondheim: Focuses on production and characterization of solar grade silicon.
- SINTEF Trondheim and Oslo: Focus on silicon feedstock, refining, crystallisation, sawing and material characterisation.
- Norwegian University of Life Sciences (NMBU): Focus on fundamental studies of materials for PV applications and assessment of PV performance in high-latitude environments.
- Agder University (UiA): Research on silicon feedstock with Elkem Solar. Renewable Energy demonstration facility with PV-systems, solar heat collectors, heat pump, heat storage and electrolyser for research on hybrid systems.

The Northern Research Institute (Norut) in Narvik also has a research group that is active in silicon solar cell research and testing of PV systems under arctic conditions.

INDUSTRY AND MARKET DEVELOPMENT

The Norwegian PV industry is divided between "upstream" materials suppliers and companies involved in the development of solar power projects. The industry supplies purified silicon, silicon blocks, and wafers in the international markets. Solar power project development is to a large extent oriented towards emerging economies.

REC Silicon is noted on the Oslo stock exchange, but the company's production of high purity silicon takes place in the United States.

Elkem Solar operates a production plant for solar grade silicon (ESS) in Kristiansand in southern Norway. This plant uses a proprietary metallurgical process that consumes much less energy than other processes for purification of silicon. The production capacity is approximately 6 000 tons of solar grade silicon per year. In addition, Elkem Solar produces multicrystalline silicon blocks at Herøya in eastern Norway for its subsidiary REC Solar. REC Solar has a yearly solar panel production capacity of 1 300 MW at its integrated wafer, cell, and solar panel manufacturing plant in Singapore.

NorSun manufactures high performance monocrystalline silicon ingots and wafers at its plant in Årdal in western Norway. Annual ingot production capacity exceeds the equivalent of 350 MW of solar panel

capacity. More than 80 % of this ingot production is converted to wafers utilizing diamond wire sawing at the Årdal plant.

Norwegian Crystals produces monocrystalline silicon blocks in Glomfjord in northern Norway. The capacity of the factory is equivalent to 200 MW per year. The company also supplies wafers to its customers.

The Quartz Corp refines quartz at Drag in northern Norway. Parts of this production are special quartz products that are adapted for use in crucibles for melting of silicon.

Scatec Solar is a provider of utility scale solar (PV) power plants and an independent solar power producer (IPP). The company develops, builds, owns, and operates solar power plants. The present portfolio of power plants has a capacity of 322 MW, and it includes plants in the Czech Republic, South Africa, Rwanda, Honduras, and Jordan. Large projects are under construction in Malaysia and Brazil, and there are agreements in place for large scale projects in Egypt.

IMPLEMENTATION

Although the Norwegian PV market is small on an international scale, the PV installation rate continued to increase in 2017. In total, approximately 16 MW of PV capacity was installed in 2016, while the total PV generation capacity installed before 2017 was approximately 26 MW. This upwards shift in the installation rate is linked to reduced installation costs for both commercial and residential rooftop installations.

The growth in residential installations in 2017 was due to a combination of increased marketing efforts with new alternatives for financing and lower solar panel prices. However, when Oslo's support scheme ended, installation rates in Oslo dropped significantly.

Installation rates of PV systems will obviously continue to depend on how financially attractive such investments are for companies and for home owners. The combination of moderate and very season dependent solar resources in Northern Europe, relatively low electricity prices, and moderate financial support is of course important in this aspect.

The Norwegian Water Resources and Energy Directorate (NVE) has proposed new rules for grid connection tariffs. This proposal aims at what is claimed to be a fairer distribution of grid costs compared to the existing tariffs. At present residential customers are billed according to their energy consumption, while grid investments to a large extent are determined by the peak power demand. The new proposal is subject to public review in 2018. If the new tariffs are implemented, there will be negative consequences for PV installations where the owner also requires relatively high peak power from the conventional grid. On the other side PV installations that reduce peak power demand will potentially benefit from the new tariffs.

PORTUGAL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

ANTONIO JOYCE, LNEG (LABORATORIO NACIONAL DE ENERGIA E GEOLOGIA)

ISABEL CABRITA, DGEG (DIRECAO GERAL DE ENERGIA E GEOLOGIA)

JOSE MEDEIROS PINTO, APREN (ASSOCIACAO PORTUGUESA DE ENERGIAS RENOVAVEIS)



Fig. 1 - 220 kW PV floating system in the North of Portugal (Photo: LNEG).

GENERAL FRAMEWORK AND IMPLEMENTATION

The policy framework for renewable energies in Portugal has led Portugal to a very good position on the topic of renewable integration on the electricity sector. The actions described in the National Renewable Energy Action Plan (NREAP) together with the actions of the National Energy Efficiency Action Plan allow Portugal to comply with the overall and national objectives of the European Renewable Energies Directive 2009/28/EC on the promotion of energy use from renewable sources.

The NREAP was defined by the Council of Ministers' Resolution nº 20/2013, published in the Portuguese Official Journal, 1st Series, Nº 70 from 10th of April 2013. This official document projects a PV contribution of 670 MW of installed capacity and 1 039 GWh of generated energy for 2020. Solar energy is expected to have an important role in the increase of decentralized power production. By the end of 2017, The National Energy Authority (DGEG) reported that the increase of the installed capacity was done mainly in the framework of the legislation for self-production (Decree-Law 153/2014, Oct. 20), with a total of 46.0 MW. This includes:

- Self-Consumption Units (UPAC): 37,0 MW
- Small Production Units (UPP), up to 250 kW: 9,0 MW

To these values, 11 MW of new utility scale power plants were added in 2017, giving a total of 57,0 MW of PV power installed in 2017; this leads to a value of cumulative PV power installed in Portugal of 566,4 MW, in 2017.

In terms of PV energy produced, in 2017, the total value is 970 GWh. This represents 2,0 % of the total electricity consumption (47 973 GWh).

NATIONAL PROGRAMME

The NREAP, published in the Council of Ministers' Resolution nº 20/2013, forecasts a PV installed capacity of 670 MW, in 2020 in Portugal and a yearly produced energy of 1 039 GWh.

Utility scale power plants follow the general legislation for independent power producers (Decree-Law 312/2001) while a specific regulatory framework (Decree-Law 153/2014) defines the rules for the self consumption regime with two options: self-consumption of the energy produced, called UPAC (units of production for self-consumption), and small scale producers that sell all the energy to the grid, called UPP (units of small scale production).

- The UPP option is applicable to any type of self-consumption solutions up to a limit of 250 kW. A reference FiT is established and, to each RES production type, a different multiplier is applied: 100 % for solar, 90 % for biomass and biogas, 70 % for wind and 60 % for hydro. The reference value for the FiT is established every year. For 2017, the value established was 95 EUR/MWh. However, if more than 2 m² of solar thermal panels are used in the consumer's installation a premium of 5 EUR/MWh is added or, in the case the developer installs an electric vehicle charging power outlet, a premium of 10 EUR/MWh will be attributed. The applied final FiT is valid for 15 years.

- UPAC is applicable to any kind of consumption installation size since it does not benefit from a FiT. The UPAC solution, besides the possibility of consuming all the energy generated, has the possibility of injecting the surplus into the grid, receiving a price per MWh evaluated at 90 % of the average value of the monthly price quoted in the Iberian market (MIBEL).

Additionally, renewable energy generators in self-consumption (both grid connected and off-grid) can trade the electricity surplus or the generated electricity with green certificates.

The Law referred to above defines the same simplified licensing procedures as the ones used in previous programmes for micro and mini generation for local grid-connected energy producers. In fact, licensing is conducted using an online internet system, the Electronic System of Registration of Generation Units (SERUP).

Following the admission to "Powering Past Coal Alliance ", an alliance created at COP23, Portugal committed to decommissioning its coal-fired power stations before 2030. This decommission will release new capacity in the electricity system which will allow to accommodate more photovoltaic installations in Portugal in the next couple of years.

The Clean Energy package, in discussion in the EU, defining the energy strategy and targets for the period 2020-2030 reflects the European Union ambition to be a worldwide leader of the renewable energy sector. In this context, Portugal sets ambitious targets for 2030 and has stated that it intends to set a goal of at least 40 % of renewables in the final energy consumption.

R&D, D

In the last years, PV R&D in Portugal had strong development within an important scientific community, comprised by a significant number of researchers working in different aspects of photovoltaics. These are mostly public research groups but some important private companies in Portugal are also addressing the innovation process on PV.

Some of the most important players in R&D activities are:

University of Minho working on PV conversion materials namely on thin film; amorphous/nanocrystalline silicon solar cells; Silicon nanowire solar cells; oxygen and moisture protective barrier coatings for PV substrates; and photovoltaic water splitting.

INL (International Iberian Nanotechnology) working on solar fuel production; Inorganic-organic hybrid solar cells, sensitized solar cells, perovskite solar cells, Cu_2O , $\text{Cu}(\text{In,Ga})\text{Se}_2$ solar cell devices and materials, quantum dot solar cells, thin film Si, encapsulation barrier, and Si-NW solar cells.

University of Oporto (Faculdade de Engenharia da Universidade do Porto) working on Solar PV cells and modelling processes.

University of Aveiro working on semiconductor physics; growth and characterization of thin films for photovoltaic applications.

University of Coimbra (Faculdade de Ciências e Tecnologia) working on dye-sensitized solar cells perovskite solar cells, bulk heterojunction organic solar cells, and metal oxide photo-electrodes for solar fuel applications.

University of Lisbon (Faculdade de Ciências) working on silicon technologies namely ribbon cells, and modelling.

University of Lisbon (Instituto Superior Técnico) working on organic cells.

New University of Lisbon (UNL) (Faculdade de Ciências e Tecnologia, UNINOVA and CENIMAT) working on thin film technologies and tandem cells.

LNEG (Laboratório Nacional de Energia e Geologia) performs R&D work on PV technologies and systems namely: development of conversion technologies, such as organic cells, perovskites, kesterites (CZTS) and CTS, for tandem cells, and also on new PV/T modules; monitoring of PV systems, namely, in the framework of Solar XXI building, a test facility for the integration of solar energy in buildings; development of pre-normative research supporting the technical secretariat of the Portuguese Technical Commission on PV Standards; development of modelling tools of PV systems and PV integration in the grid.

DGEG – Directorate-General of Energy and Geology performs research on photovoltaic mainly in the context of design and implementation of public policies. Three such cases are: cost-optimal studies applied to the periodic refreshment of national building codes (as required by European Directive 2010/31/EC, EPBD); assessing the contribution of PV systems for the national definition of nZEB – near-Zero Energy Buildings as well as the respective minimum requirements for renewable energy on-site and near-site energy production; and the development of the analytical support tools and scenarios for the future National Energy-Climate Plan (NECP), that includes modeling the contribution of PV technologies for the national energy system up to 2030 (also to be included in the Portuguese Carbon Neutrality Roadmap 2050).

Also private companies, for example, **EFACEC, Martifer Solar, Open Renewables** and **MagPower** have their own research and innovation groups.

INDUSTRY AND MARKET DEVELOPMENT

Market Development

There has been a huge impulse regarding solar PV in Portugal. In the last two years, promoters already submitted more than 2 000 MW of solar power projects to the National Energy Authority (DGEG), from which are expected a significant boost of the technology in the coming



Fig. 2 - 2,5 MW PV Power Plant at Monte das Flores (Photo: APREN).

years. Of these projects, around 460 MW have already a license to operate, with an expected 2-year period to construct the power plants. In fact, failing this, it could mean that they may lose their license. The main market characteristic of these projects is the fact that these power plants were licensed to operate in the market regime, which has high investment risk allied to the fact that there is no market aggregator in Portugal. Hence, new power plants, even if they establish a PPA, are subjected to high costs of production deviations. However, it is expected that a new regulation will be implemented in the near future to include market aggregators.

It is important to highlight two new solar PV projects in Portugal, namely floating systems that were installed in hydropower plants; one at Alto Rabagão in the North of Portugal and another in Alqueva, in the South. These projects demonstrate the versatility of solar PV and will allow testing to be carried out in extreme conditions. These are installed in areas taken up by hydraulic facilities, whether applied to hydropower, irrigation or multiple purposes.

Production of Photovoltaic Cells and Modules (including TF and CPV)

There is a considerable experience in Module production in Portugal with some factories highly automated, mainly on crystalline silicon technologies. Some examples of companies operating in Portugal in recent years are listed below:

Open Renewables – The oldest manufacturer of PV modules in Portugal with a 60 MW_p/year rate.

Martifer Solar – with a production rate of 50 MW_p/year.

Jinko – with a production rate of 30 MW_p/year.

There were cases of development of thin film technologies, such as amorphous silicon in the past. However, these companies are no longer operating.

An important PV Industry development in Portugal is related to Concentrated Photovoltaics, CPV. A totally Portuguese Engineering developed product on HCPV was produced at **Magpower**, with a production rate of 54 MW_p. This was followed up with an internationalization procedure resulting in the implementation of several projects abroad.

The electronics industry for power, in Portugal, is an important sector. Some internationally established companies, such as **EFACEC**, have facilities in the country and contribute to the PV sector, by developing and producing grid-connected inverters and controllers.

It is also important to mention the existence of several manufactures of supporting structures for PV modules and the expertise of Portuguese companies in planning and engineering PV plants.

SOLARPOWER EUROPE

SOLARPOWER EUROPE'S ACTIVITIES

AURELIE BEAUVAIS, POLICY DIRECTOR, SOLARPOWER EUROPE



Fig. 1 - Maroš Šefčovič, Vice-President of the European Commission and Isabelle Kocher, CEO of ENGIE at SolarPower Europe's 'SolarPower Dialogues' discussing the incredible achievements of solar and how solar is driving the digitalisation of the European energy transition (Photo: Michael Chia).

SolarPower Europe is a member-led association representing organisations active along the whole value chain.

SolarPower Europe's aim is to shape the regulatory environment and enhance business opportunities for solar power in Europe. It visions a future where solar is the leading contributor to Europe's energy system.

2017 was an important year for the energy sector in Europe. Indeed, intense legislative negotiations have been raging over the European Commission's "Clean Energy for All Europeans" package, which sets the scene for the evolution of the European energy mix for the decade 2020-2030 and proposes important adaptations to the power market rules.

Through a constant interaction with policymakers over the last two years, SolarPower Europe has actively pushed forward-looking reforms that will be crucial for the further development of solar in Europe and in particular:

- 35 % EU binding renewable energy target in the European electricity mix
- A proactive European framework for self-generation and consumption
- An obligation for EU countries to provide visibility on national support schemes for at least three years ahead by publishing a long-term schedule
- An "anti-retroactivity clause" to ensure the stability of financial support to renewables
- and grid connection procedures, with clear time limits
- Minimum shares of renewables in all new buildings and buildings undergoing major renovation
- The guarantee that all projects built up to 2020 will benefit from priority dispatch and access after 2020
- A restrictive framework for capacity mechanisms including an emissions target to avoid coal generation qualifying under such schemes

- The guarantee that EU countries will not go below their 2020 RES targets and that they must collectively deliver on the 2030 RES target
- An enabling framework for solar + storage applications
- An adaptation of markets rules (day-ahead, intraday, balancing) to make them fit for variable solar electricity

In addition to the highlights above, SolarPower Europe has worked intensively on crucial issues for the solar industry such as the trade case, and the recast of the Eco-Design regulation covering solar PV systems.

To enhance its voice, SolarPower Europe has built coalitions with utilities, system operators, sectoral industry associations, NGOs and other relevant stakeholders. It took an active role in the enhancement of the e-mobility platform - promoting the electrification of the transport sector, and joined the Electrification Alliance, gathering more than 50 organisations to promote the significant potential of electricity on EU's path towards decarbonisation.

SolarPower Europe has also substantially increased its visibility in the media and has organised several successful events, in particular :

- The Mid-Summer Celebration on the 21th of June 2017, with the Presence of Vice-President Maros Sefcovic and ENGIE's CEO Isabelle Kocher
- The Re-Source Event on 10th and 11th of October 2017, with over 400 attendees and high-level European policymakers
- The Digital Solar and Storage Event hosted on 4th-5th of December 2017, in Munich, with over 400 experts and business leaders of the Solar sector

During the past year SolarPower Europe has pursued and reinforced its service-oriented approach towards members by coordinating several task forces on:

- Operations and Maintenance (O&M), which led to the publication of industry best practices guidelines
- Solar tenders, which allowed our members to present their expectations regarding the design of tenders in Europe
- Environmental Footprint Task Force; delivering high-level recommendations of the European solar sector ahead of the EcoDesign/Eco-label legislation recast
- Solar and storage, which developed 10 policy priorities for the deployment of such combined solutions
- BIPV, through which our industry made several proposals to deploy solar in the building sector
- Digitalisation, focusing on how to make solar accessible to all consumers, which led to the first ever report on "Digitalisation & Solar".
- Industrial Strategy, contributing to the establishment of EU's first "Clean Energy Industrial Forum", to make EU's solar industry thrive.

In November 2017, SolarPower Europe together with its European counterparts WindEurope, RE100 and WBCSD launched the first European Platform to promote the uptake of corporate PPAs in Europe, the Re-Source Platform.



Fig. 2 - James Watson, CEO of SolarPower Europe, opening the RE-Source event which gathered over 500 corporate renewable energy buyers and sellers (Photo: Jason Bickley).

With an ever-growing team and drive, SolarPower Europe is on the verge of launching two new Task Forces in 2018:

- An "Emerging Markets Task Force", which aims at unlocking the opportunities for solar players in emerging markets
- A "Solar E-Mobility Task Force", which shall be reflecting on the contribution of Solar technologies to the E-mobility revolution

SolarPower Europe has also been active outside the Brussels sphere creating opportunities for its members by supporting or representing them at the most important business development platforms in Europe and beyond. SolarPower Europe is a Member of the Board of Directors of the Global Solar Council, and has extended its cooperation with the Terawatt Initiative, contributing to the establishment of a Common Risk Mitigation Mechanism (CRMM).

Finally, SolarPower Europe's policy and business objectives were again supported in 2017 by thought-leading research in fields such as solar PV market forecasts, financing, and electricity market design. Notably, the SolarPower Europe team published and/or contributed to:

- The Global Market Outlook 2017-2021, the most authoritative market analysis report for the European and global solar power sector.
- The European Operation and Maintenance Best Practices Guidelines 2.0, acknowledging the importance of O&M for the future performance and competitiveness of PV systems and plants.
- The world's first "Digitalisation and Solar" report, to make the most of market opportunities provided by digitalisation driving more solar deployment.
- A Solar PV Jobs & Value Added in Europe report, assessing the socio-economic contribution of solar to jobs and value added in Europe for 2017 through to 2021.
- The final report of the EU-funded CHEETAH project, developing new concepts and technologies for wafer-based crystalline silicon solar PV (modules with ultrathin cells), thin-film solar PV (advanced light management) and organic solar PV (very low-cost barriers), resulting in (strongly) reduced cost of environmentally benign/ abundant/non-toxic materials and increased module performance.
- The CrowdfundRES project, which explores how crowdfunding can provide additional and new sources of financing for renewable project developers.

SOUTH AFRICA

PV TECHNOLOGY STATUS AND PROSPECTS

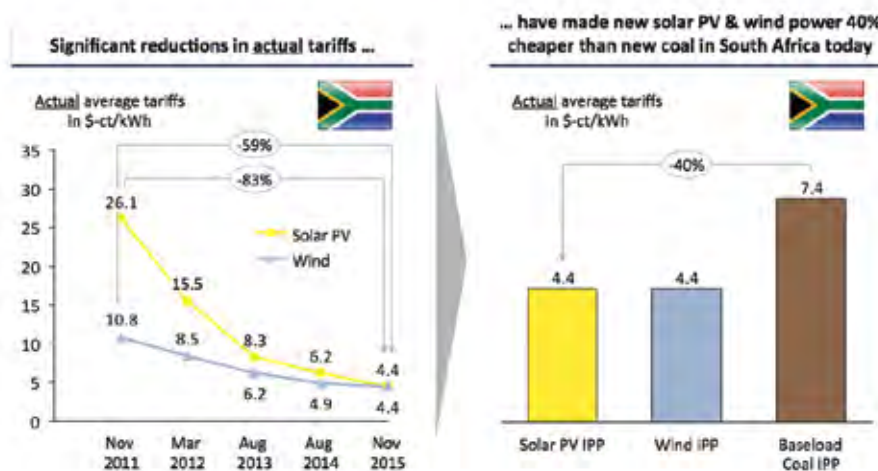
KITTESSA RORO, CLINTON CARTER-BROWN, STEPHEN KOOPMAN, CSIR ENERGY CENTRE, COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

THEMBAKAZI MALI, SOUTH AFRICAN NATIONAL ENERGY DEVELOPMENT INSTITUTE

GENERAL FRAMEWORK AND IMPLEMENTATION

The South African Department of Energy (DoE) Integrated Resource Plan (IRP) is a guiding policy document for South Africa and provides insights on how the country will expand electricity generation over the long term. The IRP 2010 plans on doubling power capacity by 2030 (compared to 2010) and includes a significant diversification of the power mix [1, 2]. The IRP was last formally approved in 2010 (IRP 2010), and a draft updated version has been the focus of public comment and is due to be formally released. The energy-share of

renewables in domestic electricity generation will increase from less than 1 % in 2010 to an anticipated 9 % in 2030. The role for solar PV in the national electricity supply mix is included in the IRP, which the DoE has an intention to update regularly, typically every 2-5 years. South Africa is also looking at introducing a carbon tax which will provide additional support for clean electricity options such as solar PV. The draft carbon tax bill still needs to be debated in parliament prior to adoption as an Act of parliament.



Notes: Exchange rate of 14 USD/ZAR assumed

Sources: <http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf>; <http://www.saippa.org.za/Portals/24/Documents/2016/Coal%20IPP%20factsheet.pdf>; http://www.ee.co.za/wp-content/uploads/2016/10/New_Power_Generators_RSA-CSIR-14Oct2016.pdf; StatsSA on CPI; CSIR analysis

Fig. 1 - Comparison of actual tariff of new solar and wind with new coal in South Africa.

The national South African solar PV procurement programs have focused on utility scale PV. Figure 1 compares the competitive bidding based tariff of new solar and wind with new coal in South Africa. The opportunities of a nationally coordinated rooftop PV program have not yet been realised, and within this context "The rapid uptake of PV over the past two years has caught national regulators by surprise, resulting in a lack of effective regulation and policy. National regulations and acts mostly predate the small scale embedded generation (SSEG) revolution and are largely inadequate in the current landscape. In the current national legal framework, this void has left it up to local municipalities, in partnership with provincial governments, to develop their own policies and practices to govern the uptake of solar PV. Municipalities are anticipated to play a huge role in unlocking investment opportunities for energy services in South Africa. Western Cape municipalities are beginning to understand the demand factors affecting their customers and many have already introduced rules and regulations to allow for small scale embedded generation." [3]

At present, the national Department is adopting a cautious approach on incentivising solar PV and in November 2017 released an amendment to the South African Electricity that exempts generators up to 1MW

from having to be licensed by the Regulator [4]. Incentives are more prevalent at the local government level where certain municipalities are offering feed-in tariffs for residents and businesses in their jurisdictions, albeit that such feed-in tariffs are typically based on energy rates that are a portion of the municipality energy purchase costs from Eskom. The CSIR is spearheading a project to enhance the South African National Wiring Code (SABS 10142) to ensure that small scale embedded generation facilities are safely installed and are compliant with relevant local and international specifications.

The National Treasury's designation of solar PV systems for local content creates opportunities for South African-based manufacturers of solar PV systems. Considering the more than 100 000 public buildings, there are significant opportunities for the installation of various sized systems as well as the manufacturing and assembly of designated components. Over and above providing opportunities for local enterprises, the government, by so doing, is providing leadership towards a more resource-efficient economy and the promotion of local goods and services. The targeted levels of local content for publicly procured solar PV systems are: laminated solar PV modules (15%); Module frames (65 %); Mounting structure (90 %) and Inverter (40 %) [5].

[1] Department of Energy, 2010

[2] Department of Energy, 2013

[3] GreenCape 2017, Energy Services: Market Intelligence Report

[4] DOE Final licensing exemption and registration notice (ERA schedule 2), November 2017

[5] GreenCape 2017, Energy Services: Market Intelligence Report

The PV GreenCard is an industry led quality label that is inclusive in nature and has been developed to promote safe and high-quality Solar PV installations within South Africa. Installers registered with the PV GreenCard are able to declare compliance with relevant standards as well as safety guidelines for PV installations. There are 47 registered installation companies in South Africa with the PV GreenCard [6].

NATIONAL PROGRAMME

In an attempt to diversify its energy mix and attract more Independent Power Producers (IPPs) to the sector, the South African government has developed the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) in 2011. This programme has been very successful in bringing renewable energy projects to commercial operation. To date, REIPPPP has successfully procured 6,4 GW from 102 IPPs across six bid windows. By the end of 2016, 2,7 GW of the procured capacity, from 51 projects, had already started operations and was delivering 2,1 GW of actual capacity to the grid.

After more than four bid rounds under REIPPPP, the cost of solar PV technology has declined over 83 % and when combined with wind and flexible generation (such as gas fired plants) is now cost-competitive with any other new-build option. Furthermore, renewable power sources account for 3,8 % of South Africa's installed capacity, from a baseline of zero in 2010 [7]. This has led South Africa to be placed among the top-ten countries globally for installed, utility-scale solar photovoltaic capacity.

The program has leveraged approximately 135,6 BUSD in investment across South Africa and projects include wind, solar (both PV and concentrating solar power) small hydro, landfill gas and biogas as sources of energy [8]. Of this, 25,8 % is from foreign financiers and investors across the globe. In the REIPPPP Eskom is the buyer of the energy and hence the success of the program is dependent on Eskom signing the associated PPAs. In the last year Eskom has stalled the program by refusing to sign the PPAs sighting financial constraints-Substantial investment combined with local content requirements has also created a local manufacturing market. However, due to the Eskom impasse on signing the PPAs, investments have decreased in the past 12 months, especially in the manufacturing of RE technology components. This is due to the manufacturing environment requiring reasonable certainty in off-take for sustainability [9]. These PPAs need to be concluded as a matter of urgency to rejuvenate the RE industry in South Africa. Early March 2018, the government announced the signing of the power purchase agreement, however, the process was delayed by a court interjection from application of labour unions [10].

The recent substantial delays in the signing of PPAs by Eskom points to regulatory uncertainty as to how the buyer of such energy will cover related costs, and certainty is necessary to prevent similar delays in future. These delays also point to the risks of procuring energy where Eskom is the sole purchaser of such energy, which could be viewed to be in conflict with Eskom's own business model and longer term sustainability as a vertically integrated utility. Alternative approaches are required that expand the options for the buyer of the energy.

[6] www.pvgreencard.co.za

[7] <https://www.csir.co.za/documents/statistics-re-sa-2017-csir-finalpdf>

[8] <https://www.export.gov/article?id=South-Africa-electrical-power>



Fig. 2 - CSIR outdoor PV testing facility installed on the roof of the Energy Centre on the CSIR campus in Pretoria.

A natural progression to complement utility scale PV is to enhance the regulatory rules to also facilitate the development of renewable energy at smaller scales, including a national approach to rooftop PV systems, and clarifying the role that municipalities and electricity consumers can and should play in the procurement of sustainable energy.

RESEARCH & DEVELOPMENT

The Department of Science and Technology (DST) of the Government of South Africa has initiated the Energy Research Programme (ERP) to develop and enhance human capital, knowledge and innovation in the field of renewable and sustainable energy research. This programme utilizes the hub-and-spokes model that recognises and supports the distribution of research capacity and expertise for a defined focus area, across more than one institution and/or divisions of an institution. The first hub-and-spokes cluster has been established to contribute to the key strategic area of Energy Security with the Centre for Renewable and Sustainable Energy Studies (CRSES) at the University of Stellenbosch serving as the hub with three spokes focusing on Solar Photovoltaic (Nelson Mandela University & University of Fort Hare), Solar Thermal (University of Pretoria & Stellenbosch University) and Wind (University of Cape Town & Stellenbosch University). The research of the PV spoke focuses on solar cell and module testing and characterisation; system evaluation and monitoring; concentrator PV cell characterisation and module design; outdoor testing; and building integrated PV design and embedded generation [11].

In addition to the PV spoke, more than 20 South Africa universities and institutes have programs that include projects in PV research and development ranging from PV materials to systems [12].

The Council for Scientific and Industrial Research (CSIR) has established an integrated energy research centre to provide decision support to South African industry and policymakers, where such support will be informed by its technical research. As part of the integrated energy research centre, the CSIR has designed and constructed an outdoor Photovoltaic (PV) testing facility at its Pretoria campus to enhance its ability to support the development of PV technology in South Africa and globally, as well as PV system design and optimisation. A picture of the CSIR outdoor PV testing facility is shown in Figure 2. This world-class facility at the CSIR will allow the testing of PV modules and systems under South African environmental conditions, assisting project developers and equipment suppliers to provide quality solutions that minimise cost, risk and maximise returns for investors.

[9] *GreenCape, Utility-scale renewable energy – 2017 Market Intelligence Report, 2017*

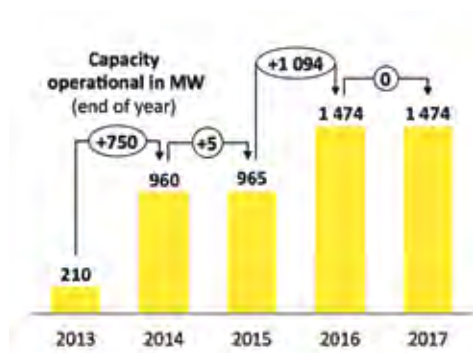
[10] <http://www.engineeringnews.co.za/article/numsa-supports-renewable-energy-wants-job-security-2018-03-15>

[11] <http://www.crses.sun.ac.za/research-current-research-other>

[12] *State of PV research*

INDUSTRY AND MARKET DEVELOPMENT

A total of 8,1 GW of renewables (mainly from wind and PV) for procurement from IPPs has already been allocated as an outcome of the REIPPPP. Of this, 6,3 GW has preferred bidder status, 4,0 GW has reached financial close and signed the Power Purchase Agreements with Eskom, and 1,5 GW of solar PV are operational and feeding energy into the grid by December 2016 (Figure 3). There has been no significant change in on-line/connected plants in 2017.



Notes: RSA = Republic of South Africa. Solar PV capacity = capacity at point of common coupling. Sources: Eskom; DoE IPP Office

Fig. 3 - Total utility scale PV Installed capacity in South Africa. From 1 November 2013 to 31 December 2016, 1 474 MW of large-scale solar PV were commissioned in South Africa.

Within the context of the now stalled REIPPPP, utility scale renewable project developers spend considerable time in developing projects to bid into competitive procurement processes. The sustained development of such projects requires reasonable certainty that the process is fair, transparent and has the support of key stakeholders. Developers and investors require certainty that contractual obligations will be met, often necessitating the likes of sovereign guarantees to manage risks regarding the ability of the buyer of the energy to honour payments where the purchases of the energy are entities of the state. An equitable allocation of risks is essential so that project developers only have risks that are under their direct control, and transparent mechanisms are required for the management of pass-through risks such as changes in exchange rates. Developers require certainty that procurement programs will proceed, and that access to the electrical grid will be fair and equitable. Developers also need reasonable certainty on the future pipeline of projects, as is required to support the establishment of local offices, the development of multiple projects and to stimulate local manufacturing and assembly. Policy uncertainty on the type, magnitude and timing of future energy projects is a key constraint in supporting local economic development of the renewable energy industry in South Africa.

According to Green Cape [13], the rooftop solar PV market has been a significant driver of growth of the energy services market. It is estimated more than 100,000 small scale embedded generators has been installed throughout South Africa by the end of 2016. Figure 4 shows the distribution of small scale embedded PV generators installed across end-user application. It can be seen from the figure that commercial and industrial sectors presents, the highest installed capacity in South Africa [14].

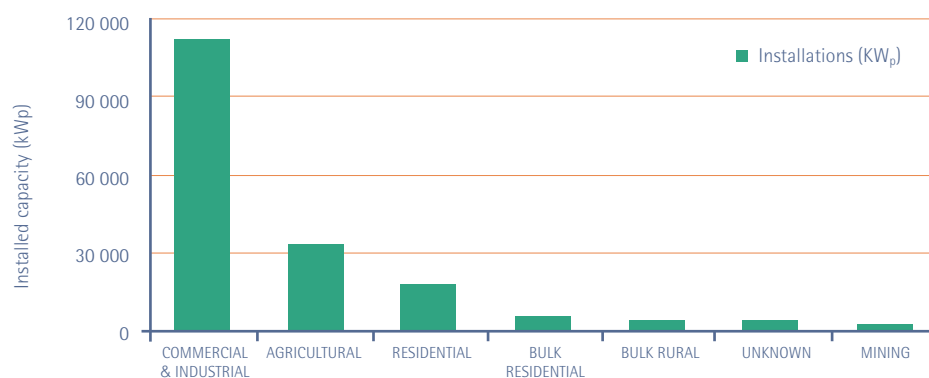


Fig. 4 - Distribution of small scale embedded PV installations across end-user segments.

[13] [3] GreenCape 2017, Energy Services: Market Intelligence Report [14] PQRS, 2016. SA Solar PV list – March 2016. [Online] Available at: <http://pqrs.co.za/>

[14] PQRS, 2016. SA Solar PV list – March 2016. [Online] Available at: <http://pqrs.co.za/>

SPAIN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

ANA ROSA LAGUNAS ALONSO, CENTRO NACIONAL DE ENERGÍAS RENOVABLES, CENER

GENERAL FRAMEWORK

The general Renewable Energies scenario during 2017 included no large additions of PV capacity installed in Spain, with very low newly installation grid connected (1 MW out of a preliminary report from grid operator) and no clear accountability of self-consumption or off grid capacity added. In this scenario, an optimistic point is that the general opinion of population is bouncing towards the positive side for PV use and deployment. The addition of new capacity from the government auctions for RREE installations will have an important impact both on PV and wind, but had not yet materialized in 2017. Finally, and due to no modification on existing regulations, self-consumption, seen as an interesting possibility, did not have a notable increase in 2017 either; with close to 19 MW registered. However, the total installations in the country could go up to 100 MW. Concerning the electricity generation in Spain and the contribution of the renewable energies to the demand coverage during 2017, the results are shown in Figure 1. An important decrease in demand coverage (only 30,8 % versus almost 40 % in previous year) is seen. The decrease in percentage of demand coverage is mainly due to the lower contribution of hydraulic power.

In numbers, the total coverage of electricity demand by renewable energies was close to 31 % (30,8 % estimated); more than seven points lower than in 2016.

This negative trend, with respect to 2016, has been due mostly to the decrease of hydro; almost to half of the previous year (7,7 %, versus 14,9 % in 2016) and a slight loss of wind (0,3 points less) compensated with PV (+0,2) and CSP (+0,1) contributions. In the scenario of almost no renewable capacity added is always meteorology that is responsible for the RES electricity generation variations and 2017 had extra sunshine and much drier weather. 2017's ranking has Wind (17,9 %) first, followed by Hydraulic (7,7 %). Photovoltaic was at 3,2 % and Solar Thermal at 1,9 %.

Information presented corresponds to consolidated values up to 2016, reported by the grid operator REE (Red Eléctrica de España). For 2017, data are estimations as of December 13, 2017, for both peninsular and extra-peninsular territories. Final information for the year will appear in the July 2018 timeframe. Off grid and self-consumption capacity is very difficult to identify for now.

NATIONAL PROGRAMME

There is no specific national program concerning PV technology, however, during the year 2017, and with the interest to accomplish the requirements for energy and climate goals of EU for 2020, a series of auctions from the government to install renewable capacity in Spain have been issued. As a result of those tenders, 3,9 GW of new PV capacity should be added until 2020.

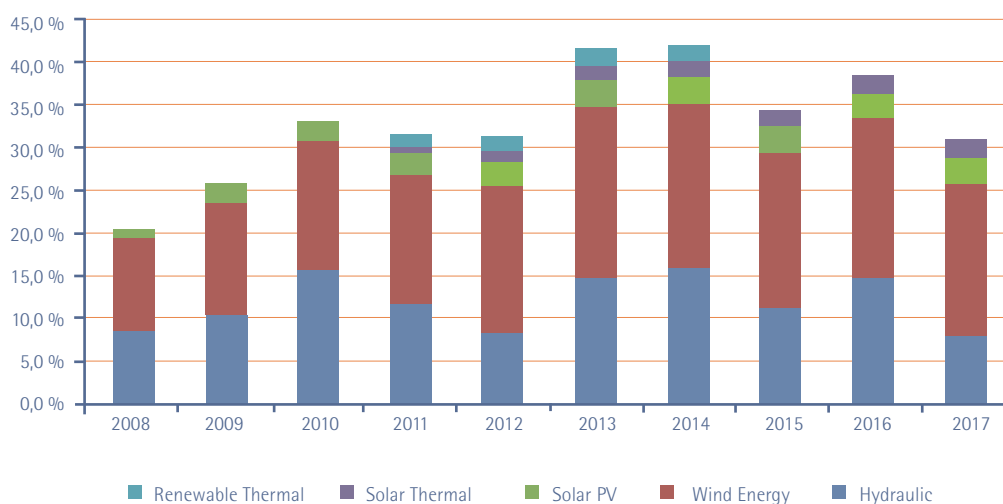


Fig. 1 – Percentage of demand coverage from renewable energies (2008, 2009 data out of CNE, 2010 -2017, REE).

No new tenders have been announced after, but, the actual circumstances of PV technology and the LCOE that could be achieved in Spain make it a clear player for the energy generation market. New solutions for self-consumption and the option to be off-grid are being considered by the population as a clean and affordable option to the electricity supply. Also, governments of some autonomous communities are developing support programs for PV installations and specifically, the Canary Islands obtained a modification on the self-consumption law, which will favour expected new installation deployment there.

Electricity generation out of PV is presented in Figure 2 per each autonomous community. The evolution, which has been quite stable for last years, is expected to be modified heavily by the new 3,9 GW capacity that should be added from government tenders. That capacity will not be uniformly spread throughout the country and predictably will go to the sunniest regions. Evolution of percentage of demand coverage per each autonomous community (Figure 3) will also change in an important way after 2017.

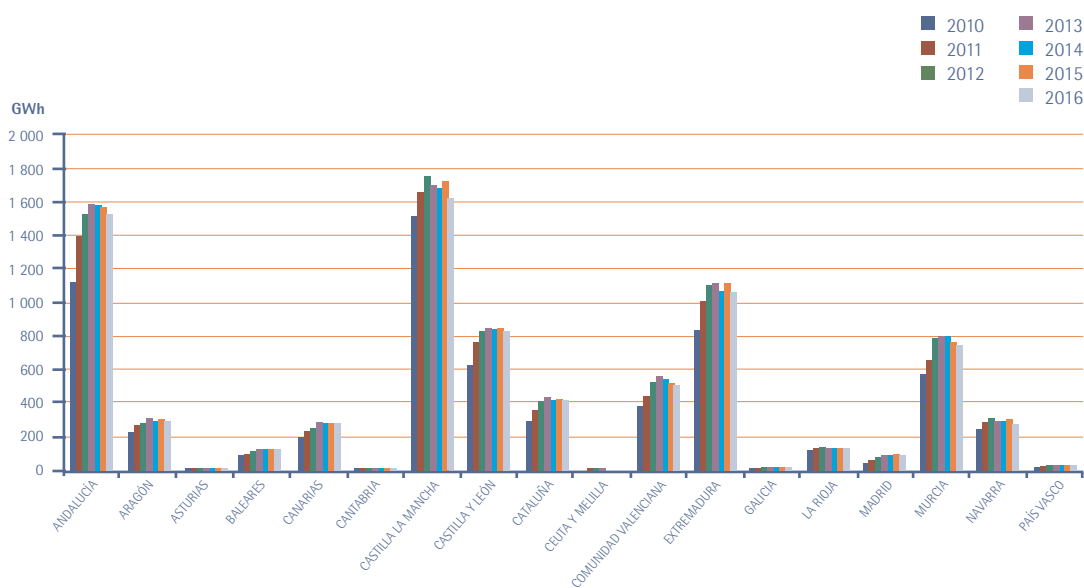


Fig. 2 – Electricity generation out of PV per each autonomous community.

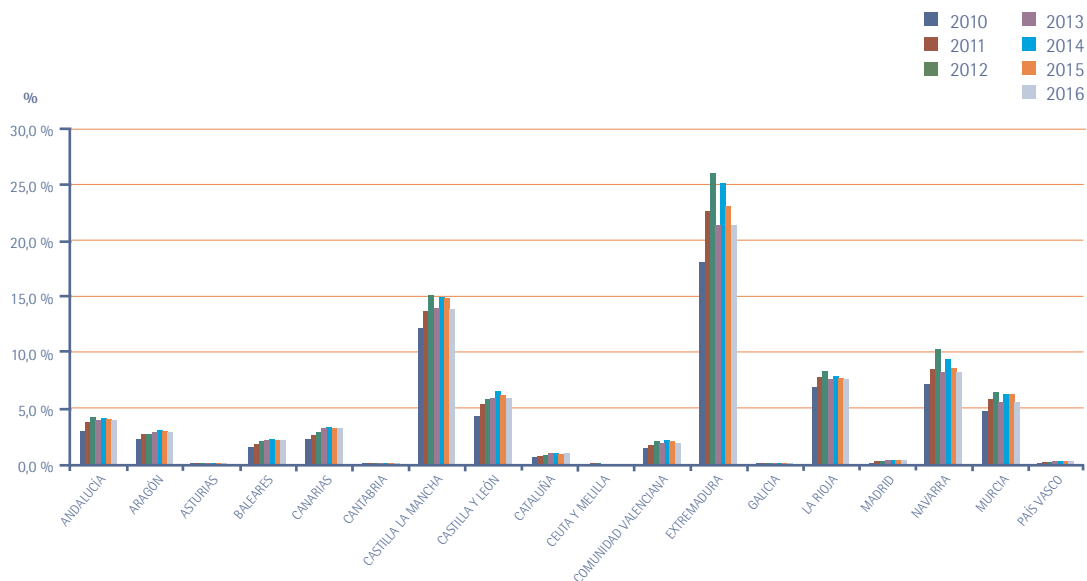


Fig. 3 – Evolution of percentage demand coverage by PV per each autonomous community.



Fig. 4 – Demonstrator installed in ITMA building out of BIPV elements (transparent PV and LED integrated) developed in the ETFE-MFM project.



Fig. 5 – 75 MW PV plant built by COBRA in Kimberley, Rep. of South Africa (Photo: ©Grupo Cobra).

R&D, D

R&D activity continues its development driven by two main concepts: on one side, the support to optimum generation out of PV plants, and on the other, the innovation through new products including PV, such as the BIPV (Building Integrated Photovoltaics). BIPV concerns a constructive element that has PV as part of it, therefore accomplishes two goals: construction and electricity generation. These products also support another pillar of EU concerning climate change as is the "Energy Efficiency on Buildings" and in general energy efficiency in the cities. Examples of those are the project ETFE-MFM (www.etfe-mfm.eu) led by ITMA that finished November 2017 and with other Spanish participation from ACCIONA and CENER, as well as the ongoing project PVSITES (www.pvsites.eu) led by TECNALIA, with participation of CRICURSA, ONYX and ACCIONA on the Spanish side.

Concerning emerging PV technologies, the important activity related to basic research on low cost technologies such as OPV and promising perovskites should be mentioned, as well as the participation on development through "Round Robins" (inside EERA activities) or the StableNextSol (www.stablenextsol.eu) COST action, also led by Spanish ICN2.

Finally, another area of R&D is related to the introduction of PV technology in the day to day activity, and for that it is necessary to study the capacity of hybridization with other generation and storage sources that will allow the continuous availability of the electricity, if needed. New PV technology developments are part of the microgrids considered on the smart city concepts. In that scenario is basically the development of tools for accurate management of the electricity generation by PV out of variable irradiation conditions. The recently launched STARDUST project, led by CENER and with partners from seven countries in Europe, works on this, among other aspects.

INDUSTRY STATUS

Industrial development has almost run out of activity on PV module manufacturing in the country. Some products might be developed in Spain, but are usually manufactured abroad. However, the local manufacturing activity has increased a great deal on the point of structures, with companies leading the world market in the horizontal tracking sector (SOLTEC, STI NORLAND, etc.), and continues with success on inverters (INGETEAM) and materials with EVASA (www.evasa.net), one of the few manufacturers of encapsulants in Europe. The capacity installed during 2017 (grid connected) was only close to 1 MW, as reported by the grid operator Red Eléctrica de España

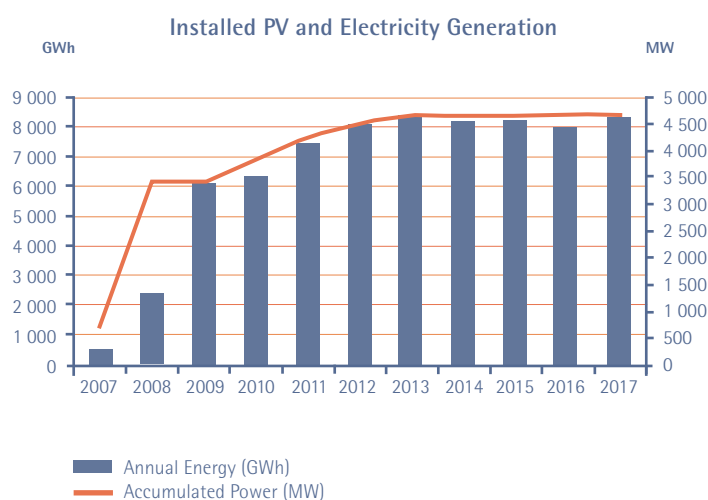


Fig. 6 – Evolution of yearly electricity generation and accumulated installed power for PV technology (Source: UNEF-CNMC; production 2012 - 2017 REE-preliminary data).

(REE). However, values are just preliminary and not yet confirmed. Information about self-consumption is also not yet confirmed, which could be around 19 MW, neither is full off-grid available. In total, these numbers could go up to 100 MW.

Figure 6 represents the accumulated power grid connected, which is quite stable, and the annual energy generation that has variation also due to climatology. Spain's official databases for PV installations that report grid connected PV systems are noted with their AC value (the nominal power injected into the grid). The 4,7 GW nominal AC power on the graphic translates into 5,4 GW peak power of PV modules installed in the field.

Estimations for 2018 are optimistic, from the point of view of new PV installations, as 3,9 GW should be built until 2020. The biggest amount of capacity to be installed within the auction per one company corresponds to 1,55 GW of COBRA (www.grupocobra.com), that have already announced a 500 MW to be installed in Murcia, southeastern Spain. Also, new resolutions of the European Parliament concerning self-consumption initiatives and rules make it possible to have an optimistic approach on that part of PV deployment, too.

SWEDEN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

TOBIAS WALLA, SWEDISH ENERGY AGENCY

PIERRE-JEAN RIGOLE, SWEDISH ENERGY AGENCY

GENERAL FRAMEWORK AND IMPLEMENTATION

According to the EU burden-sharing agreement, Sweden is required to achieve a renewable energy share of 49 % by 2020. However, Sweden has increased this goal to a renewable energy share of at least 50 % of the total energy use.

In 2016, the government, the Moderate Party, the Centre Party, and the Christian Democrats reached an agreement on Sweden's long-term energy policy. This agreement consists of a common roadmap for a controlled transition to an entirely renewable electricity system, with target as follows:

- By 2040, Sweden should achieve 100 % renewable electricity production. This target is not a deadline for banning nuclear power, nor does it mean closing nuclear power plants through political decisions.
- By 2045, Sweden is to have no net emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions.
- By 2030 an energy-efficiency target of 50 % more efficient energy use compared with 2005. The target is expressed in terms of energy relatively to GDP.

Incentives for Renewables

Sweden has a technology-neutral market-based support system for renewable electricity production called the electricity certificate. Sweden and Norway have shared a common electricity certificates market since 2012, wherein certificates may be traded between borders.

The objective of the common certificates market is to increase the production of renewable electricity by 28,4 TWh by 2020, compared to 2012. This corresponds to approximately 10 % of total electricity production in both countries—achieved principally through hydropower, bio-power and wind power. PV still accounts for less than 0,1 % of the Swedish electricity production. In the Swedish energy policy agreement signed in 2016, the electricity certificate support scheme was extended to 2030 with an added ambition of 18 TWh.

Subsidy for PV installations

Since a capital subsidy for PV installations was introduced in 2009, the number of grid connected installations has increased rapidly. The original subsidy covered up to 60 % of the costs of a PV system, but following decreasing prices this level has been lowered to 30 % to enterprises and 20 % to individual person in 2014. The subsidy was increased to 30 % to individual starting from the beginning of 2018. The subsidy has become popular and the volume of applications is occasionally greater than the available funds. In response to the large demand, the Swedish government decided to increase the budget for the subsidy from 40 MEUR to 93 MEUR per year for the period 2018–2020. Since November 2016, there is an additional capital subsidy for households investing in electricity storage in order to increase the PV self-consumption.



Fig.1 - PV system at Uppsala Science Park used in the UppScaleSolar project with the sensor for solar irradiance measurement (Photo: Joakim Munkhammar).

In 2015, a new tax credit scheme on small-scale renewable electricity production, which in practice acts much like a feed-in tariff, was introduced. The scheme entitles the owner of a PV system to a tax credit of 0,06 EUR per kWh of electricity fed into the grid, as long as you are a net electricity consumer. The tax credit is drawn from the income tax, and has a cap of 1 900 EUR per year.

Besides the support systems there are ongoing efforts from Swedish authorities to simplify the process of procuring a PV system, for example the National Board of Housing, Building and Planning has submitted a proposal to simplify and clarify the process of obtaining a building permit for PV installations. The Swedish Energy Agency has ongoing information and knowledge dissemination efforts; for example, through a national project where local energy advisors are trained in PV regulations and applications.

Public Perception

There is a strong opinion in favour of PV technology in Sweden, and about 80 % of the population thinks that efforts towards implementation should increase [1].

NATIONAL PROGRAMME

The Swedish Energy Agency is the governmental authority responsible for most energy-related issues including implementation of governmental policies and decisions related to incentive in the energy sector, information on energy system and climate change, providing the government and the public with statistics, analyses and forecasts, and founding of research and innovation.

[1] Svenska folkets åsikter om olika energikällor - https://som.gu.se/digitalAssets/1656/1656970_svenska-folkets---sikter-om-oilka-energik--llor-1999-2016.pdf



Fig. 2 - Apotea's warehouse and logistic center in Morgongåva - 1 500 kW - Sweden's largest roof-mounted PV system (under installation) (Photo: Gustaf Kumlin / Apotea.se).

In 2016, the agency developed a proposal for the first national strategy in order to promote solar electricity. It suggests that a yearly production of 7-14 TWh electricity from PV can be feasible in Sweden in 2040 (note that this figure is not an official national target). This yearly production would be equivalent to 5-10 % of the electricity consumption if energy usage is the same in 2040 as it is today.

RESEARCH, DEVELOPMENT AND DEMONSTRATION

Research, development and demonstration is supported through several national research funding agencies, universities and private institutions in Sweden. However, among the national research funding agencies, the Swedish Energy Agency is specifically responsible for the national research related to energy. With its annual budget of 140 MEUR, they provide the main funding source for PV; with approximately 55 programmes and 900 projects running.

In 2016, the Swedish Energy Agency has published its strategy defining priorities within PV and solar thermal electricity (STE). Prioritized research areas are: Grid integration, Innovative and flexible solar cell and BIPV, high efficiency solar cell, competitive solar thermal electricity, resource efficiency, ecological environment and sustainability, prosumers perspective, and integration in attractive and sustainable cities.

In 2016, a new research and innovation programme was launched, "El från solen", covering PV and solar thermal electricity (STE). The budget for the entire programme period (2016-2020) is about 17 MEUR. The programme includes both national and international research and innovation project, innovation procurement and expert studies. International projects are conducted in the EU collaboration SOLAR-ERA.NET Cofund. In addition to the research program, the Swedish Energy Agency also provides funding to PV companies though dedicated project supporting their technology development.

Highlights

There are strong academic environments performing research on a variety of PV technologies, such as CIGS thin film, dye sensitized solar cells, polymer solar cells, nanowire solar cells, perovskites and more. There is also research on enhancement techniques for conventional silicon cells.

Comprehensive research in CIGS and CZTS thin film solar cells is performed at the Ångström Solar Center at Uppsala University. The objectives of the group are to achieve high performing cells while utilizing processes and materials that minimize the production cost and the impact on the environment. The Center collaborates with the spin-off company Solibro Research AB (a company of Hanergy), and Midsummer AB.

At Lund University, the division of Energy & Building Design studies energy-efficient buildings and how to integrate PV and solar thermal into those buildings. There is research at the same university on nanowire for solar cells and an innovative production technique called Aerotaxy. The research is performed in collaboration with the company Sol Voltaics AB. Based on the GaAs nanowire, Sol Voltaics is developing a product called Solfilm, which can be used a single junction solar cell or in combination with existing crystalline silicon to form a tandem solar cell.

An ongoing collaboration between Linköping University, Chalmers University of Technology and Lund University, under the name Center of Organic Electronics, carries out research on organic and polymer solar cells. Different areas of use are being investigated, such as sunshade curtains with integrated solar cell. In 2017, the spin-off company Epishine was created to commercialize the technology.

Research on dye-sensitized solar cells is carried out at the Center of Molecular Devices, which is a collaboration between Uppsala University, the Royal Institute of Technology (KTH) in Stockholm and the industrial research institute Swerea IVF. Two Swedish start-up companies, Exeger and Dyenamo, are developing and commercializing the product based on this technology.

Others which are involved in PV research are the Universities of Chalmers, Luleå, Umeå, Dalarna, Karlstad and Mälardalen.

INDUSTRY AND MARKET DEVELOPMENT

The cumulative installed grid-connected power has grown from only 250 kW in 2005 to 205,5 MW in 2017. The market for solar cell in Sweden grew by 63 % to 79,2 MW installed capacity compared to



Fig. 3 - PV system on green roof, SPP, Stockholm - 32 kW (Photo: Solkompaniet).

48,4 MW in 2015. However, PV still accounts for only about 0,1% of the Swedish electricity production, which leaves a large potential for growth. It has been estimated that the potential for electricity produced by roof-mounted solar cells in Sweden amounts to over 40 TWh per year.

The Swedish PV market is dominated by customers who buy and own the PV systems on their own, although sometimes using bank loans as financing sources. In past years, some companies have also started to offer third-party financing as a method of realizing a PV installation.

Sun Renewable Energy AB is the only one remaining solar cell factory for silicon PV in Sweden. The company took over the business after the bankruptcy of SweModule AB and expects the production to start again in 2018.

A fast-growing number of small to medium-sized enterprises exist, that design and sell PV products and systems. Many of these companies depend almost exclusively on the Swedish market. The capital subsidy programme has resulted in more activity among these companies and since there has been a lot of interest from private households, there are several companies that market products specified for this market segment. Some utilities are selling turn-key PV systems, often with assistance from PV installation companies.

There are a few companies exploring other types of solar cells. Midsummer AB inaugurated their factory in 2011, where they produce thin-film CIGS cells to develop their manufacturing equipment, which is their main product. Exeger AB is offering dye sensitised solar cells for powering consumer electronics, and during 2014, they completed a pilot plant. Soltech Energy Sweden AB is developing their own PV integrated roof tiles, and PPAM Solkraft AB is developing different niche products such as bifacial (two-sided) PV modules. Some companies (e.g. Ferroamp AB and Optistring AB) develop balance-of-system equipment such as smart inverters or energy hubs.

SWITZERLAND

PV TECHNOLOGY STATUS AND PROSPECTS

STEFAN NOWAK, NET NOWAK ENERGY & TECHNOLOGY LTD.

AND STEFAN OBERHOLZER, SWISS FEDERAL OFFICE OF ENERGY (SFOE)



Fig. 1 - Swissolar Prize Winner 2017: The most powerful PV façade in Switzerland on the F. Hoffmann-La Roche AG's parking garage in Kaiseraugst, Switzerland. This façade system has a total installed capacity of 633 kWp and an estimated production of 473 000 kWh per year (Photo: © BE Netz AG, Ebikon).

GENERAL FRAMEWORK AND IMPLEMENTATION

2017 has been a decisive year for the Swiss energy policy providing for the long-term strategy and general framework for the coming decades. Prepared by the Federal Council, discussed by the two political chambers (National Council and Council of States) over the previous years, a public vote (referendum) on a fully revised energy act was taken in May 2017 as a first measure of the implementation of the "Energy Strategy 2050" (www.energystrategy2050.ch). The key elements of the new Energy Act are a reduction of the total energy consumption by a strong increase in energy efficiency and the promotion of renewable energy. The construction of new nuclear power stations will be prohibited.

The "Energy Strategy 2050" includes photovoltaic power systems as a key pillar of the long-term strategy for the future Swiss electricity supply. In all scenarios, the role of photovoltaics is acknowledged and expected to contribute in the order of at least 10 – 12 TWh to the national electricity supply by 2050 (60 TWh for 2016). The recent deployment trends (1,80 TWh end of 2017) are presently above the long-term scenarios.

During the year 2017, three elements characterized the national regulatory framework for photovoltaic power systems: a onetime investment subsidy for systems up to 30 kW, a feed-in-tariff scheme for systems above 10 kW and, applicable since 2014, measures for self-consumption. As the financial means for the different support schemes have their origin in a fixed levy on the electricity bill, there continues to be a cap on the total amounts available, resulting in a long waiting list for the feed-in-tariff for photovoltaic power systems. Therefore, self-consumption and new business models implemented by utilities and other commercial operators contribute increasingly to the market deployment.

With the entry in force of the new Energy Act by 1st of January 2018, the support schemes for PV systems has changed: the onetime investment subsidy is extended to all sizes of PV systems whereas as the feed-in tariff scheme (feed-in remuneration at cost (KEV)) is gradually replaced by a feed-in remuneration closer to the market requirements. For systems below a capacity of 100 kW, only the onetime investment subsidy will be available. Although the original feed-in tariff support scheme (KEV) can be applied for PV systems up to 2022, due to the long retroactive waiting list, no newly built systems are expected to benefit from the original system.

As a new element, different endconsumers have the possibility to connect together and to act as a collective towards the local energy supplier. This new measure allows for more flexibility for self-consumption and fosters the integration of PV in the local electricity grid.

Among the early actions of the new energy strategy, an action plan for an increased energy research throughout all relevant energy technologies has been launched in 2013. In 2017, the eight national competence centres for energy research (SCCERs) defined under this action plan have started into their second term for the period 2017 – 2020. The goal of these SCCERs is to build up new permanent research and innovation capacities, as well as institutional networks in the different technology areas. In addition to the SCCERs, CSEM (Centre Suisse d'électronique et microtechnique) runs a PV Technology Centre in Neuchâtel with the mission to support technology transfer and industrial development in the area of photovoltaics.

Two complementary national research programmes – NRP 70 "energy turnaround" (www.nfp70.ch) and NRP 71 "Managing Energy Consumption" (www.nfp71.ch) – continued their projects in 2017.

Alongside these structural measures, important additional financial means have been foreseen to support research activities in the different areas on the project level. Moreover, the financial means of the Swiss Federal Office of Energy (SFOE) for pilot and demonstration projects remain at a high level, aiming at speeding up the technology transfer from research into industrial processes, products and applications.

The development of the photovoltaic sector in Switzerland builds on a strong research and technology base, a diversified industrial activity and a continuous development of the market deployment efforts. A comprehensive research programme covers R&D in solar cells, modules and system aspects. The Swiss energy research strategy is defined by an energy RTD master plan updated every four years with a new period covering the years 2017 – 2020. The master plan developed by the Federal Commission for Energy Research (CORE) in cooperation with the SFOE is based on strategic policy goals (energy & environment, science & education, industry & society) (www.energy-research.ch).

NATIONAL PROGRAMME

Switzerland has a dedicated national [photovoltaic RTD programme](#) which involves a broad range of stakeholders in a strongly coordinated approach. The SFOE research programme Photovoltaics focuses on R&D in a system and market oriented approach, from basic research, over applied research, product development, pilot and demonstration projects all the way to accompanying measures for market stimulation. The programme is organised along the entire value chain and addresses the critical gaps from research over technology to the market place. Thorough component and system analysis, as well as testing, aim at increasing efficiency and performance. Accompanying measures to raise the quality and reliability of photovoltaic power systems include work on standards and design tools.

The strategy to promote international co-operation on all levels continued, related to activities in the Horizon 2020 Programme of the European Union, the European PV Technology and Innovation Platform, the European SOLAR-ERA.NET Network, the IEA PVPS programme and in technology co-operation projects. The new SOLAR-ERA.NET (www.solar-era.net) Cofund Programme, coordinated by Switzerland, executed a new joint call, again covering both PV and concentrated solar power (CSP). Within the IEA PVPS Programme, Switzerland presently leads Task 9 Deploying PV Services for Regional Development and in 2017 the newly established Task 16 Solar Resource for High Penetration and Large Scale Applications (co-lead) (see this report p.15 and p.40).

RESEARCH, DEVELOPMENT AND DEMONSTRATION

In 2017, more than 60 projects, supported by various national and regional government agencies, the European Commission and the private sector, were conducted in the different areas of the photovoltaic energy system. Innovative solutions, cost reduction, increased efficiency and reliability, industrial viability and transfer as well as adequate market orientation are the main objectives of the research efforts.

In the field of solar cell research, priorities lie on heterojunction structures and passivating contacts for high-efficiency crystalline silicon solar cells as well as on different thin-film solar cell technologies for building integration, in particular CIGS cells. Perovskite solar cells and tandem cells with these are increasingly being investigated. Further downstream, new approaches for building and grid integration are being developed and tested in pilot and demonstration projects.

Work at the Swiss Federal Institute of Technology (EPFL) and the CSEM PV Technology Centre in Neuchâtel have focussed on heterojunction and passivating contacts for high-efficiency crystalline silicon solar cells. As part of the activities related to passivating contacts, new process steps (e.g. thermal annealing and selective front side contacts) compatible with industry practice were successfully explored.

On the more fundamental R&D side, in a recent project on perovskite / silicon heterojunction tandem structures, 22,7 % monolithic tandem cells and 25,6 % 4-terminal tandem cells were achieved. Another highlight of the photovoltaic research at CSEM in Neuchâtel in collaboration with the NREL in the United States was the demonstration of a new one-sun record conversion for tandem solar cells of 32,8 % achieved with a gallium indium phosphide / crystalline silicon solar cell. The Neuchâtel PV group extended its cooperation with PV and other industries.

With regard to CIGS solar cells, the Swiss Federal Laboratories for Materials Testing and Research (Empa) have continued their work focussed on flexible CIGS cells on plastic and metal foils. As for silicon solar cell research, the efforts are directed both to increased efficiency as well as industrial implementation. The work aimed for development of novel strategies to reduce non radiative recombination mechanism in order to improve the photovoltaic parameters in CIGS solar cells towards 25 % power conversion efficiency. To do so, novel passivation strategies for bulk and especially interfaces have been explored. On the way towards industrial implementation of flexible CIGS solar cells, cooperation continued with the company Flisom which is commissioning a 15 MW pilot production plant.

For dye-sensitised solar cells, work continues at EPFL on new dyes and electrolytes as well as high temperature stability of the devices. Further rapid progress has been achieved at the Laboratory of Photonics and Interfaces at EPFL concerning perovskite-sensitized solar cells.

On the part of application oriented research, emphasis continues to be given to building integrated photovoltaics (BIPV), both for new solutions involving different solar cells as well as for new mounting systems and structures for sloped roofs and facades. Using new approaches and designs for surface appearance and coloured PV modules, a number of new pilot projects have made good progress in 2017. Using coloured, crystalline silicon-based modules, PV systems in heritage protected zones are starting to be realised (Fig. 2), thereby providing opportunities for applications in critical zones. As part of the analysis of such systems, the losses in energy yield using different technologies to create the colour appearance are being assessed.



Fig. 2 - A southwest view of the PV installation on a farm house in Ecuivillers, Fribourg, Switzerland. With their terracotta appearance, these innovative PV roof tiles provide a perfect integration into the townscape (photos: © CSEM & © ISSOL).

As a recent topic rapidly gaining relevance in some countries and regions, grid integration has continued to generate interest and innovative projects have extensively analysed the implications of PV on the distribution grid. Through detailed modelling work, methods to considerably increase the share of PV in distribution grids have been identified. Based on these more theoretical studies, new pilot projects have started investigating different approaches and experiences with high penetration PV in various grid configurations. High levels of PV penetration in distribution grids are thus no longer considered as insurmountable barriers.

With the ongoing market development, quality assurance and reliability of products and systems, as well as standardisation, continue to be of high priority. The Swiss centres of competence at the Universities of Applied Sciences of Southern Switzerland (SUPSI) and Bern (www.pvtest.ch) carefully evaluate products such as PV modules, inverters and new systems. A number of further Universities of Applied Sciences (e.g. ZHAW Winterthur, Wädenswil, Rapperswil) have developed their PV system infrastructure and analysis. Long term experience with the operation of photovoltaic power systems is carefully tracked for a number of grid-connected systems, ranging between 10 and more than 30 years of operation. During 2017, all Universities of Applied Sciences with PV related activities have met in a workshop to explore cooperation opportunities, in view of strengthening the applied research base from components to systems and applications.

INDUSTRY AND MARKET DEVELOPMENT

Swiss industrial PV products cover a large part of the PV value chain starting from materials, production equipment and small scale manufacturing of solar cells and modules, over diverse components and products all the way to system planning and implementation. A broad range of competitive technologies, products and services are offered to the growing PV market, both domestically and abroad.

The company Meyer Burger, one of the largest equipment suppliers for complete PV module manufacturing lines and advanced PV module technologies, continued its efforts in advanced solar cell technology (silicon heterojunction, smart wire, glass-glass modules). Other technology companies active in the supply of equipment for solar cell manufacturing include Indeotec and Evatec.

Flisom, a company active in CIGS thin film technology on flexible substrates, has progressed with the implementation of a 15 MW pilot production of flexible CIGS modules in Switzerland. For this purpose, Flisom continues to work closely with Empa. After a short time of start-up of individual tools and setting of process parameters cells with efficiencies around 14 % have been achieved and process optimization on the large area started. A first product received the IEC certification early in the project and modules of 3 m length are undergoing IEC certification. In 2017 shipment of first product started in small numbers.

Small production facilities for PV modules are operated by Megasol, Meyer Burger and Sunage. Different companies are active in the manufacturing of coloured PV modules by various techniques, e.g. Swissinso, Solaxess and Üserhuus, as well as for dye-sensitized solar cells, e.g. H.Glass (formerly glass-2-energy) and Solaronix. Measuring equipment for PV module manufacturers is produced by Pasan (a part of Meyer Burger Group). Solar cabling and plugging systems are offered by Huber & Suhner, Leoni Studer and Stäubli Electrical Connectors (formerly Multi-Contact). A number of companies work on mounting systems such as Designergy, dhp technology, Montavent or Schweizer Metallbau.

Based on the US company Power One, ABB is now a leading worldwide inverter supplier. ABB is further active in the technologies for PV grid integration. Studer Innotec continues as a leading producer of stand-alone and grid-tied inverters, increasingly combined with storage units for self-consumption.



Fig. 3 - PV System at Philip Morris in Onnens, Switzerland. The entire system (mounted on several roofs) is presently the largest PV installation in Switzerland; with a capacity of 8,3 MWp, it produces approximately 8 GWh of solar power per year (Photo: © aventron AG).

Alongside an increasing PV capacity being installed in Switzerland, a clear growth of the number of companies as well as that of existing businesses involved in planning and installing PV systems can be observed. Considerable know-how is available amongst engineering companies for the design, construction and operation of a large variety of different applications, ranging from small scale, stand-alone systems for non-domestic, professional applications and remote locations, over small domestic grid-connected systems to medium and large size grid-connected systems in various types of advanced building integration. System sizes have increased over the past years

to multi-megawatt installations on building complexes (e.g. 8,3 MW at Philipp Morris premises in Onnens, Fig. 3).

The annual market volume for grid-connected systems is estimated at 260 MWp for 2017, about the same as for 2016. The total installed capacity by the end of 2017 has risen to above 1,9 GW (Fig. 4) approaching about 240 W/capita. With this installed capacity, close to 3 % of the annual national electricity consumption can now be covered by photovoltaics in Switzerland, which ranks PV number two in renewable electricity sources in Switzerland after hydropower.

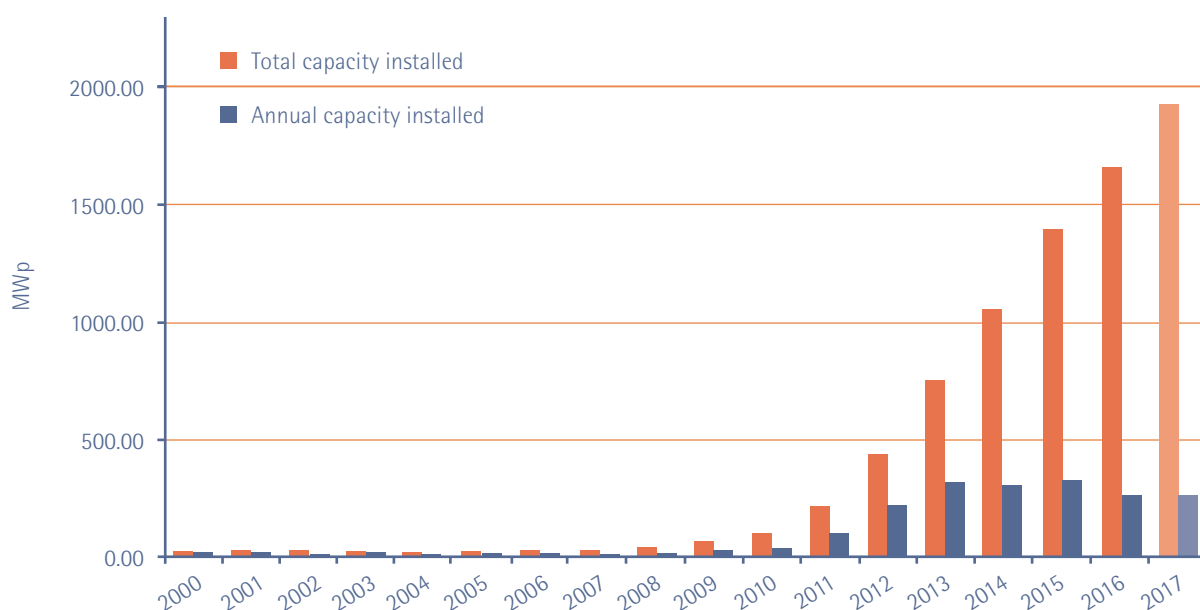


Fig. 4 - Evolution of the installed photovoltaic capacity in Switzerland since the year 2000 (total and annual installed capacity, estimated values for 2017).

THAILAND

PV TECHNOLOGY STATUS AND PROSPECTS

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Fig. 1 – The Mobile Solar Cells Trailer Project to Support Electric Power in Three Southern Border Provinces for Military Units and Neighborhoods. Capacity of 6 kW / vehicle, a total of 12 vehicles can replace about 130,000 units of electricity per year, operated by the Internal Security Operations Command and support budget by the energy conservation fund (Photo: DEDE).

GENERAL FRAMEWORK AND IMPLEMENTATION

Thailand has continued solar systems installation, both ground-mounted PV power plants and PV rooftop systems. This has been in accordance with the Alternative Energy Development Plan 2015 (AEDP 2015) with installed capacity of 6 000 MWp being the target by 2036. The solar incentive program for government agencies and agricultural cooperatives using ground-mounted systems was carried out through the year 2017. At the end of 2017, Thailand finished its study of the rooftop PV self-consumption pilot project evaluation. The result will be used for policy and measures improvement for the future PV rooftop policy.

In addition, the solar power sector would be included as the energy efficiency devices. A few government agencies have started PV rooftop system installation for self-consumption. The distribution utilities service the PV systems installation sector and the generation utility has been continuously working with a new transmission line for the renewable energy power systems that will be completed in 2019.

The new FiT incentive program is for renewable energy power generation, namely SPP Hybrid Firm. SPP is small power producer which incorporates renewable energy generation with a generating capacity of more than 10 MW but not exceeding 90 MW, supplying the electricity to the grid. It has met 300 MW of the target and the

scheduled commercial operation date (SCOD) will be in 2020-21, depending on the new transmission lines project.

NATIONAL PROGRAM

In 2016-17 the national program to promote PV systems installation progressed. The first phase for the government agencies and agricultural cooperatives program was finished by the end of 2016, then the second phase was announced at the end of April 2017. This program limits each PV system capacity to not more than 5 MWp. All of the commercial PV systems completed during the first phase are the agricultural cooperatives with 281 MWp of capacity and the FiT rate is 5,66 THB/kWh. The second phase includes 100 MWp for government agencies and 119 MWp for the agricultural cooperatives. The commercial operation date will be at the end of 2018 with the FiT rate at 4,12 THB/kWh. The total for the government agency and agricultural cooperative program is 500 MWp, while the remainder of 300 MWp is cancelled.

The PV rooftop pilot program which the target was set at 100 MWp for households and buildings/factories with electricity consumption during daytime. As the prosumer self-consumption concept, the applicants are allowed to feed electricity back to the grid without any compensation from the Government and has already COD to



Fig. 2 - 250 kW Solar Floating Project by EGAT at Sirinthorn Dam, Ubon Ratchathani Province. This is a project for preparation and development of Solar Floating Systems in Thailand with the goal of continuing to target GW in 2021 (Photo: EGAT).

the distribution grid at only 5,63 MWp. After studying the result of this project, the policymakers try to develop the new PV rooftop program, which has the scope to encourage households and buildings/factories to produce electricity in the day time for self-consumption. Trends for support schemes in the near future are net-metering or net-billing. This program is going to be considered for approval by the Government.

In addition, the SPP Hybrid Firm program was announced in February 2017. This program uses the competitive bidding method for selection. The FiT rate of the SPP Hybrid Firm for a period of 20 years is composed of a fixed FiT plus a FiT variable. In 2017, the fixed FiT and FiT variable were 1,81 and 1,85 THB/kWh, respectively. The commercial operation could be started in 2020 due to the new transmission lines for renewable energy.

R&D, D

Throughout 2017, research projects on PV rooftop systems carried on from 2016. Chulalongkorn University finished analyzing the Rooftop PV self-consumption pilot project evaluation, supported by the Department of Alternative Energy Development and Efficiency (DEDE). The other project was the Government's PV rooftop demonstration project with a new business model for public utility, supported by the Energy Policy and Planning Office (EPPO) and Energy Conservation Fund. The results of this study will be applied to the Government's public utility budget.

DEDE has continued the project of revising the solar radiation map and applying the Geographic Information System (GIS) to re-estimate potential for solar farms and solar rooftops in the industrial sector. The result of both studies will be beneficial for solar investment and policy direction with the most updated information.

In 2017, the 5 MW of PV power plant from the Electricity Generation Authority of Thailand (EGAT), namely, the Thap Sakae PV power plant, was commercially operated for one year. The project provides a comparison of four different types of PV technologies, such as crystalline silicon, amorphous silicon, microcrystalline amorphous silicon and CIGS (copper indium gallium di-selenide). Each PV technology has 1 MW of capacity with a fixed ground-mounted

system, except the crystalline silicon which has a solar tracking system. In addition, EGAT has released 2,6 MW from the floating PV power plant at Wang Noi power station, which will be commercially operational at the end of 2018.

For the distribution utilities, the Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA) have been involved in the smart grid and smart life program. PEA released the PEA HIVE platform for smart homes which has self-control automation and is user-friendly. MEA has conducted the demonstration project of 2,2 MW of PV rooftop power generation for the Government.

The National Electronics and Computer Technology Center (NECTEC), King Mongkut's University of Technology Thonburi (KMUTT) and Silpakorn University (SU) have conducted the Perovskite Solar Cells: Potential and Trend in Thailand Project. Additionally, they have been involved in the energy storage project for electrical vehicles as well as organizing a forum on renewable energy challenges and the new generation of company PV power plants.

INDUSTRY AND MARKET DEVELOPMENT

In 2017, the accumulative PV system installation was 2 692 MWp (data as of November 2017). The PV system installation increased by approximately 10 % over 2016, and the annual capacity is 246 MWp. Very Small Power Producers (VSPP), who supply the renewable energy electricity with generating capacity not exceeding 10 MW, hold the major market share with 85,2 % of total PV capacity.

The PV rooftop systems program was introduced in 2014 through the FiT incentive scheme. In 2017, the PV rooftop systems were increased continuously in government buildings and the industrial sector to reduce the electricity tariff. The new program for PV rooftop self-consumption systems will be coming in the future.

Furthermore, foreign PV manufacturers have invested in Thailand due to the supportive government policies and attractive investment incentives of the Board of Investment since 2015. In 2017, Thailand had about 15 module manufacturers with 5 000 MW/year of capacity. This production is mainly exported.

TURKEY

PV TECHNOLOGY STATUS AND PROSPECTS

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GENERAL FRAMEWORK AND IMPLEMENTATION

Turkey, located in Southeastern Europe and Southwestern Asia, has an area of about 780 580 km². Agricultural and forest land represent 50 % and 15 % of total land respectively. The rest of the land is used for other purposes. The total population is approximately 80 million in 2017, and the population growth rate 1,05 % per year for last fifteen years. Nearly 75 % of the total population represented the people living in urban areas [1]. With a young and growing population, low per capita electricity consumption, rapid urbanization and strong economic growth, Turkey is one of the fastest growing energy markets in the world. Turkey's total energy demand has been increasing rapidly. Imported fossil fuels dominate Turkey's total primary energy consumption by 75 % [2]. However, one of the government's priorities is to increase the ratio of renewable energy resources to 30 % of total energy generation by 2023. According to the study from the Ministry of Energy and Natural Resources (ETKB), with a high demand scenario in 2023, Turkey's energy demand will increase approximately 7,5 % per year, and will reach 538 TWh. Based on the low demand scenario in 2023, it is expected to reach 480 TWh with an annual increase rate of 6,7 %. Similarly, for the year of 2030, Turkey's energy demand will reach 757 TWh in the high demand scenario and 610 TWh in the low demand scenario, respectively [3-5].

As seen in Table 1, Turkey has 85,2 GW installed capacity of electricity by the end of 2017. The breakdown of installed capacity of electricity by sources is as follows: 55,08 % fossil fuels (natural gas, coals, liquid fuels etc.), 32,01 % hydro, 7,65 % wind, 4,01 % solar and 1,25 % geothermal [2]. Almost the total of natural gas and around 40 % of coal were imported. Therefore, Turkey needs to boost up its self-sufficiency by handling its rich potential of renewable energy sources (RES).

TABLE 1 – BREAKDOWN OF INSTALLED CAPACITY BY ENERGY RESOURCES IN 2016 AND 2017

ENERGY RESOURCES	INSTALLED CAPACITY (MW) (2016)	INSTALLED CAPACITY (MW) (2017)	ADDED CAPACITY (MW) (2016-2017)	INCREASE (%) (2016-2017)
Fossil fuels based thermal power plants	44 411,7	46 926,5	2 514,8	5,7
Hydroelectric	26 681,1	27 273,1	592	2,2
Wind	5 751,3	6 516,2	764,9	13,3
Solar PV	832,5	3 420,7	2 588,2	310,9
Geothermal	820,9	1 063,7	242,8	29,6
Total	78 497,5	85 200,2	6 207,7	8,5

The privatization of energy generation assets, coupled with a strategy to clear the way for more private investments, has resulted in an increased share of private entities in the electricity generation sector, from 32 % in 2002 to 75 % in 2017 [6]. Turkey's power distribution network is completely in the private sector's hands. The liberalization and privatization of electricity generation and distribution increased the amount of private investments and results with increase of generation capacity and energy access security.

NATIONAL PROGRAMME AND LEGISLATION

Solar energy is the most important renewable energy source, which is still untapped in Turkey with a minimum potential of 500 GW. At the end of 2017, cumulative installed PV power in Turkey reached about 3 420,7 MW and increased very rapidly with a 311 % growth compared to the previous year's figure of 832,5 MW [2]. The photovoltaic installations started to take off in 2014 with 40 MW installed capacity and a fivefold increase to 208 MW in 2015 and 580 MW in 2016 and reached 832,5 MW at the end of 2016. By the end of 2017, the cumulative installed power reached to 3 420,7 MW with newly installed capacity of 2 588 MW (Table 2).

TABLE 2 – MONTHLY FIGURES FOR TOTAL INSTALLED PV POWER IN 2017 [2]

MONTH	TOTAL INSTALLED (MW)		
	LICENSED	UNLICENSED	TOTAL
January	12,90	847,70	860,60
February	12,90	886,00	898,90
March	12,90	1 041,20	1 054,10
April	12,90	1 090,80	1 103,70
May	12,90	1 152,80	1 165,70
June	12,90	1 349,70	1 362,60
July	12,90	1 460,11	1 473,01
August	12,90	1 566,44	1 579,34
September	12,90	1 752,92	1 765,82
October	13,90	2 046,20	2 060,10
November	13,90	2 231,80	2 245,70
December	17,90	3 402,80	3 420,70

Table 2 shows the huge increase by end December 2017. The main reason was the increase in distribution costs of PV power plants which will be installed in 2018 by four times mainly for unlicensed PV installation. The distribution costs were 0,7597 TRYkr/kWh in 2016, 2,5628 TRYkr/kWh in 2017, and will be 11,31 TRYkr/kWh in 2018. For example, for a PV power plant with a installed capacity of 1 MW, if it is assumed to generate 1 600 MWh energy for the base scenario, the expenditure will be 22,9 % of the total endorsement gained from the energy sales for the annual distribution cost. Therefore, the investors were in a rush in the last month for getting operation approval for their PV power plants before December, 31, 2017 [7].

In Turkey, two main laws, 6446 (New Electricity Market Law) and 6094 (Law Amending the Law on the Utilization of Renewable Energy Resources in Electricity Generation), are directly related to the utilization of solar energy. The Law 6446 introduces some important changes in the current electricity market system, including amendments to license types, framing its provisions around each type of market activity, specific provisions for certain license types (generation, transmission, distribution, wholesale, retail, auto-producer and auto-producer group), the introduction of a preliminary licensing mechanism and investment incentives, such as extended deadlines and grace periods for environmental compliance. The Law 6094 introduces significant amendments to improve the incentive mechanism under the Renewable Energy Law (Law No: 5346) and encourage renewable energy investment opportunities [4].

According to the Law 6094, a purchase guarantee of 13,3 USDcents/kWh is given for solar electric energy production for ten years. The incentives are available for the PV power plants for 10 years which are or will be in operation before December 31, 2020. Some supplementary subsidies for local equipment products for the first five years of operation are as follows:

- PV module installation and mechanical construction (+0,8 USDcents/kWh),
- PV modules (+1,3 USDcents/kWh),
- PV cells (+3,5 USDcents/kWh),
- Inverter (+0,6 USDcents/kWh),
- Material focusing solar energy on PV modules (+0,5 USDcents/kWh).

The Renewable Energy Designated Areas (YEKAs) are defined under a separate regulation issued in the Law 5346. YEKAs in privately owned or state-owned lands identify the feasible areas for large-scale renewable energy projects. The ETKB provided the details as follows: (i) determination of potential YEKAs, (ii) feasibility and infrastructure studies, (iii) publication of final YEKAs in the Official Gazette, (iv) prerequisites and procedures for the applicants, (v) auction procedures, (vi) implementation of manufacturing facility, (vii) construction of renewable energy power plants.

The Regulation on YEKAs has come into force following its promulgation in the Official Gazette dated October 9, 2016. Although the concept of YEKAs was introduced in Turkish legislation in 2005, it remained mostly inactive until this date. The objectives of the Regulation can be regarded as forming large-scale YEKAs in order to make effective and efficient use of renewable energy sources, and rapidly completing investment projects by assigning these areas to investors, and enabling high-tech equipment used in the generation facilities to be domestically manufactured or supplied and contribute to technology transfer. YEKAs will be determined and developed following either (i) the necessary studies undertaken by the General Directorate of Renewable Energy, or (ii) following a tender to be held for the allocation of connection capacity [8].

While projects conducted within the framework of YEKA benefit fifth-area investment incentives, companies with the highest rate of domestic transfer of technology and production will be given priority [10]. The first bidding was held in Karapinar, Konya with an allocated capacity of 1 GW since the tender announcement for Karapinar YEKA (announced as a YEKA in 2015) was published by the ETKB on October 20, 2016. The project is a major step for large-scale renewable energy investments. The project is developed by one investor with the requirement to set up a manufacturing facility and conduct research and development activities [9]. The bidding was conducted in March 20, 2017. The tender was conducted in a reverse auction and the ceiling price per megawatt was set at 8 USDcent/kWh. At the tender for the Karapinar Renewable Energy Resource Area (YEKA), a consortium has been awarded by submitting the lowest bid, 6,99 USDcent/kWh, to construct the largest PV power plant with an installed capacity of 1 GW (AC) in Turkey. The purchase guarantee price is valid for 15 years. As part of the award criteria, the consortium will build a fully integrated solar cell and module factory with a capacity of 500 MW within the next 21 months. The new facility consists of integrated ingot, wafer, cell and module processes. In addition to the manufacturing facility, the consortium will establish on-site research and development (R&D) center with 100 permanent employees. The Karapinar YEKA-1 Solar Power Plant tender is the first practice in the energy sector to be based on the condition of localization and YEKA-based price determination [10-13].

By the end of 2017, the Turkish Energy Market Regulatory Authority (EPDK) has published a draft net metering regulation for rooftop PV installations with a power range of 3 kW to 10 kW. Households in Turkey will be able to produce solar energy by installing rooftop and façade solar panels and therefore supply their own electricity. According to the new legislation, electricity distribution companies will handle the new applications from the customers for the installation procedures. The installations for up to 3 kW of solar capacity will be approved immediately if the application complies with the regulation. For the capacity above 3 kW and up to 10 kW, the distribution company can approve depending on the availability of the transformer capacity. The new rules for residential PV will likely come into force in the first half of 2018, while other net metering rules for commercial and industrial solar power systems may be issued at a later stage, eventually by the end of 2018. Under the new scheme, owners of residential rooftop PV systems will be entitled to sell surplus power to the country's power distributors. Currently, there is no public support scheme regulating the installation of residential solar in the country [14,15].

In terms of research and development, Turkey's capacity has been increasing in the recent years. In addition to the General Directorate on Renewable Energy, the Marmara Research Center of the Technological and Scientific Research Center of Turkey also carries on solar energy related research projects along with a number of universities. Ege University, Mugla University, Middle East Technical University, Istanbul Technical University, Kocaeli University, Harran University and Firat University can be counted among the chief academic institutions

in the country that are involved with solar energy research. Solar photovoltaic science and engineering is also gaining ground in the curriculum of related undergraduate and graduate programs in such institutions. Surely the proliferation of such programs and research will help in meeting the countries need for expertise in the area [16].

Solar investments can also benefit from the general investment incentive scheme employed in the country. The recently adopted incentive system has four distinct components. These are the General Investment Incentive Plan, Regional Investment Incentive Plan, Large Scale Investments Incentive Plan and the Strategic Investments Incentive Plan. The possible incentives under these categories include different levels of value added tax breaks, customs duty exemptions, interest support and social security premium support for business owners. Within the regional incentive framework, the country is divided into six regions based on the level of development and the amounts of incentives are provided accordingly. Large scale investments have set minimum investment amounts for different sectors and strategic investments are classified as those that would help reduce the current account deficit of the country. Solar sector currently employs around 20 000 workers [16].

INDUSTRY AND MARKET DEVELOPMENT

By the end of 2017, there were 3 616 PV power plants (3 420,7 MW in total) in operation, of only three (17,9 MW in total) are in the licensed segment. The legislation defines the unlicensed electricity power limit as maximum 1 MW. Until the beginning of 2016, some investors had preferred to install MW scaled PV power plants in total by covering a few unlicensed plants, but it is now prohibited by the changed amendments made to the Unlicensed Electricity Generation Regulation on 23 March 2016. In Turkey, 3 613 small-scale, unlicensed, PV power plants (up to 1 MW) are already in operation with an installed capacity of 3 402,8 MW in 2017 [2]. In 2017, only one PV power plant in the licensed segment were connected to the national grid.



Fig. 1 - One of the PV power plants in Kayseri (12 MW) [17].

Regarding PV manufacturing activities, currently there is not any manufacturer for feedstock, ingots and wafers in Turkey. Currently, there are more than 20 PV module manufacturers in Turkey with a production capacity of more than 2 000 MW annually [18]. There are also a few PV module constituents (glass, frame etc.) manufacturers in Turkey.

The PV market of Turkey is being accelerated and development is visible in all dimensions; from production to installation with the support of raising awareness in all levels of society.

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THE UNITED STATES OF AMERICA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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GENERAL FRAMEWORK AND IMPLEMENTATION

In the United States (U.S.), photovoltaic (PV) market development is supported by both national and state-level financial incentives, though state and local policies in support of increased solar deployment often vary in form and magnitude. To date, a national-level deployment mandate has not been implemented, however individual state mandates have been successfully implemented. Despite the lack of a unified national framework, existing policy at the national and state level and rapidly declining technology costs have enabled PV to continue to grow rapidly in the U.S. By the end of 2017, the U.S. was expected to reach 51,5 GWD_c of cumulative installed capacity, an increase from 40,9 GWD_c in 2016, and 25,8 GWD_c in 2015 [1]. Moreover, while state mandates, in the form of renewable portfolio standards (RPS), have historically been a major driver to solar deployment, 2017 has seen an increase in the number of systems being installed outside of state mandates due to PV's cost competitiveness with conventional sources of generation.

Several state-level policy and financing mechanisms have emerged that have the potential to encourage further solar market expansion through the establishment of widespread local and utility programs. Such policies include low-cost loan programs, as well as time of use rate structures. Third-party ownership (a mechanism that allows a developer to build and own a PV system on a customer's property and then sell the generation back to that customer) continues to be a popular option for financing the installation of PV, particularly in the residential sector. However, loans and cash purchases of systems are increasing in popularity due to both the declining cost of solar and new loan products entering the market. Loans have even eclipsed third-party ownership in some residential markets [2]. Companies have also issued innovative financing mechanisms to raise cheaper sources of capital through public markets.

The end of 2017 saw a significant national tax policy change that may impact U.S. solar expansion. The biggest change in the new policy affecting the solar industry lowers the federal corporate tax rate from 35 %, where it had been since 1986, to 21 %. The law also includes a provision [3] that may reduce the value of energy tax credits to large multinational companies, and caps the amount of interest deductions most large companies can make to 30 % of adjusted taxable income. These changes will likely decrease participation from tax equity investors, thereby potentially raising the relative cost of financing new installations. On the other hand, the new tax law also allows non-utility project owners to take 100 % depreciation on capital expense during the first year of operation through 2022. Additionally, with a lower corporate tax rate, project owners will likely be subject to fewer tax payments from electricity revenue, thereby receiving more net project cash flow.

[1] GTM Research SEIA, Q4 2017: U.S. Solar Market Insight. December 2017.

[2] *Id.*

[3] Public law no. 115-97, Base Erosion and Anti-Abuse Tax (BEAT) provision.

A case filed in April 2017 before the U.S. International Trade Commission (ITC) resulted in a proclamation by the President of the United States placing tariffs on solar modules and cells imported into the U.S. The four-year tariff begins at 30 %, ad valorem, in 2018, reducing 5 % each year. However, the proclamation exempts the first 2,5 GW of imported cells from the tariff and a few developing countries (up to 3 % per country, 9 % total); further tariff exemptions to certain products and countries may follow.

U.S. Annual PV Installations

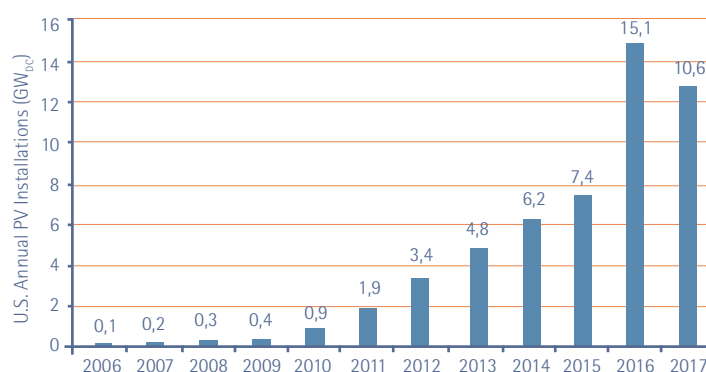


Fig. 1 - U.S. Annual PV Installations. Source: GTM/SEIA, U.S. Solar Market Insight Report 2017 Year in Review. 2018.

NATIONAL PROGRAM

The U.S. supports the domestic installation and manufacturing of PV generating assets for domestic consumption. Financial incentives for U.S. solar projects are provided by the national government, state and local governments, and some local utilities. Historically, national incentives have been provided primarily through the U.S. tax code, in the form of a 30 % Investment Tax Credit (ITC) (which applies to residential, commercial, and utility-scale installations) and accelerated 5-year tax depreciation (which applies to all commercial and utility-scale installations and to third-party owned residential, government, or non-profit installations). Under the new tax plan, project owners will now be able to depreciate 100 % of their capital expenses during the first year of system operation through 2022; starting in 2023, the percentage of capital equipment that can be expensed immediately drops 20 % per year (e.g., 80 % in 2023 and 60 % in 2024) until the provision drops to 0 % in 2027. Though the ITC was set to expire in 2016, the 30 % credit has been extended to 2020. Beginning in 2020, the credits will step down gradually until 2022 where they will remain at 10 % for commercially owned systems, and expire for systems owned by individuals [4].

[4] The credit for residential customers drops to 26 % and 22 % for projects placed in service in 2020 and 2021, respectively. Commercial and utility projects under construction before 2020 receive the full 30 % credit. The credit then falls to 26 % for commercial and utility projects starting construction in 2020 and 22 % for commercial and utility projects starting construction in 2021. For any solar project that starts construction after 2021, or which fails to be placed in service by January 1, 2024, the ITC for commercial and utility projects reverts to 10 %.



Fig. 2 - Phil Doucette (left) and Jim Mitchell (right) of Newport Renewables install solar panels on the Powers Building, part of a 330 000 kWh, 890 panel project covering three government buildings in the Capitol Hill complex. The Rhode Island Statehouse is visible in the background (Photo: Robert Beadle).

State incentives in the U.S. have been driven in large part due to the passage of Renewable Portfolio Standards (RPS). An RPS, also called a renewable electricity standard (RES), requires electricity suppliers to purchase or generate a targeted amount of renewable energy by a certain date. Although design details can vary considerably, RPS policies typically enforce compliance through penalties, and many include the trading of renewable energy certificates (RECs). A clean energy standard (CES) is similar to an RPS, but allows a broader range of electricity generation resources to qualify for the target. As of August 2017, twenty-nine states, three territories, and Washington D.C., had RPS policies with specific solar or customer-sited provisions, with an increasing number of states adopting aggressive RPS goals of procuring 50 % or more of their electricity from renewable sources [5]. Many states also require utilities to offer net metering, a billing mechanism which credits electricity produced by a solar energy system fed back to the grid. In 2017, the number of states with net metering laws decreased from 41 to 38, as some states, including California, have begun to transition to new compensation mechanisms for customer-connected PV systems.

The U.S. government also supports the advancement of PV through its work at the Department of Energy's (DOE) Solar Energy Technologies Office (SETO), discussed in the section below, and has supported the demonstration of PV and other renewable technologies through the DOE Loan Program Office's Loan Guarantee Program [6].

RESEARCH, DEVELOPMENT & DEMONSTRATION

The DOE is one of the primary bodies that supports research, development, and demonstration (RD&D) of solar energy technologies. In February 2011, the Secretary of Energy launched the SunShot Initiative, a program focused on driving innovation to make solar energy systems cost-competitive with other forms of energy. To accomplish this goal, several DOE offices, including DOE's SETO, Office of Science, and Advanced Research Projects Agency - Energy (ARPA-E)

collaborated to support efforts by national laboratories, academia, and private companies to drive down the cost of utility-scale solar electricity to about 6 USD cents per kilowatt-hour by the year 2020. In late 2016, the DOE updated the SunShot goal and will now work to further reduce the installed cost of solar energy to 3 USD cents per kWh by 2030, while enabling greater adoption by addressing grid integration challenges and market barriers [7].

By funding a portfolio of complementary RD&D concepts, SETO promotes a transformation in the ways the U.S. generates, stores, and utilizes solar energy. These research and development activities fall into five broad categories, which in fiscal year 2017, were funded at the levels found in Table 1:

1. Photovoltaic (PV) Research and Development, which supports the research and development of PV technologies to improve efficiency, durability, and reliability, as well as lower material and process costs to reduce the levelized cost of solar generated electricity.
2. Concentrating Solar Power (CSP), which supports research and development of CSP technologies that reduce the cost of solar energy with systems that can supply solar power on demand, even when there is no sunlight, through the use of thermal storage.
3. Systems Integration, which develops technologies to enable improved integration of solar power with the grid including power electronics and systems-level research on renewables integration.
4. Balance of Systems Soft Cost Reduction, which works with stakeholders at the state and local levels to cut red tape, streamline processes, and increase access to solar.
5. Innovations in Manufacturing Competitiveness, which helps groundbreaking technologies and business models transition to the market by supporting efforts on developing commercial prototypes and scaling-up.

[5] North Carolina Clean Energy Technology Center. *Renewable Portfolio Standard Policies*. Accessed February, 2018. <http://www.dsireusa.org/resources/detailed-summary-maps/>

[6] A full list of projects funded with DOE loan guarantees is available at: <https://energy.gov/lpo/loan-programs-office/>

[7] Since solar energy does not match demand at higher penetrations, even lower prices are needed to spur development. More information on the SunShot 2030 Goal of 3 USDcents/kWh can be found here: <https://www.energy.gov/eere/solar/sunshot-2030>



Fig. 3 - Alliston Watts removes a PV module after a damp test for accelerated stress testing (Photo: Lindsey Dillon).

TABLE 1 – BREAKDOWN OF SOLAR ENERGY TECHNOLOGIES PROGRAM FY 17 ENACTED FUNDING

Photovoltaic R&D	64 MUSD
Concentrating Solar Power	55 MUSD
Systems Integration	57 MUSD
Balance of Systems/ Soft Cost Reduction	15 MUSD
Innovations in Manufacturing Competitiveness	16,6 MUSD
Total	207,6 MUSD

Funding provided by SETO is shown in table 1. In addition, the Department of Energy's Office of Science and ARPA-E, the National Science Foundation, the Department of Defense, the National Aeronautics and Space Administration, and states such as California, New York, Florida and Hawaii also fund solar R&D.

INDUSTRY AND MARKET DEVELOPMENT

The U.S. market, in terms of annual installed capacity, decreased from roughly 15,1 GW in 2016 to 10,6 GW in 2017. This decrease is due to a slowdown in utility and residential installations. The unprecedented increase in installed capacity seen from 2015 to 2016 was largely due to expectations from developers and utilities that the ITC would expire. Many planned installations were accelerated to meet the expected deadline, which caused the subsequent lull in installations in 2017. In the residential sector, solar installation companies have been transitioning away from less profitable, customer-direct sales channels, the effect of which has reduced growth in the residential segment [8].

PV capacity continues to be concentrated in a small number of states, such as California, which represents roughly 40 % of the national market. However, this trend is changing slowly as 33 states currently have 100 MW or more of PV capacity [9]. Due to the continued reduction in system pricing, as well as the availability of new loan products and financing arrangements, a significant portion of PV systems have recently been installed without any state incentives, and analysts have estimated that 75 % of utility-scale PV installed in 2017 had been procured outside of RPS obligations, based on PV's competitiveness with other sources of generation [10]. While 21 GW of contracted utility scale PV projects are in the pipeline as of October 2017, total installations in 2018 are expected to fall year-over-year before increasing again to 2016-levels in 2019-2022 [11].

U.S. PV manufacturing contracted in the first three quarters of 2017, with cell and module production declining 64 % and 47 % relative to the first three quarters of 2016 [12]. Domestic PV module and cell manufacturing has been substantially affected by reductions in price and margin which began in mid-2016; the two largest U.S. cell manufacturer companies – Suniva and SolarWorld – filed for bankruptcy in 2017 and initiated layoffs. However, U.S. manufacturing has a significant presence in other parts of the PV value chain, including polysilicon, encapsulants, wiring, and fasteners. The manufacturing sector employed 36 885 people in 2017, a 3 % decrease from 2016 [13].

Industry-wide, approximately 156 769 jobs relating to solar were added from 2010 to 2017, and the industry has grown to a total of over 250 000 employed in 2017 [14]. 2017 saw a decline of approximately 10 000 jobs from 2016, largely attributable to the ITC extension, manufacturing decreases, and changes in strategy by large residential installers [15].

[8] GTM Research/SEIA, Q4 2017: U.S. Solar Market Insight. December 2017.

[9] *Id.*

[10] *Id.*

[11] *Id.*

[12] *Id.*

[13] Solar Foundation. (2017). *National Solar Jobs Census 2017*. Washington, DC: The Solar Foundation.

[14] *Id.*

[15] *Id.*

IEA PVPS COMPLETED TASKS DELIVERABLES – WHERE TO GET THEM?

All IEA PVPS reports are available for download at the IEA PVPS website: www.iea-pvps.org.

TASK 2 – PERFORMANCE, RELIABILITY AND ANALYSIS OF PHOTOVOLTAIC SYSTEMS (1995-2007)

Task 2 Reports & Database

1. Analysis of Photovoltaic Systems, T2-01:2000
2. IEA PVPS Database Task 2, T2-02:2001
3. Operational Performance, Reliability and Promotion of Photovoltaic Systems, T2-03:2002
4. The Availability of Irradiation Data, T2-04:2004
5. Country Reports on PV System Performance, T2-05:2008
6. Cost and Performance Trends in Grid-Connected Photovoltaic Systems and Case Studies, T2-06:2007
7. Performance Prediction of Grid-Connected Photovoltaic Systems Using Remote Sensing, T2-07:2008

TASK 3 – USE OF PHOTOVOLTAIC POWER SYSTEMS IN STAND ALONE AND ISLAND APPLICATIONS (1993-2004)

Task 3 Reports

1. Recommended Practices for Charge Controllers, T3-04:1998
2. Stand Alone PV Systems in Developing Countries, T3-05:1999
3. Lead-acid Battery Guide for Stand-alone Photovoltaic Systems, T3-06:1999,
4. Survey of National and International Standards, Guidelines and QA Procedures for Stand-Along PV Systems, T3-07:2000
5. Recommended Practices for Charge Controllers, T3-08:2000
6. Use of appliances in stand-alone PV power supply systems: problems and solutions, T3-09:2002
7. Management of Lead-Acid Batteries used in Stand-Along Photovoltaic Power Systems, T3-10:2002
8. Testing of Lead-Acid Batteries used in Stand-Along PV Power Systems – Guidelines, T3-11:2002
9. Selecting Stand-Along Photovoltaic Systems – Guidelines, T3-12:2002
10. Monitoring Stand-Along Photovoltaic Systems: Methodology and Equipment – Recommended Practices, T3-13:2003
11. Protection against the Effects of Lightning on Stand-Along Photovoltaic Systems – Common Practices, T3-14:2003
12. Managing the Quality of Stand-Along Photovoltaic Systems – Recommended Practices, T3-15:2003
13. Demand Side Management for Stand-Along Photovoltaic Systems, T3-16:2003
14. Selecting Lead-Acid Batteries Used in Stand-Along Photovoltaic Power Systems – Guidelines, T3-17:2004
15. Alternative to Lead-Acid Batteries in Stand-Along Photovoltaic Systems, T3-18:2004

TASK 5 – GRID INTERCONNECTION OF BUILDING INTEGRATED AND OTHER DISPERSED PHOTOVOLTAIC SYSTEMS (1993-2003)

Task 5 Reports

1. Utility Aspects of Grid Interconnected PV Systems, T5-01:1998
2. Demonstration Tests of Grid Connected Photovoltaic Power Systems, T5-02:1999
3. Grid-connected Photovoltaic Power Systems: Summary of Task 5 Activities from 1993 to 1998, T5-03:1999
4. PV System Installation and Grid-interconnection Guideline in Selected IEA Countries, T5-04: 2001
5. Grid-connected Photovoltaic Power Systems: Survey of Inverter and Related Protection Equipment, T5-05: 2002
6. International Guideline for the Certification of PV System Components and Grid-connected Systems, T5-06:2002
7. Probability of Islanding in Utility Networks due to Grid Connected Photovoltaic Power Systems, T5-07: 2002
8. Risk Analysis of Islanding of Photovoltaic Power Systems within Low Voltage Distribution Networks, T5-08: 2002
9. Evaluation of Islanding Detection Methods for Photovoltaic Utility-interactive Power Systems, T5-09: 2002
10. Impacts of Power Penetration from Photovoltaic Power Systems in Distribution Networks, T5-10: 2002
11. Grid-connected Photovoltaic Power Systems: Power Value and Capacity Value of PV Systems, T5-11: 2002

TASK 6 – DESIGN AND OPERATION OF MODULAR PHOTOVOLTAIC PLANTS FOR LARGE SCALE POWER GENERATION (1993-1998)

Task 6 Reports, Papers & Documents

1. The Proceedings of the Paestrum Workshop
2. A PV Plant Comparison of 15 plants
3. The State of the Art of: High Efficiency, High Voltage, Easily Installed Modules for the Japanese Market
4. A Document on "Criteria and Recommendations for Acceptance Test"
5. A Paper, entitled: "Methods to Reduce Mismatch Losses."
6. Report of questionnaires in the form of a small book containing organized information collected through questionnaires integrated with statistical data of the main system parameters and of the main performance indices
7. The "Guidebook for Practical Design of Large Scale Power Generation Plant"
8. The "Review of Medium to Large Scale Modular PV Plants Worldwide"
9. Proceedings of the Madrid Workshop

TASK 7 – PHOTOVOLTAIC POWER SYSTEMS IN THE BUILT ENVIRONMENT (1997–2001)

Task 7 Reports

1. Literature Survey and Analysis of Non-technical Problems for the Introduction of BIPV Systems, T7-01:1999
2. PV in Non-Building Structures - A Design Guide, T7-02:2001
3. Potential for Building Integrated Photovoltaics, T7-04:2001
4. Guidelines for the Economic Evaluation of Building Integrated Photovoltaics, T7-05:2002
5. Market Deployment Strategies for Photovoltaics in the Built Environment, T7-06:2002
6. Innovative electric concepts, T7-07:2002
7. Reliability of Photovoltaic Systems, T7-08:2002
8. Book: "Designing with Solar Power - A Source Book for Building Integrated Photovoltaics (BIPV)", Edited By Deo Prasad and Mark Snow, Images Publishing, 2005 (ISBN 9781844071470)

TASK 8 – STUDY ON VERY LARGE SCALE PHOTOVOLTAIC POWER GENERATION SYSTEM (1999–2014)

Task 8 Reports

Task 8 published extensive reports as a series of "Energy from the Desert" books, focusing on VLS-PV systems. The books showed that the VLS-PV is not a simple dream but is becoming realistic, and have become well-known all over the world.

1. Book: "Energy from the Desert: Feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems", James and James, 2003 (ISBN 1 902916 417)
2. Report: "Summary – Energy from the Desert: Feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems", 2003
3. Report: "Summary – Energy from the Desert: Practical Proposals for Very Large Scale Photovoltaic Systems", 2006
4. Book: "Energy from the Desert: Practical Proposals for Very Large Scale Photovoltaic Systems", Earthscan, 2007 (ISBN 978-1-84407-363-4)
5. Book: "Energy from the Desert: Very Large Scale Photovoltaic Systems, Socio-Economic, Financial, Technical and Environmental Aspects", Earthscan, 2009 (ISBN 978-1-84407-794-6)
6. Report: "Summary – Energy from the Desert: Very Large Scale Photovoltaic Systems, Socio-Economic, Financial, Technical and Environmental Aspects", 2009
7. Book: "Energy from the Desert: Very Large Scale Photovoltaic Power - State-of-the-Art and into the Future", Earthscan from Routledge, 2013 (ISBN 978-0-415-63982-8(hbk) /978-0-203-08140-2(cbk))

8. Report: "Summary - Energy from the Desert: Very Large Scale Photovoltaic Power - State-of-the-Art and into the Future", 2013
9. Report: "Energy from the Desert: Very Large Scale PV Power Plants for Shifting to Renewable Energy Future", 2015 (ISBN 978-3-906042-29-9)
10. Report: "Summary - Energy from the Desert: Very Large Scale PV Power Plants for Shifting to Renewable Energy Future", 2015
11. Brochure: "Energy from the Desert: Fact sheets and the Summary of the Research", 2015

TASK 10 – URBAN SCALE PV APPLICATIONS (2004–2009)

Task 10 Reports

1. Compared Assessment of Selected Environmental Indicators of PV Electricity in OECD Cities, T10-01:2006
2. Analysis of PV System's Values Beyond Energy -by country, by stakeholder, T10-02:2006
3. Urban BIPV in the New Residential Construction Industry T10-03:2008
4. Community Scale Solar Photovoltaics: Housing and Public Development Examples T10-04:2008
5. Promotional Drivers for Grid Connected PV, T10-05:2009
6. Overcoming PV Grid Issues in Urban Areas, T10-06:2009
7. Urban PV Electricity Policies, T10-07:2009
8. Book: Photovoltaics in the Urban Environment, Routledge, ISBN 9781844077717

TASK 11 – HYBRID SYSTEMS WITHIN MINI-GRIDS (2006–2012)

Task 11 Reports

1. Worldwide Overview of Design and Simulation Tools for PV Hybrid Systems, T11-01:2011
2. The Role of Energy Storage for Mini-Grid Stabilization, T11-02:2011
3. Sustainability Conditions for PV Hybrid Systems: Environmental Considerations, T11-03:2011
4. COMMUNICATION BETWEEN COMPONENTS IN MINI-GRIDS: Recommendations for communication system needs for PV hybrid mini-grid systems, T11-04:2011
5. Social, Economic and Organizational Framework for Sustainable Operation of PV Hybrid Systems within Mini-Grids, T11-05:2011
6. Design and Operational Recommendations on Grid Connection of PV Hybrid Mini-grids, T11-06:2011
7. PV Hybrid Mini-Grids: Applicable Control Methods for Various Situations, T11-07:2012
8. Overview of Supervisory Control Strategies Including a MATLAB® Simulink® Simulation. T11-08:2012

ANNEX A

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COLOPHON

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