Technology Collaboration Programme
by iea

International Energy Agency
Photovoltaic Power Systems Programme

PVPS

ANNUAL REPORT
2021

PHOTOVOLTAIC POWER SYSTEMS TECHNOLOGY COLLABORATION PROGRAMME

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

ANNUAL REPORT 2021

Cover photo (source: K Water)

Floating PV system on a water reservoir at the Hapcheon dam, in the South Korean province of South Gyeongsang. Commissioned in November 2021, built by Korean developer Scotra with modules provided by Korean-based manufacturer Hanwha Q-Cells, this 41.5 MW system is Korea's largest floating PV plant so far.

COLOPHON

Task Status Reports
PVPS Task Managers
Editor
Emily Jessica Mitchell
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MESSAGE FROM THE CHAIR

For almost 3 decades, the PVPS programme of the International Energy Agency has been working to bring together and allow cooperation between generations of researchers across all inhabited continents in the field of solar photovoltaics.

This long-term and in-depth work has enabled step by step progress in the integration, operation and ultimately the acceptability of solar energy in a wide range of applications.

In 2021, solar energy has finally become what all these generations of researchers have dreamed of: THE technology at the center of the ecological transition needed to face the climate emergency.

In this context more than ever, our PVPS programme is strategically very well positioned, being the only meeting place bringing together both a great geopolitical variety of some thirty countries and international entities, as well as a wide scope of innovative projects ranging from solar mobility to integration in both networks and buildings.

I have the great honor to chair the programme since early 2021. I would like to take this opportunity to acknowledge the immense work accomplished by my predecessor Stefan Nowak over the course of almost 20 years. The stakes are very high at this point in time, given the central role that photovoltaics will play globally in the coming decade, but this is also a most exciting challenge.

More than ever, PVPS must provide a service as a knowledge broker and exchange forum for its member countries and beyond. Of course, the programme will continue to uphold its scientific excellence to maintain the recognition of our work as an indisputable reference, but it is crucially important to get the message out to let the world know that solar is indeed one of the central renewable energies today. Trends in global data suggest that the annual market volume could exceed 200 GWp as early as this year 2022 will further double or even triple by 2030.

In this new period in the governance of PVPS, we also welcome Emily Mitchell in the role of Executive Secretary, who takes the place of Mary Brunisholz. Mary is highly appreciated for her tremendous work over many years in her secretarial capacity. Looking forward, together with the Management Board, Executive Committee Members,Task Managers and IEA colleagues, Emily and I will do our utmost to make the PVPS more useful than ever as a key piece of the energy transition puzzle.

As you read this report, you will notice that the format has evolved somewhat compared to previous editions. Our aim is to better serve our readers while faithfully reporting on our achievements. We hope you find the updates attractive and informative and that you pass on the key messages within your networks.

During my first year as PVPS Chair, I understood more than ever that the strength of our programme lies in its collaborative approach and its function as an international forum where all the countries of the world's photovoltaic ecosystem are invited to progress together.

Enjoy your reading!

Daniel Mugnier

Chair

March 2022

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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 IEA'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 Energy End-Use Technologies, Fossil Fuels, Renewable Energy Technologies 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 nine renewable energy agreements and is supported by the Renewables and Hydrogen Renewable Energy Division at the IEA Secretariat in Paris, France.

IEA PVPS

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the Technology Collaboration Programmes (TCP) 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 Task Managers. By end 2021, eighteen Tasks were established within the PVPS programme, of which eight are currently operational.

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

IEA PVPS CURRENT TERM (2018 – 2023)

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 many countries. IEA PVPS is using its current term:

- to serve as a **global reference on PV for policy and industry decision makers** from PVPS TCP member countries and bodies, non-member countries and international organisations; with the addition of its most current PVPS TCP members, it embraces all continents and subcontinents;
- to provide 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;
- to act as an **impartial and reliable source of information** for PV experts and non-experts concerning worldwide trends, markets and costs;
- to provide meaningful **guidelines and recommended practices** for state-of-the-art PV applications in meeting the needs of planners, installers and system owners;
- to contribute to 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;
- to establish a fruitful **co-operation between expert groups on decentralised power supply** in both developed and emerging countries;
- to provide an overview of **successful business models** in various markets segments;
- to support the **definition of regulatory and policy parameters** for long term sustainable and cost effective PV markets to operate.

Last executive committee meeting in November 2021 in Paris

Therefore, in this term, the IEA PVPS TCP is placing particular emphasis on:

New CONTENT:
- More focus on the role of PV as part of the futures **energy system**;
- PV interaction with other technologies (storage, grids, heat-pumps, fuel cells, bioenergy, etc.);
- Integration of PV into buildings, communities and cities, the mobility sector, industry and utilities.

New ways of COLLABORATION, to closely collaborate with other partners in the energy sector:
- Increase the IEA internal collaboration, with the IEA Secretariat, other TCPs, other international energy organisations and agencies;
- To link PVPS even more closely to national PV associations, in order to provide reliable and unbiased facts and practices;
- With specific sectors such as utilities and regulators, the mobility sector, the building sector and the industry sector;
- Open up **more cooperation possibilities** beyond the usual partners until now; e.g. non-IEA PVPS countries, non-PV networks and associations, etc.

Supported by new ways of COMMUNICATION:
- The adapted work needs significantly adapted ways to communicate our work (broader target audience, wider view of PV in the energy system, etc.);
- Changes in communication concern all tools used: website, newsletters, webinars, report summaries, one-pagers, press releases, conferences, workshops, social media, etc.

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.

IEA PVPS OBJECTIVES

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

- PV technology development
- Competitive PV markets
- An environmentally and economically sustainable PV industry
- Policy recommendations and strategies
- Impartial and reliable information.

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 Task Managers. 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 (concluded in 2018);
- 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. PV Sustainability of Photovoltaic Systems. Begun in 2007;
- Task 13. Performance, Operation and Reliability of Photovoltaic Systems. Begun in 2010;
- Task 14. Solar PV in the 100 % RESP Power System. 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 2018.
- Task 18. Off-Grid and Edge of Grid Photovoltaic Systems. Begun in 2019.

The **Task Manager** is responsible for implementing, operating and managing the collaborative project. Depending on the topic and the Tasks, the internal organisation and responsibilities of the Task Managers can vary, with more or less developed subtask structures and leadership. Task Managers are responsible towards the PVPS ExCo and they generally represent their respective Tasks at meetings and conferences. The Task Managers compile a status report, with results achieved in the last six months, as well as a Workplan for the coming period. These are 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.

TASK 1

STRATEGIC PV ANALYSIS & OUTREACH

Task managers: Gaëtan Masson (Becquerel Institute, Belgium), Izumi Kaizuka (RTW Corporation, Japan)

Fig.1 - 57th IEA-PVPS Task 1 Meeting in Paris, France, November 2021

INTRODUCTION

Task 1 researches continuously the status and drivers of PV development in IEA PVPS countries and globally. In that respect, it aims at providing every year at least two reports and special events highlighting the key developments in the PV sector.

→ **Read about the objectives and structure of Task 13 in the Annex**

TASK ACCOMPLISHMENTS

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. The role of Task 1 is evolving towards more intelligence and data collection and less communication which is currently being centralized for the whole programme by the team of the executive secretary.

- In addition to the subject managed in general by the Task 1 group, 2022 will be a year of focus on the question of social acceptance. This subject is increasingly at the core of discussions, due to the growing visibility of PV development and will result in clear analysis in the Trends report and events organized by Task 1 in 2022.

OUTLOOK

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.

26TH 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 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-five 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 prior year's PV market developments and is published begin of April. 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.

DATA MODEL AND DATA ACQUISITION FOR PV REGISTRATION SCHEMES AND GRID CONNECTION – BEST PRACTICE AND RECOMMENDATIONS

This report jointly written by Task 1 and Task 14 provides a first comprehensive set of recommendations to properly register PV installations, follow and update them. The aim is to provide grid operators but also policymakers with a clear picture of the situation of the fleet of PV plants, their characteristics and more.

REVIEW OF PV SELF-CONSUMPTION POLICIES

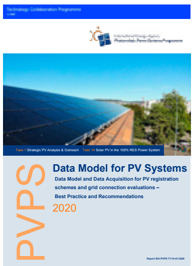
This new report published in 2016 has been partially updated in 2021 and will be published in 2022. It analyzes and compares policies supporting the local self-consumption of PV electricity. It accompanies the most recent developments in regulatory updates in key countries allowing PV system owners to become real prosumers. It provides an independent, fair and accurate analysis on the policy evolutions currently ongoing in several countries, highlighting the technical, economic and regulatory challenges associated to the development of PV for prosumers.

All Task 1's PVPS Publications, including 12 new Technical Reports from 2021, are available here

DATA MODEL FOR PV SYSTEMS

TASK 1 HIGHLIGHT

H. Fechner, W. Johnston, G. Neubourg, G. Masson, P. Ahm, G Altenhöfer-Pflaum, F. Tilli, P. Hüsser



Data Model for PV Systems

Task 1 Webpage

KEY MESSAGE

Knowing the PV installed fleet is essential for grid management, system stability and fair and sound policy decisions. Too often, the reported installed capacity lacks detailed information, when available and the variety of data collected differs significantly depending on the country. This report defines a data model of registering accurately PV systems.

OBJECTIVE

This report aims at providing clear guidelines for registering and updating data about installed PV system with comprehensive guidelines and usable recommendations. The report presents a complete data Model and data acquisition for PV registration schemes and grid connection evaluations, including best practices and recommendations.

METHODOLOGY

The rapid growth of Distributed Energy Resources (DER) in the grid brings up new challenges in power system management. Instead of managing a few hundred medium and large power plants in a country, in certain countries there are more than a million DER systems connected to the grid. This report shows how different countries deal with the DER data collection, with a focus on PV systems. This report also provides a complete overview of all the relevant aspects that need to be addressed and foresee information that will be relevant in the future.

BASIC RECOMMENDED DATA FOR DATABASE
Administrative data (identification number, name of the owner, contact details)
Location (address, coordinates)
Nominal AC power
Nominal DC power
Date of finalization of project* / commissioning* / system update / decommissioning

Fig.2 - Independent of the purpose of the database, a set of basic data is recommended to be collected for every PV system.

A growing trend towards centralised databases can be observed, in several countries, the owner of DER are obliged to register their systems in a central database and to keep this register up to date. However, the data model and thereby the level of detail in the individual registers varies a lot: Some countries such as Spain just require basic power data, whereas other countries such as Denmark or Germany require detailed system information.

The most important recommendations in the report are:

- Countries should operate a database for DER, in particular for PV power systems.
- A DER database shall be open for multiple stakeholders.
- A DER database shall cover all DER, not just a part of them, e.g. systems that are granted a FIT.
- The use of the DER database shall be compulsory.
- A DER database shall reduce the overall administrative load for PV system planning, realisation, commissioning and operation. Therefore, the database shall substitute or support existing administrative processes.

Data of PV plants are necessary for a range of use cases. Policy makers should know the impact of policies on the market, FIT agencies must know exactly which system produces how much energy, and system operators must be able to calculate the impact of the PV system to their grid, to name just a few. In this report, the different use cases are addressed and recommendations for the implementation of a database are given.

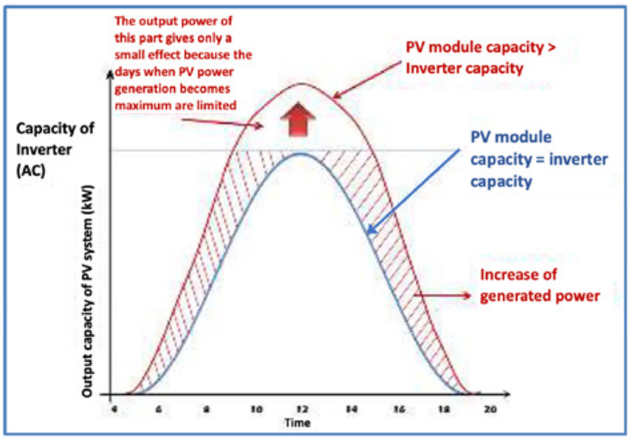


Fig.3 - Power output curves with/without optimization. Courtexy RTS Corp. Japan

For the global PV market development, all data are reported in DC. For the grid operator, DC does not exist since the distributed generation unit is feeding in AC power. When the AC capacity of the inverter is equal to the installed DC capacity, the annual output of the PV system is maximized.

TASK 12

PV SUSTAINABILITY ACTIVITIES

Task Managers: Garvin Heath (NREL, USA); Jose Bilbao (UNSW, Australia)

INTRODUCTION

The deployment of photovoltaic (PV) systems has followed an exponential growth over the last years, following improvements in performance and cost reductions of the technology. That growth is bound to continue over the next decades as PV is expected to play a major role in the decarbonization of the global energy system, eventually leading to multiple Terawatts of installed capacity.

Shaping and channeling the transformation of the global energy system requires an understanding of the sustainability of PV systems – 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, case studies, international guidelines and research is the mission of Task 12, which started working on a revamped workplan in 2018 that will progress through 2022.

→ **Read about the objectives and structure of Task 12 in the Annex**

TASK ACCOMPLISHMENTS

Task 12 published three reports and one factsheet during 2021. Below there is a summary of the highlights of each publication.

METHODOLOGICAL GUIDELINES ON NEA OF PV ELECTRICITY

Net Energy Analysis (NEA) is a structured, comprehensive method to quantify if a given energy source can provide a net energy gain (i.e., an energy surplus) to the end user. The report included an in-depth discussion on the energy return on investment (EROI), and how is to be interpreted against the similar-sounding metrics cumulative energy demand (CED) and non-renewable cumulative energy demand (nr-CED). Transparency in reporting these metrics is of the utmost importance as parameters and findings can vary significantly with geographical zones, system boundary conditions, and modelling approach. The report proposes six key parameters that must be documented in NEA publications tackling PV systems: 1) PV technology - e.g., mc-Si, CdTe, CIGS, and others; 2) Type of system - e.g., rooftop, ground mount, fixed tilt or tracker; 3) Module-rated efficiency and degradation rate, if not included in performance ratio; 4) Lifetime for both PV modules and balance of system; 5) Location of installation; 6) Annual irradiation level, system performance ratio (PR), and the expected annual electricity production. Other 10 important aspects that should be include in reports can be found in the publication.

PV MODULE DESIGN FOR RECYCLING GUIDELINES

With the concern around availability of raw materials, and under the umbrella of 'circular economy', significant attention has been brought to recycling PV technologies. By 2050, estimates have projected that 78 million tonnes of raw materials will be embodied in end of life of PV modules. Estimates suggest a possible revenue of US$11-$12 revenue per module when these materials are recovered, enabling profitable recycling businesses without government support. After consideration of several general design for recycling guidelines, experts have consolidated a set of specific guidelines for crystalline-Si modules: 1) Durable identification of module construction and composition could enable safer and more efficient recycling processes; 2) Backsheet composition has particularly important implications for recyclability; 3) Metal choices can have significant impacts on recycling processes and costs; 4) Minimizing encapsulant use or using reversible encapsulants can facilitate disassembly of PV modules: 5) Decreasing the number and complexity of module materials presents trade-offs related to recyclability and economics; 6) Using different sealants in the aluminium frame could enable module separation without component damage.

PRELIMINARY ENVIRONMENTAL & FINANCIAL VIABILITY ANALYSIS OF CIRCULAR ECONOMIC SCENARIOS

This study assesses whether satisfying the expected service lifetime of a PV system through circular economy scenarios generates a greater environmental and financial benefit than recycling used panels and installing newer panels with higher efficiencies in their place. The analysis shows that it is better for the environment to keep a panel in use for its 30-year lifetime instead of replacing it with new, more efficient panels, for the cases examined. Adding repair activities and/or additional transport is unlikely to change this conclusion. Furthermore, in the analysis of a utility-scale PV system, satisfying the 30-year service lifetime of PV panels proves financially competitive to the "recycle and acquire new" scenario from an LCOE perspective. However, satisfying the 30-year service lifetime in the residential market through reusing PV modules does not appear to be financially desirable, owing to surface-area restrictions as well as the lower remaining power density and limited remaining lifetimes of prematurely decommissioned panels. In addition, using net present value as the key performance indicator in a utility-scale investment suggests that new panels are more attractive than prematurely decommissioned panels in this context.

PV FACTSHEET

The objective of this work is to quantify the emissions of 1 kWh of electricity generated by a 3 kWp rooftop PV system in central Europe. The image below presents the GHG emissions contribution of the system lifecycle for different PV technologies. Almost all emissions are from the manufacturing of the system, while there is little impact from end-of-life activities and almost no impact at all from their operation.

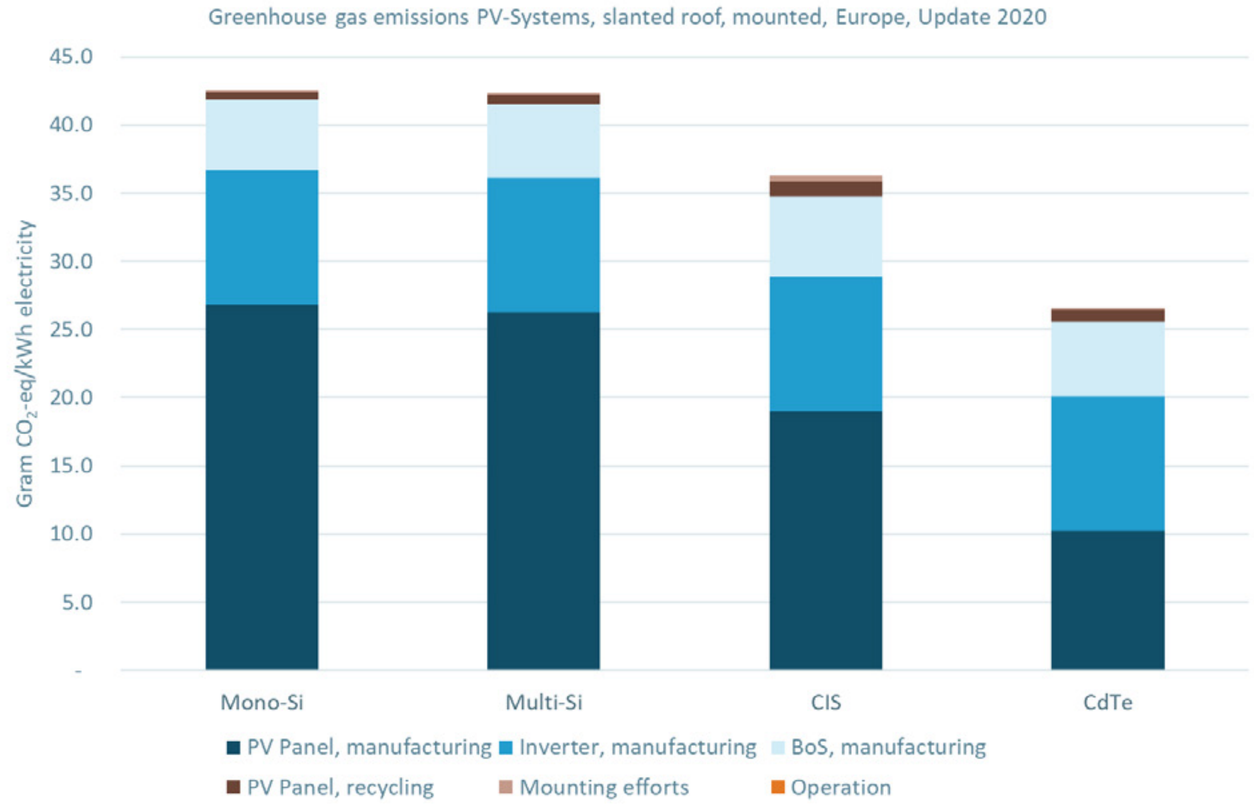


Fig.4 - 1 kWh AC electricity. Annual yield (Europe): 975 kWh/kWp, including degradation (linear, 0.7 %/a). To adjust results for a degradation rate of 0.5 %/year multiply results by 0.968; while for a degradation rate of 0.9 %/year, multiply results by a factor of 1.053. Service life: 30 years (Panel), 15 years (inverter)

OUTLOOK

In 2022, Task 12 members will deliver the final reports for the current 2018-2022 workplan and develop a new workplan for the next five years. This new workplan, currently under development must be reviewed and approved by the PVPS executive committee.

Currently Task 12 has several reports in the making, with a combination of original research and updates to our reports with LCI data, all of which are expected to be published in 2022 to close the current workplan.

A summary of the expected reports include:

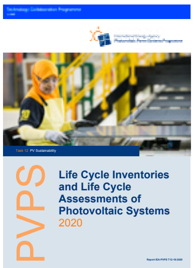
- Integrated Techno-Economic Analysis / LCA of CdTe
- Analysis of PV take-back and recycling in Germany
- Innovative methods for Ag and Si recycling from PV
- LCA of recycling technologies
- LCI data and report (updated edition)
- PV factsheet (updated edition)
- LCA of PERC technology
- Carbon footprint of floating PV
- Current PV sustainability standards

All Task 12's PVPS Publications, including 4 new Technical Reports from 2021, are available here

LCI & LCA OF PV

TASK 12 HIGHLIGHT

R. Frischknecht; L. Krebs



Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems

Task 12 Webpage

KEY MESSAGE

Carbon emissions associated with the generation of 1 kWh of solar electricity from PV systems are around 95 % lower than emissions from fossil fuel generators, which can emit up to 1 kg of CO_2 per kWh.

OBJECTIVE

The objective of this work is to quantify the emissions of 1 kWh of electricity generated by a 3 kWp rooftop PV system in central Europe.

METHODOLOGY

PV Life Cycle Assessment (LCA) is a structured, comprehensive method of quantifying and assessing the associated emissions from material and energy flows in the life cycle of PV, including manufacturing, transport, installation, use, and end of life.

	unit	Mono-Si	Multi-Si	CIS	CdTe
Greenhouse gas emissions	g CO_2-eq	42.5	42.3	36.3	26.5
Resource use, fossil fuels	MJ	0.54	0.54	0.54	0.38
resource use, minerals and metals	mg Sb_{eq}	5.28	5.35	4.65	5.26
particulate matter	10^{-9} disease incidences	3.63	3.51	1.38	1.08
acidification	mmol H+ eq	0.36	0.36	0.23	0.19
water scarcity	l water-eq	7.49	6.71	4.88	3.08
module efficiency	%	19.5	18.0	16.0	18.0
Data		2017-2019		2010	2018-2019

Fig.5 - Environmental impacts of 1 kWh of electricity from PV systems using different solar cell technologies.

The carbon emissions associated with the generation of 1 kWh of solar electricity from PV systems are far lower than emissions from fossil fuel generators, which can emit up to 1 kg of CO_2 per kWh, ranging from 26.5 (CdTe) to 42.5 (mono-Si) gCO_{2eq}. All technologies show a similar level of minerals and metals use with CIGS being the lowest.

	Mono-Si	Multi-Si	CIS	CdTe
Greenhouse gas emissions	40.2%	63.7%	79.0%	94.8%
Resource use, fossil fuels	44.6%	66.1%	79.6%	95.9%

Fig.6 - Environmental impacts improvements of 2018 PV systems relative to 2011 systems

Current PV systems have lower environmental impacts associated to the generation of 1 kWh of electricity compared to PV systems manufactured in 2011. In terms of GHG emissions mono-Si PV systems have experienced a 60 % emissions reduction, CIGS around 21 % reduction, and CdTe a 5 % reduction.

	unit	Mono-Si	Multi-Si	CIS	CdTe
NREPBT	year	1.2	1.2	1.3	0.9

Fig.7 - Non-renewable energy payback time

Non-renewable energy payback time (NREPBT) is defined as the period required for a renewable energy system to generate the same amount of energy (in terms of non-renewable primary energy equivalent) that was used to produce the system itself. The NREPBT of the PV systems studied varied from 0.9 (CdTe) to 1.2 (mono-Si) years.

TASK 13

PERFORMANCE, OPERATION AND RELIABILITY OF PHOTOVOLTAIC SYSTEMS

Task Managers: Ulrike Jahn, Boris Farnung (VDE Renewables, Germany)

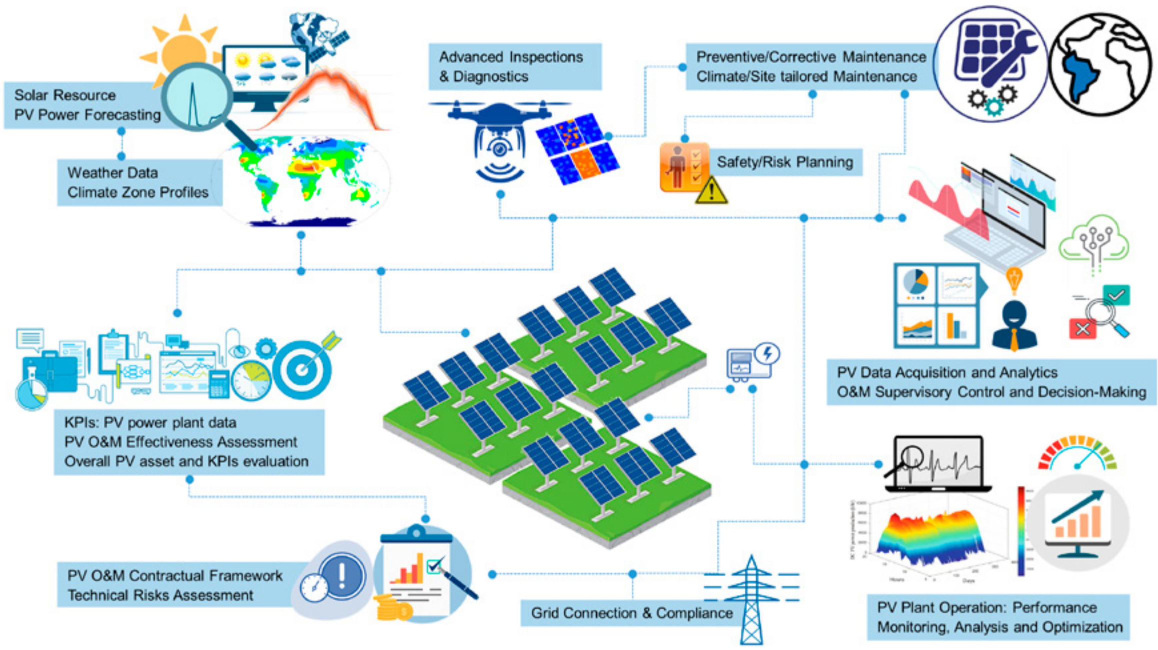


Fig.8 - Overview of operations and maintenance (O&M) aspects and services for PV power plants during their technical life cycle (source: CEA-INES).
In our guidelines and best practices for optimised O&M for PV plants in different climates, we discuss and emphasise site/climate-specific aspects of PV O&M, ranging from the regulatory, risk, safety and asset management levels to the operational level, in particular monitoring/inspections, data analysis, maintenance and optimisation. Financiers and investors can use these O&M guidelines as a benchmark for assessing the operational risk of PV plants, which feeds into the decision-making process for project financing and investment.

INTRODUCTION

Task 13 of the PVPS programme aims to support market actors in improving the operation, reliability and quality of PV components and systems. The operational data collected from PV systems in different climates during the project will allow conclusions to be drawn about reliability and yield estimates.

Task 13 will continue to be needed for the foreseeable future and is critical to the well-being of the PV industry. The reliability of PV systems and modules has been and will continue to be an issue for investors and operators. The PV industry continues to undergo rapid change, both in terms of scale, with global capacity nearly doubling every three to four years, and in terms of the use of new technologies (e.g. changing cell thicknesses, introduction of PERC technology, bifacial cells) and new deployment locations and methods, such as floating PV and agricultural PV.

These combined effects mean that the reliability and performance of PV modules and systems need to be further investigated to ensure that PV continues to be a good investment, as past performance of similar technologies is not a complete/reliable predictor of future performance of new installations and integrated PV application.

→ **Read about the objectives and structure of Task 13 in the Annex**

TASK ACCOMPLISHMENTS

There are several motivations for investigating **new materials for PV modules**. Reducing or replacing expensive materials is important for the overall economics of module production. For example, reducing the use of silver or replacing it with copper or aluminium significantly reduces costs for manufacturers. Another example is the use of thinner glass for the top layers or switching from more expensive PVF to cheaper PVDF material for the back sheets. Speeding up the manufacturing process is another way to reduce production costs. Lamination is usually the slowest step in a module production line, and manufacturers are very interested in materials that can speed up this process step. Fast or ultra-fast curing EVA potting compounds, for example, have reduced the time required for cross-linking from 25 minutes to 10 minutes today. Switching to thermoplastic potting compounds that do not crosslink could reduce these times even further. An obvious motivation for material innovation is to increase performance. This can be achieved by increasing the number of busbars, increasing active area through shingling, increasing light absorption through anti-reflective coatings, or increasing internal reflection through highly reflective back sheets or white templates between cells. The trend towards increasing the size of wafers also leads to increases in performance.

Another strong motivating factor is improving the sustainability of modules. Some manufacturers are seeking recognition of environmentally responsible material choices by using various labelling standards to identify good sustainability practices.

The process of **material innovation for photovoltaics** is further complicated by the complex interactions within a PV module. The advantage of a material can be negated by its interaction with another component. EVA, for example, is inexpensive and highly effective for encapsulation, but decomposes to acetic acid, which can lead to corrosion of the metallisation if it cannot escape from the module housing due to the use of an impermeable backsheet. New materials must function within the entire module package and in coordination with the other existing materials. Consumers and manufacturers rely on international standards, such as those of the Solar Photovoltaic Energy Systems Technical Committee TC 82, to ensure that new materials do not cause unexpected performance or reliability problems. Another problem is that module manufacturers do not usually provide details of their bills of materials, and the bill of materials for a particular module model may vary depending on the date and place of manufacture. There are several non-destructive methods for characterising and identifying module materials, including FTIR, NIR and Raman spectroscopy.

Innovations in bifacial cells and modules have led to new optimised bifacial system designs. The reflectivity of the ground (albedo) is one of the most important site characteristics that influences the performance of bifacial PV systems. Locations where a lot of snow falls usually benefit from bifacial PV systems, as the albedo is higher during these times. The performance advantage of bifacial PV systems is expressed as "bifacial gain", i.e. the additional share of total energy generated by a bifacial PV system compared to a monofacial system with the same orientation and size. The bifacial gain increases with the albedo, the diffuse component, the height of the array, the row spacing and the distance between the modules. The light incident on the rear of the array is much more non-uniform than the light incident on the front. This non-uniformity results in some electrical mismatch within each module and can also affect rows of modules, depending on their configuration. Another characteristic of bifacial arrays is that they operate at higher DC levels than monofacial arrays; therefore, system designers may need to adjust calculations for sizing cables, fuses and inverters. International electrical design and safety regulations are being actively revised to accommodate bifacial PV technologies. Despite this advantage, economies of scale are also important. A recently published global analysis of the economics of bifacial PV found that bifacial PV systems installed on single-axis trackers have the lowest cost of electricity (LCOE) for the vast majority of potential PV sites on Earth (93 % of the Earth's land area).#

The energy production of a PV power plant plays an important role in the market valuation of a project, as it is an important factor in the financial models for the profitability of a solar project*. In this respect, the technical conditions of the PV plant and PV modules have a great impact on the system performance and the value of the plants (plant performance). In order to provide plant operators or asset managers with the assurance that PV power plants comply with current standards and deliver the promised yield, **on-site testing procedures with portable test equipment** (mobile PV test centres) are commonly used. There are different application areas for mobile PV test centres in different project phases. The presented on-site testing methods are helpful tools to identify drivers for underperforming PV power plants. Their particular strength is that the tests are carried out without dismantling and shipping the PV modules to a laboratory, which often means long transport distances, transport risks and a long downtime of the PV strings. In addition, the on-site testing methods enable a more targeted fault analysis, as the PV modules are not selected blindly. The quality and significance of the test results are comparable to those of laboratory tests. On the other hand, on-site tests are dependent on weather conditions, which is a disadvantage compared to working under controlled conditions in a laboratory. On-site testing therefore requires more organisational effort and careful planning.

OUTLOOK

RELIABILITY plays an essential role in new technologies, designs and manifestations of PV modules and systems for future energy markets. Cost reduction, climate-specific PV technologies/designs, the role of digitalisation, drivers for reliability and economic KPIs, etc. are becoming increasingly important to the public.

Task 13 will continue to provide unique and fundamental analysis of PV components and systems, including new applications such as floating PV and agricultural PV that impact the reliability and performance of PV systems over their lifetime. With a strong technical focus, the broad participation of experts from around the world will make the Task's findings relevant to PV research and industry stakeholders. It will contribute to technological requirements, risk mitigation and standardisation.

The rapidly changing PV landscape, with emerging research activities and challenges, means that the field is constantly evolving, with new technologies and system designs being developed every year. International collaboration on reliability, durability and performance is critical to ensure that IEA members and their stakeholders stay abreast of critical issues facing the PV industry.

All Task 13's PVPS Publications, including 8 new Technical Reports from 2021, are available here

C. D. Rodríguez-Gallegos et al., "Global techno-economic performance of bifacial and tracking PV systems," Joule, vol. 4, pp. 1–28, 2020.

* ETIP Fact Sheets: PV the cheapest electricity source almost everywhere," [Online]. Available: https://etip-pv.eu/publications/fact-sheets/, update of September 2020. [Accessed 07 12 2020].

PV PLANT TESTING

TASK 13 HIGHLIGHT

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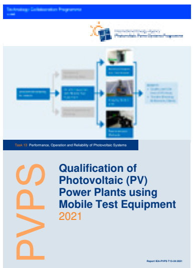

Qualification of Photovoltaic (PV) Power Plants using Mobile test Equipment

Task 13 Webpage

KEY MESSAGE

New, innovative techniques and on-site inspection methods using portable test equipment are provided to give plant operators and asset managers confidence that PV power plants perform at current standards and provide the promised electrical and financial yield.

OBJECTIVE

To present on-site inspection methods, which are helpful tools to identify drivers for underperforming PV power plants. Their particular strengths lie in the fact that the tests are carried without dismantling and shipping the PV modules to a laboratory. In this report, solutions are presented to prevent long downtime of PV strings & systems and to ensure that the technical conditions of the PV power plant are at an optimal performance level.

METHODOLOGY

Various on-site inspection techniques using portable test equipment will be presented ranging from PV output power characterization, to imaging techniques for localizing cell cracks or open-circuit failures to spectroscopic methods for materials analysis. All chapters are structured in the same way to facilitate comparison of methods. Besides technical information and field experience, they also provide good practice recommendations for field use and evaluate uncertainties compared to laboratory inspection methods.

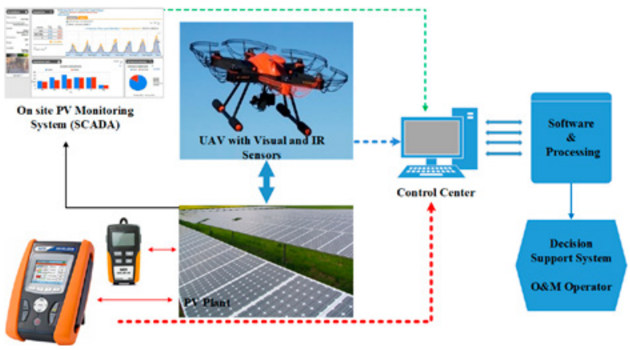

Fig.9 - Drone-based inspection: Concept of autonomous monitoring systems for qualifying PV power plants

This drone-based system can carry out the monitoring for large-scale PV plants completely autonomously. The data is classified by the ground station and forwarded to a central database, where the signal characteristics are acquired by SCADA. The final evaluated data is then forwarded to the O&M support.

Fig.10 - PV plant inspection vehicle using modular test equipment for on-site performance testing of PV power plants in China.

The PV system testing vehicle is a type of converted vehicle from a van or box truck in which the test equipment is installed. With its multifunctional design, this testing vehicle can perform tests, analyses, and evaluations of PV system performance parameters according to IEC standards.

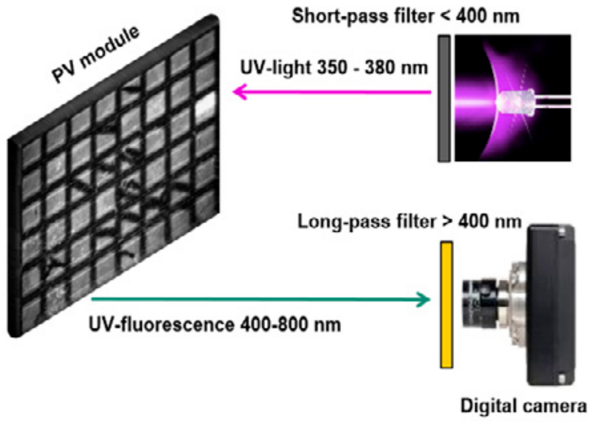

Fig.11 - UV fluorescence imaging technique: Basic Ultraviolet fluorescence measurement setup

M. Köntges, A. Morlier, G. C. Eder, E. Fleiß, B. Kubicek, and J. Lin, Review: Ultraviolet Fluorescence as Assessment Tool for Photovoltaic Modules, IEEE J. Photovoltaics, Vol. 10, no. 2, pp. 1–18, 2020.

One imaging technique is to irradiate the entire PV module with a UV excitation light source and observe the fluorescence effect (UVF) with a digital camera using a long pass filter. With this technique, degradation modes of the PV module such as cell cracks, snail traces and delamination of the encapsulant can be detected. This UVF method is non-invasive, easy to use and fast to apply.

TECHNICAL RISKS IN PV

TASK 13 HIGHLIGHT

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Quantification of Technical Risks in PV Power Systems

Task 13 Webpage

KEY MESSAGE

Comprehensive work provided to serve as handbook for quantifying and minimising risks of PV system failures, under consideration of the economic benefits.

OBJECTIVE

Quantitative evaluation of technical risks in PV systems is one of the most important criteria for investments in existing and new PV projects. This report brings together knowledge on methods for assessing technical risks and mitigation measures in terms of their economic impact and effectiveness during operation and maintenance of PV power plants.

METHODOLOGY

Four common practices (FMEA, MCDA, RAM, CPN) for assessing the impact of technical risks are compared and evaluated.

Case studies are used to collect data of the most important and most frequent failures modes to supply the central database with the required information.

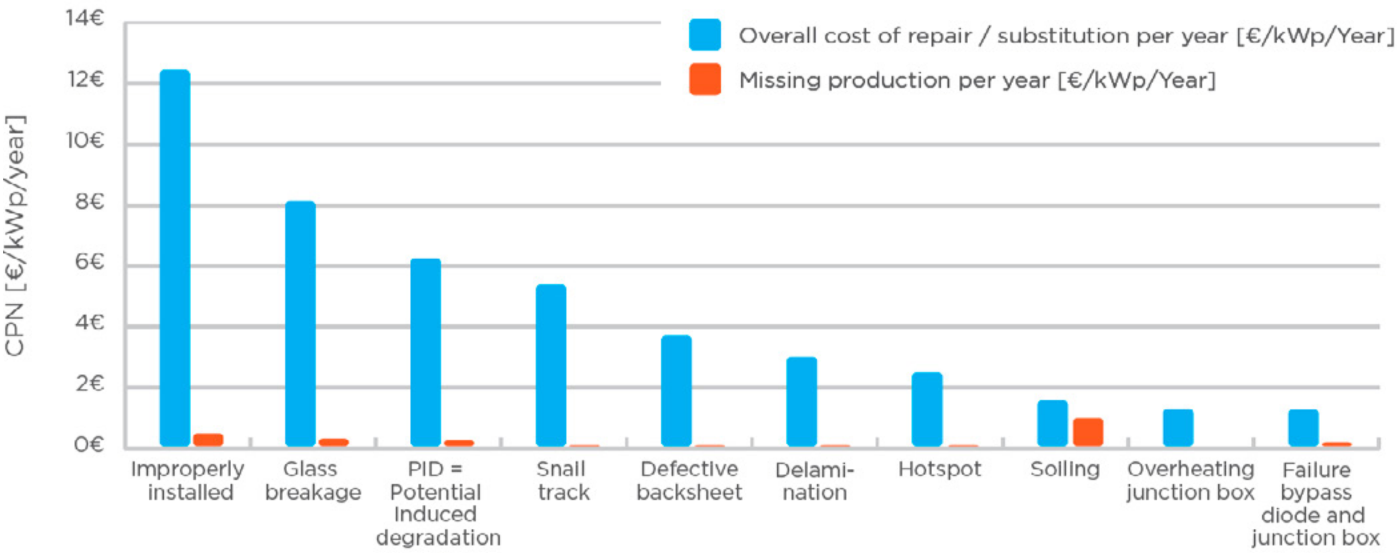

Fig.12 - Cost Priority Number (CPN), repair costs and performance losses for top 10 risks of PV modules

The CPN method assesses the economic impact of PV projects based on factors such as power loss and downtime. The methodology helps to identify and classify technical risks and their economic impact by assigning a cost metric that, based on collected statistics, supports preventive and corrective measures, which would then lower the impact of failures on the availability and performance of a PV plant.

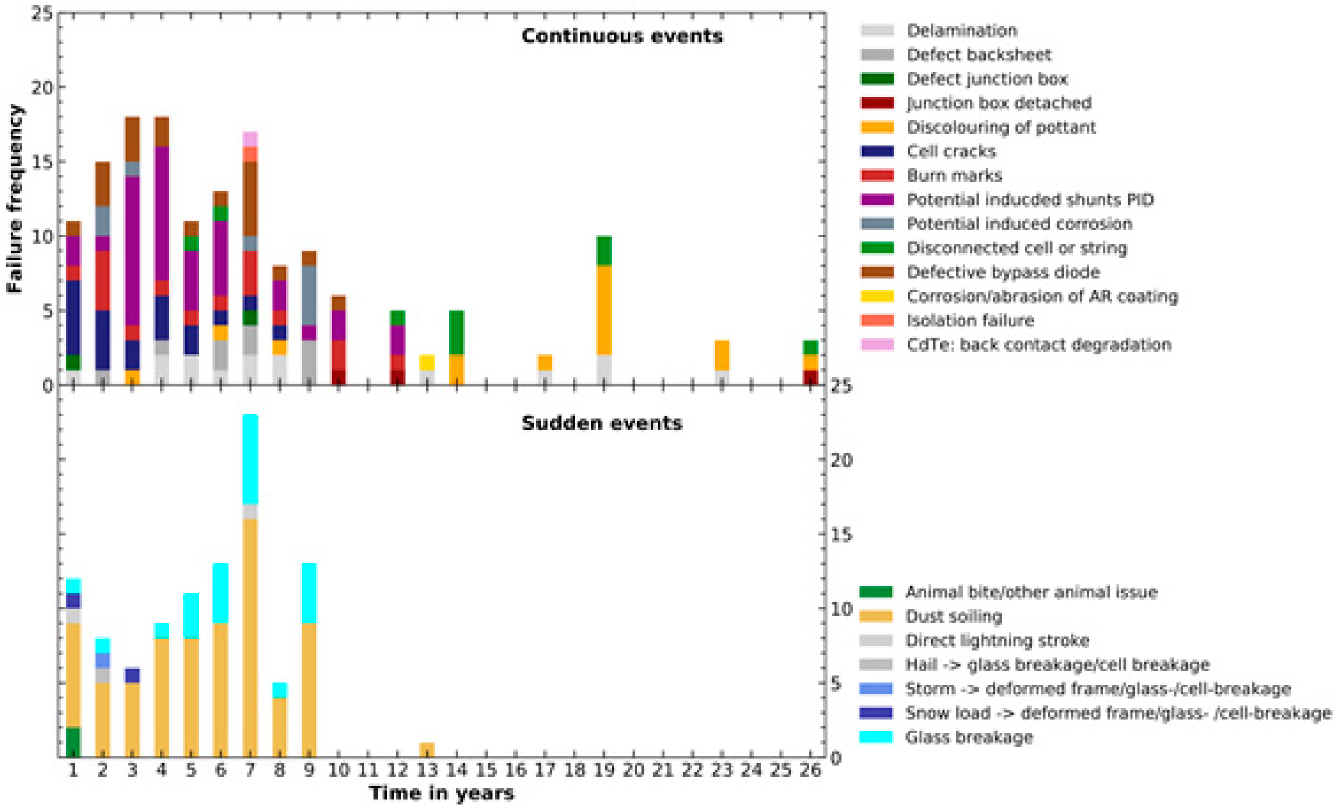

Fig.13 - Frequency distribution of PV module failures with an impact on the system power

The frequency distribution of PV module failures is split into failures which lead to a degradation and sudden occurring failures. PID effects, cell cracks and defective bypass diode failures seem to dominate the failure statistic in the first seven years of plant operation. For sudden events, the failure glass breakage and dust soiling fully dominate the failure statistics.

Component Defect	Module **Front delamination**		**PVFS 1-3**
Appearance	Any local separation of the layers between (i) the front glass and the encapsulant or (ii) the cell and the encapsulant, visible as bubbles or as bright, milky area/s. It may appear continuous or in spots. The position and size of the delamination or bubble depends on the origin and progress of the failure.		
Detection	VI, (INS)		
Origin	The adhesion between the glass, encapsulant, active layers, and back layers can be compromised for many reasons. Typically, it is caused by the manufacturing process (e.g. poor cross linking of EVA, too short lamination times, too high pressure in the laminator, contaminations, improper cleaning of the glass, incompatibility of EVA with soldering flux, inadequate storage of the raw material) or environmental factors (e.g. thermal stresses, external mechanical stresses, UV). Delamination is generally followed by moisture ingress and **corrosion**. It is therefore more frequent and severe under hot and humid conditions.		
	Production ■	Installation □	Operation ■
Impact	Delamination or bubbles do not automatically pose a safety issue, but they can result in **reduced insulation** of the component and increased safety risk when they form a continuous path between electric circuit and the edge due to possible water ingress. Moisture in the module will decrease performance due to an increase of series resistance, affect long term reliability and in some cases also the structural integrity of the module. Moreover, delamination at interfaces in the optical path will result in additional optical reflection and subsequent decrease in current. This can be the origin of current mismatch. If the mismatch is significant, it will trigger the bypass diode and cause further power loss. The inverter might also shut down due to leakage current's leading to a further performance loss. Manufacturing related delamination issues often affects a relevant percentage of modules within the same production batch and consequentially has a big impact on system performance.		
	Safety:	Performance:	
Mitigation	Corrective actions	Preventive actions (recommended)	Preventive actions (optional)
	Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules. In case of individual module testing all modules which failed the insulation and/or wet-leakage test should be replaced.	Check validity of IEC 61215 certification and BOM, ground fault detection by inverter or other devices at all time.	Extended testing (e.g. damp heat), pre-shipment inspections (e.g. cross linking level of EVA) regular visual system inspections.

Fig.14 - Example of a PV Failure Fact Sheet (PVFS).
Component: PV module; Defect: Front glass delamination

A PV Failure Fact Sheet (PVFS) contains all important information on a specific type of defect. The appearance, detection, occurrence, impact and risk mitigation measures are described in detail. The impact (including rating scale) on the safety, performance and reliability of the component and system and its severity are given. For every failure, a range of possible ratings is given, one for the safety and one for the performance.

TASK 14

SOLAR PV IN THE 100 % RES BASED POWER SYSTEM

Task Managers: Roland Bründlinger (AIT, Austria); Gerd Heilscher (THU, Germany)

Fig.15 - Decentral Renewable Energy Systems like these local PV-roof installations at Solar-Siedlung Vauban, Freiburg have to support the stability of the energy network with ancillary services in the future. IEA PVPS Task14 presents solutions from IEA PVPS member countries on (smart) grid integration for a future 100 % RES based power system. (copyright Rolf Disch SolarArchitektur info@rolfdisch.de)

INTRODUCTION

PV has today become a visible player in the electricity system in many countries and the integration of growing shares of variable renewables into the power systems has become a truly global issue 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, new fundamental challenges arise, which are being addressed through global cooperation.

To ensure smooth further deployment of PV and avoid 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 connection via static power electronics and the large number of small-scale systems located in the distribution grids. Resolving the technical challenges is critical to allow PV to be fully integrated into the power system, from serving local loads to serving as grid resources for the interconnected transmission, distribution and generation system.

→ **Read about the objectives and structure of Task 14 in the Annex**

TASK ACCOMPLISHMENTS

In 2021, Task 14 work focused on the preparation of joint reports and publications, 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 (see Fig 15).

The two reports published in 2021 address specific aspects related to the integration of Solar PV in different types of power systems:

The first report on "Best practices for high penetration PV in insular power systems" presents experiences with the integration of Solar PV on islands, which are often positioned as global laboratories for the transformation of the energy system. Solar PV is being deployed at an accelerating rate in insular power systems for a number of reasons including reduced cost, improved versatility in deployment scale, and ease of maintenance and operations. Many insular territories are located in areas with high solar irradiance. This report summarizes the general attributes of insular power systems, emphasizing best practices and key insights that have accelerated their transformation, impeded their progress and/or are relevant to more traditional power systems globally.

The second report published in 2021 on "PV as an ancillary service provider" provides a collection of laboratory and field experiences from different IEA PVPS countries and for different ancillary services and PV inverter functions. Field experiences and lessons learned from PV systems and PV hybrids are presented in the report: Frequency control services, power curtailment, voltage support, PV hybrids in insular power systems, Power quality support and new services from PV systems. To effectively apply the different grid support functions, which can be provided by Solar PV systems, it is important to understand their practical interrelations. For this purpose, a hierarchical model has been developed, where the various functions are assigned to individual levels of the pyramid, building on each other.

Complementing its technical work, Task 14 continued contributing to conference sessions with the following well-received events:

September 28, 2021: Task 14 organised a special session dedicated to "Experiences with the provision of ancillary services from PV Systems" at the 2021 Solar Integration Workshop in Berlin/Online. The conference was hosted by energynautics, Germany.

- Setting the scene - PV as an ancillary service provider and case studies on PV voltage control services, Dr. Markus Kraiczy, Fraunhofer IEE, Germany (+Co-Authors as listed below)
- Experiences with frequency control services from Wind and Solar PV in Australia, Prof. Iain MacGill, Dr. Navid Haghdadi, UNSW, Australia
- Power control of Solar PV through Smart Grid infrastructure in Germany, Prof. Gerd Heilscher, TH Ulm, Germany
- Insular power systems with hybrid PV: application for ancillary services on El Hierro, Prof. Ricardo Guerrero-Lemus, D. Cañadillas, F. Boda, Universidad de La Laguna, Spain

OUTLOOK

Task 14 activities in 2022 will focus on the work on the reports on "Central reactive power management at the Transmission-Distribution interface with the support of DER", "Analysis of the state of the art of communication and control concepts for PV systems in Task 14 countries",

"Capabilities of Smart Inverters and Power Interfaces" and "PV in the Smart Grid - Recommendations for current and future applications and infrastructures".

On the dissemination side, targeted conference papers and presentations from Task 14 experts are planned at major conferences and related events in Task 14 member countries.

In addition, the successful series of Task 14 grid integration workshops on 100 % PV and RES scenarios in electricity grids is planned to be continued in 2022.

All Task 14's PVPS Publications, including 2 new Technical Reports from 2021, are available here

ANCILLARY SERVICES FROM PV

TASK 14 HIGHLIGHT

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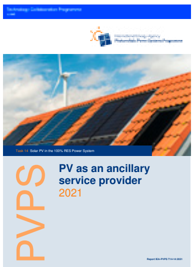


PV as an ancillary service provider

Task 14 Webpage

KEY MESSAGE

Laboratory and field experiences from IEA PVPS countries highlight the technical capabilities and the future potential of Solar PV systems to provide power system services.

OBJECTIVE

The report aims to highlight the status and the potential of PV and PV hybrids as ancillary service providers. The report provides a collection of laboratory and field experiences from different IEA PVPS countries and for different ancillary services and PV inverter functions.

METHODOLOGY

Field experiences and lessons learned for different ancillary services provided by PV systems and PV hybrids are presented in the report: Frequency control services, power curtailment, voltage support [1], PV hybrids in insular power systems, Power quality support and new services from PV systems.[2]

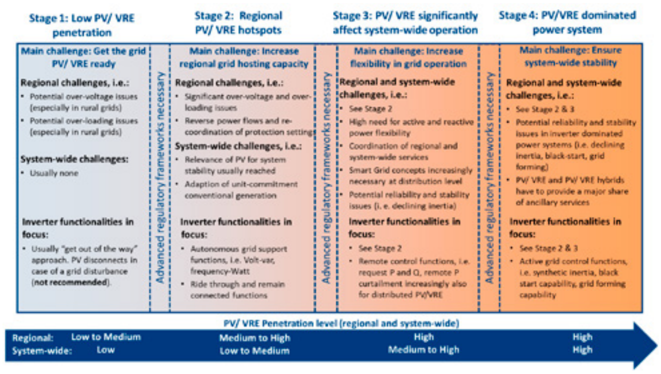


Fig.16 - PV penetration levels and identified challenges for the integration of Solar PV and VRE in the electrical power system

Grid integration challenges heavily depend on the local, regional and system wide penetration of PV and other Variable Renewable Energy (VRE) systems. To address the challenges, a model has been developed representing 4 different penetration stages in electric power systems, associated challenges, needs and barriers.

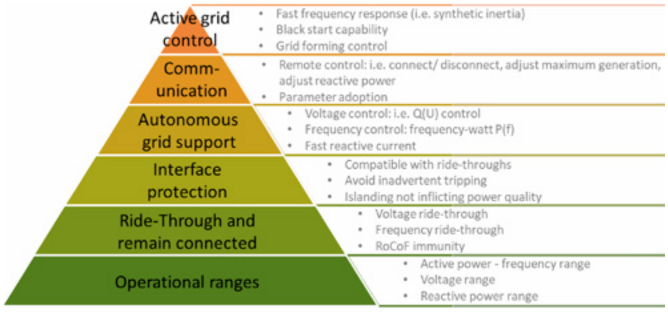


Fig.17 - Hierarchical model for the definition of interrelations between various grid support functions of PV inverters

To effectively apply the different grid support functions, which can be provided by Solar PV systems, it is important to understand their practical interrelations. For this purpose, a hierarchical model has been developed, where the various functions are assigned to individual levels of the pyramid, building on each other.

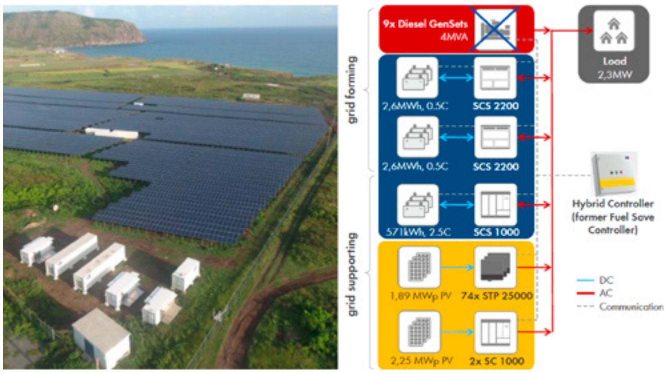


Fig.18 - PV hybrid system on the island of St. Eustatius. Left: PV storage system view from above. Right: system setup

The St. Eustatius PV hybrid power plant, with its conventional and inverter-based generation, combined with battery storage and a parallel operation of grid forming and grid supporting control, proves that a stable operation of power grids is feasible without conventional must-run-units and their inertia and fault current contribution.

REFERENCES

These are relevant older reports from Task 14:

M. Kraiczy, A. AlFakhri, T. Stetz and M. Braun, "Do It Locally: Local Voltage Support by Distributed Generation – A Management Summary," Report IEA-PVPS T14-08:2017, 2017.

T. Stetz, M. Rekinger, I. Theologitis and et.al, "Transition from Uni-Directional to Bi-Directional Distribution Grids: Management Summary of IEA Task 14 Subtask 2," Report IEA PVPS T14-03:2014, 2014.

TASK 15

ENABLING FRAMEWORK FOR THE ACCELERATION OF BIPV

Task Managers: Johannes Eisenlohr (Fraunhofer ISE, Germany); Francesco Frontini (SUPSI, Switzerland)

INTRODUCTION

Building Integrated PV (BIPV) is receiving increasing attention in many countries, as it can provide renewable energy close to consumers with very high social acceptance. On the way towards zero energy buildings and fully renewable energy systems, BIPV can facilitate using the large areas of building envelopes for renewable energy production. For a large-scale deployment of BIPV, architectural, aesthetical, environmental, economic, and technical requirements need to be considered to maintain the high social acceptance that this technology currently has in most countries.

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

→ **Read about the objectives and structure of Task 15 in the Annex**

TASK ACCOMPLISHMENTS

ANALYSIS OF NATIONAL BIPV ECOSYSTEMS

Following the framework of the Technological Innovation System (TIS), Task 15 experts have gathered data on the BIPV innovation ecosystem through interviews and questionnaires targeting relevant stakeholders throughout the value chain, and by some statistic datasets. During 2021 the efforts were focused mostly on Spain, Austria, Sweden, and Italy, but also Australia and the Netherlands. The data has or will be analysed to describe the current situation of actors and rules within the BIPV value chain within each country, but also analysing in what way a variety of actors' activities, interactions, resources, and limits define the weaknesses and opportunities for BIPV to advance towards a mature market. Final results on these Technological Innovation System (TIS) analyses are yet to be defined. Preliminary results indicate that BIPV market take off in multiple countries is challenged by weak knowledge dissemination towards construction and property industries, lack of competent/properly-educated professionals, weak social networks among BIPV-actors or actor groups, and lack of guidance and market incentives for BIPV. Also, the absence of harmonised standardisation and certification plays a hampering role for BIPV-development. Based on this systematic analysis, Task 15 has worked on overcoming these barriers resulting in the following findings and publications.

SUCCESSFUL BUILDING INTEGRATION OF PHOTOVOLTAICS – A COLLECTION OF INTERNATIONAL PROJECTS

The book "Successful Building Integration of Photovoltaics – A Collection of International Projects" has been published. This book shares the experience of people who thought of applying photovoltaics (and finally did!), as well as showing how buildings can look like when having a photovoltaic skin. It is demonstrated, how barriers of BIPV implementation have been overcome in these individual projects, thanks for example to the large availability of variegated photovoltaic components and modules, as well as the knowledge of all the stakeholders involved in the process. The booth also provides role models for new projects and for overcoming these barriers on a more general level.

CATEGORIZATION OF BIPV APPLICATIONS

A technical report on "Categorization of BIPV applications" was elaborated and published. For decades, many classification schemes have been used (in reports, guidelines, FIT, literature), but the BIPV community has never reached consensus about a reference categorization. Thus, the intention of the report is an integrated approach drawn upon experience on building and PV sector. It provides a streamlined categorization especially on BIPV system level into different applications of PV in roofs, facades and as external elements.

CROSS-SECTIONAL ANALYSIS OF BIPV

To describe the electrical and building function of BIPV-systems, performance parameters/ indicators (PIs) in 4 categories were defined: energy relevant, economic, environmental, and visual performance indicators. Based on these PIs and the newly developed classification scheme for BIPV installations and site-specific information, a multidimensional evaluation matrix for planned and built BIPV-installation was developed. This can be used now for the evaluation of BIPV-projects (cross-sectional analysis) with the aim to draw conclusions on the performance of the specific installations. An important point here is the comparison of the requirements made in the planning phase with the results achieved after completion and ongoing operation of the BIPV system.

Regarding energy-related features of BIPV modules and systems, a detailed analysis has been carried out, addressing thermal, solar, optical, and electrical aspects. The most relevant results will be included in the BIPV Guidebook scheduled for 2023. The thermal, solar, and optical properties of BIPV modules, together with the electrical efficiency, determine the balance between energy saving, electricity generation, aesthetics, and visual comfort. Reaching an equilibrium is not the only challenge for BIPV designers, as the particular operating conditions of BIPV systems, such as non-homogeneous irradiance, complicate the electrical design and the forecasting of BIPV performance.

PRE-NORMATIVE BIPV RESEARCH

A highlight of pre-normative international research within Task 15 on BIPV characterisation methods has been the opening of two channels to ensure that the research work can be transferred into international BIPV standards. One is the joint working group (JWG 11) that was formed between IEC TC 82 and ISO TC 160 specifically to handle standards that address BIPV at a global level. The JWG had its inaugural meeting in April and is currently addressing a draft standard on accounting for the effect of electricity extraction on the Solar Heat Gain Coefficient (SHGC) of BIPV glazing components. It is hoped that the results of the sensitivity study carried out by Task 15 experts will be taken into account in the standard. The second avenue is offered by the five-year revision of EN 50583:2016, the first international BIPV standard. The topics of wind-driven rain, performance-based evaluation of electrical and mechanical properties and again SHGC have been identified as topics, where input will be provided from STE activities. The membership of both of these standardisation committees includes several Task 15 participants, facilitating the transfer.

OUTLOOK

In 2022, the national analyses of the BIPV ecosystems (TIS) will be continued and synthesized on an international level to draw general conclusions in addition to findings on national levels.

Newly developed methods of Task 15 for cross-sectional analysis of BIPV systems will be applied to real BIPV installations followed by a publication of the evaluation methodology.

A detailed analysis of energy-related features of BIPV modules and systems will be published and the technical guidebook for BIPV drafted (publication scheduled for 2023).

Existing BIPV design and analysis methods, approaches and workflows practiced globally, which have already been assessed by a global survey by Task 15, will be published. These cover the workflows, methods and tools for solar irradiation modelling, power output simulation, building performance modelling and financial and design outcome assessment.

Also a mapping of international fire safety testing facilities for BIPV will be made available.

All Task 15's PVPS Publications, including 2 new Technical Reports from 2021, are available here

REFERENCES

Building Integrated Photovoltaics: A practical handbook for solar buildings' stakeholders. Status report 2020, available here: https://solarchitecture.ch/wp-content/uploads/2020/11/201022_BIPV_web_V01.pdf

Saretta, E., Bonomo, P., Maeder, W., Nguyen, V.K., Frontini, F., 2022. Digitalization as a driver for supporting PV deployment and cost reduction. EPJ Photovoltaics 13, 1. https://doi.org/10.1051/epjpv/2021013

J. Polo, N. Martín-Chivelet, M. Alonso-Abella, C. Alonso-García, Photovoltaic generation on vertical façades in urban context from open satellite-derived solar resource data, Sol. Energy. 224 (2021) 1396–1405. https://doi.org/10.1016/j.solener.2021.07.011

T. Kuhn, C. Erban, M. Heinrich, J. Eisenlohr, F. Ensslen and D.H. Neuhaus, Review of Technological Design Options for Building Integrated Photovoltaics (BIPV), Energy and Buildings, 231 (2021). https://doi.org/10.1016/j.enbuild.2020.110381

BIPV PROJECT COLLECTION

TASK 15 HIGHLIGHT

Tjerk Reijenga; Michiel Ritzen; Alessandra Scognamiglio; Karin Kappel; Francesco Frontini; Dieter Moor; Astrid Schneider; Peter Illich; Véronique Delisle; Konstantinos Kapsis; Limin Liu; Laura Maturi; Jennifer Adami; Hisashi Ishii; John van Oorschot; Anna Gerd Imenes; Nuria Martin-Chivelet; Bengt Stridh; Rickard Nygren; David Larsson; Pierluigi Bonomo; Erika Saretta; Helen Rose Wilson

Successful Building Integration of Photovoltaics – A Collection of International Projects

Task 15 Webpage

KEY MESSAGE

A collection of 25 international projects gives insight into successful building integration of photovoltaics providing numbers, pictures and stakeholder interviews.

OBJECTIVE

The goal of the work is to show best practice examples for BIPV implementation, providing inspiration and guidance for decision-makers (building owners, architects, project managers). What makes BIPV projects successful? How have typical barriers been overcome? 25 projects with a wide range of architectural styles provide answers.

METHODOLOGY

The international network of BIPV experts in Task 15 have collected case studies that are considered best practice. Information regarding technology, design process, aesthetics, financing and barriers in the individual projects have been collected from different stakeholders and lessons learned have been deduced.

Fig.19 - Copenhagen International School (DK).
© C.F. Møller Architects / Adam Mørk

Completed BIPV façade of the Copenhagen International School in Denmark. The school including the BIPV façade was constructed in 2017 (C.F. Møller Architects). 12 000 colored modules on all facades provide a nominal power of 700 kWp.

Fig.20 - BIPV roofs for the zero-energy Väla Gård office, Helsingborg (SE), © Skanska Torben Ådahl

BIPV modules integrated into the roof of zero energy office buildings (by Tengbom arkitekter). 70 kWp of crystalline Silicon based PV modules produce 68 000 kWh annually with a large fraction of own-consumption by heat pumps, ventilation and tenants' use of electricity and thus the BIPV contributes significantly to the zero energy goal.

Fig.21 - Social housing apartment with BIPV facade, Best (NL)
© BEAR-iD

The BIPV facades of this social housing apartment (by NB Architecten) features CIGS modules with 250 kWp nominal power. The design was developed in a way that standard CIGS panels could be used. Together with roof-top PV and heat pumps, the BIPV provides an "energy budget" which covers the energy consumption of each apartment.

CATEGORIZATION OF BIPV

TASK 15 HIGHLIGHT

Pierluigi Bonomo; Gabriele Eder; Nuria Martin Chivelet; Johannes Eisenlohr; Francesco Frontini; Costa Kapsis; Alessandra Scognamiglio; Helen Rose Wilson; Rebecca Yang

[Categorization of BIPV applications]

[Task 15 Webpage]

KEY MESSAGE

BIPV systems can be classified into applications in roofs, facades and external integrated devices. A common set of categories and terms facilitates stakeholder cooperation.

OBJECTIVE

By providing a categorization scheme for BIPV, the report encourages an integrated perspective and an inter-disciplinary approach. A common set of categories and terminology on five levels (application, system, module, component and material) facilitates effective exchange of innovation and cooperation among all the stakeholders.

METHODOLOGY

Based on an analysis of existing classification schemes for building skin technologies, Task 15 has worked on a streamlined hierarchical approach to classify different BIPV systems for roofs, facades and externally integrated devices. Definitions, descriptions, and pictures of all (sub-) categories and an international glossary were collected.

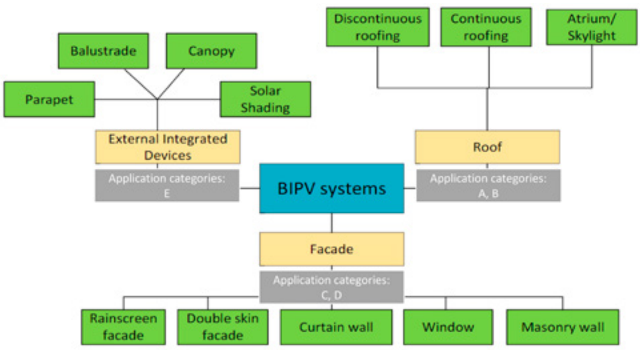


Fig.22 - Categorization of BIPV systems.

On system level, BIPV can be categorized into applications in the roof, in the façade, and external integrated devices. The subcategories (green boxes) provide a set of common terminology, with synonyms and translations in a number of different languages given in the glossary of the report.

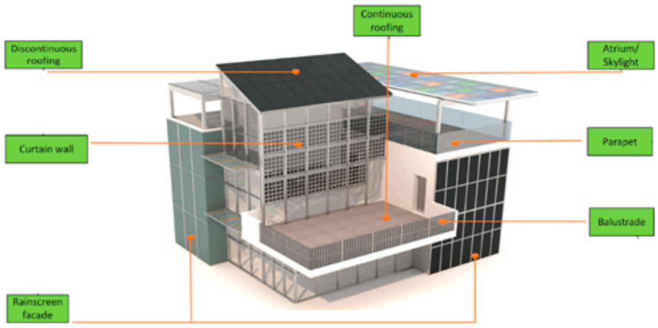


Fig.23 - Visualization of different BIPV systems demonstrating the wide range of possible applications of BIPV. © SUPSI

Selected examples of some of the identified subcategories of BIPV systems are shown on a single building model to demonstrate the wide range of possible applications of BIPV.

TASK 16

SOLAR RESOURCE FOR HIGH PENETRATION AND LARGE SCALE APPLICATIONS

Task Managers: Jan Remund (Meteotest, Switzerland); Manajit Sengupta (NREL)

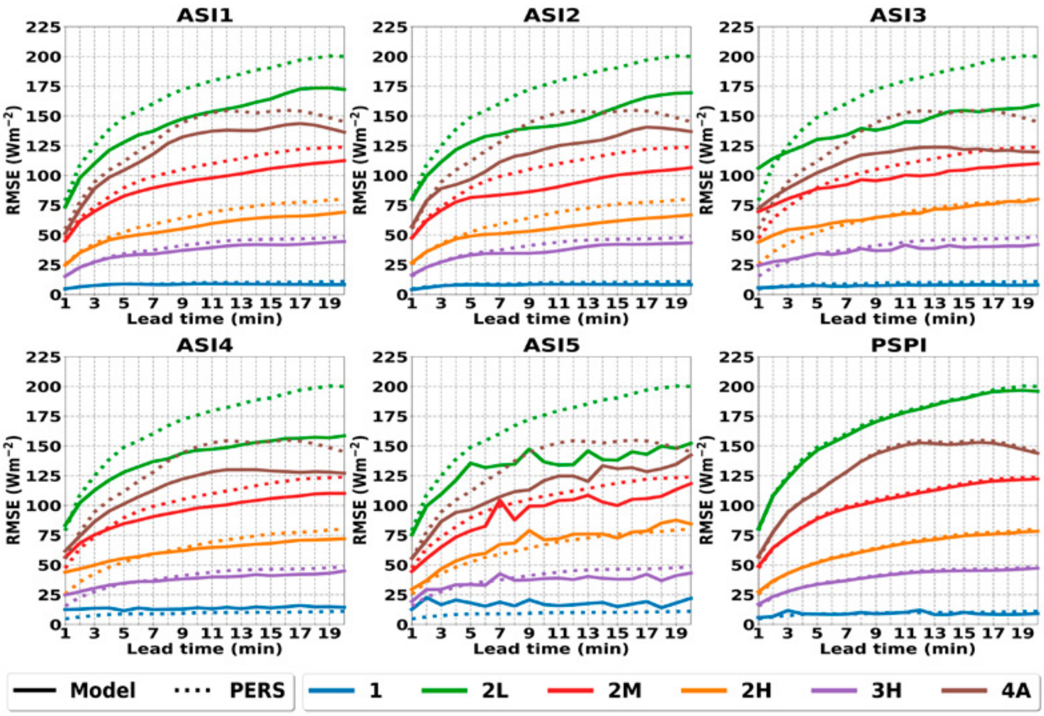


Fig.24 - Root mean square error (RMSE) variability, under the 6 different cloud clusters and forecast minutes. The time horizon ranges from 1 to 20 min with a latency of 1 min. The color represent different cloud classes: 1 = cloud free, 2L = broken. low clouds, 2H = broken, high / middle clouds, 2M = broken, multiple clouds, 3L = broken with half low clouds and half cloud free, low clouds, 3H = broken with half low clouds and half cloud free, high clouds, 4A: overcast half of the day, broken during other half

INTRODUCTION

Task 16 provides access to comprehensive international studies and experiences with solar resources and forecasts. It supports different stakeholders from research, instrument manufacturers as well as private data providers and utilities.

Task 16 is a joint Task with the TCP SolarPACES (Task V). It collaborates also with the Solar Heating and Cooling (SHC) – the third TCP regarding solar topics. The main goals of Task 16 are to lower barriers and costs of grid integration of PV and 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
- 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
- Contribute to or setup international benchmark for data sets and for forecast evaluation.

→ **Read about the objectives and structure of Task 16 in the Annex**

TASK ACCOMPLISHMENTS

The main work of Task 16 is concluded every 3-4 years in the Solar Resource Handbook – officially entitled "Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications". In May 2021 the third Edition of this handbook has been published. Some aspects of this comprehensive 10 chapters and 348 pages report are given in the Report Summaries Document. The report includes the work done in the first phase of IEA PVPS Task 16 between 2017 and 2020. 41 authors from 13 countries have written the report, which is the product of the collaboration between NREL and IEA PVPS. After the publication is before the publication: The 4th edition has already been initiated in 2021. A stronger update including new chapter structures is planned for the 4th edition. The Handbook was presented at two online workshops and also at several scientific conferences. It's available on both NREL and IEA PVPS webpages.

In the following a short selection of ongoing work – two per Subtask - is listed:

SUBTASK 1 – EVALUATION OF CURRENT AND EMERGING RESOURCE ASSESSMENT METHODOLOGIES

Benchmark for solar resource and forecast data:

The work on the benchmark for solar resource and forecast data is ongoing. This effort is led by DLR (Stefan Wilbert) and CSP Services (Anne Forstinger). The first part of the work – the quality check of ground data has been described in a paper presented at SWC 2021. 161 stations have been evaluated – 129 have been selected for the benchmark. Data availability ranges between 30 and 80 %.

Studies of reference cells

Modeling the output of reference cells using spectral data and reference cell temperature data produces minimal uncertainties for clear sky and cloudy conditions for a two-axis tracking surface. An improved model that included the transmission of diffuse irradiance through the glazing significantly improved the modeling, especially during cloudy periods.

Future work will model different reference cells and use data from different locations. In addition the experiment will be repeated for reference cells on a one-axis tracking surface and at a fixed and horizontal tilt. Current efforts are aimed at developing python based models to facilitate the analysis of the data (Vignola et al, 2021).

SUBTASK 2 – ENHANCED DATA & BANKABLE PRODUCTS

Report about gap filling

A draft version of report on GAP-Filling method (activity 2.1) has been written by Mines Paristech (Philippe Blanc, FRA). It will be finalized in spring 2022.

Solar radiation at urban scales

In the topic of solar radiation at urban scales, CIEMAT has developed a methodology for computing solar radiation at facades based on Digital Surface Model (DSM) from LIDAR data and the computation of the sky view factor (SVF). The methodology has been applied to modeling PV arrays being monitored in a CIEMAT building. The results showed general agreement with the power monitoring data excepting in the east wall where irregular shading by trees produces more deviations (Polo et al., 2021).

SUBTASK 3 – EVALUATION OF CURRENT AND EMERGING SOLAR RESOURCE AND FORECASTING TECHNIQUES

Benchmark of all sky imagers

The benchmark of all sky imagers has been successfully executed and fully analyzed. 5 different all sky imager systems participated in this intercomparison. Results showed that the forecasts beat the persistence in many cases – and are therefore valuable. A journal paper under the lead of Andreas Kazantzidis (Univ. Patras, GRE) has been written and a 2nd paper about ramp detection was almost finalized.

Progress in regional PV power forecasting

Within two new projects in Italy the following aspects were studied: the impact of different upscaling methods, the impact of the quality of the NWP, the impact of the size of the controlled area, quantify the Machine Learning complexity limit for our NN base model, quantify the margin of reduction in the system's demand/supply imbalance and flexibility requirement that can be achieved in Italy by increasing forecast accuracy and grid reinforcements

OUTLOOK

Task 16 will continue it's work in 2022. The current phase will end mid-2023. The work includes new benchmarks of satellite based resource data and forecasts. Such benchmarks haven't been done since 2015.

A special effort will be done in benchmarking probabilistic forecasts and to describe state of the art methods for gap filling.

Work on firm PV power – how to reach secured electricity with PV 24/7 for the whole year – will continue. A case study for Switzerland will be published.

The next update of the Solar Resource Handbook – the 4th edition – has been initiated (the 3rd edition was published in May 2021). The main authors and editors are redefining the chapter structures and will start to write the next update.

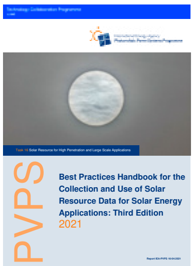
The results of the collaboration will be disseminated in conferences, journals and workshops.

All Task 16's PVPS Publications, including 1 new Technical Reports from 2021, are available here

SOLAR RESOURCE HANDBOOK

TASK 16 HIGHLIGHT

A. Betti; P. Blanc; M. David; Y-M. Saint-Drenan; A. Driesse; J. Freeman; R. Fritz; Ch. Gueymard; A. Habte; R. Höller; J. Huang; A. Kazantzidis; J. Kleissl; C. Köhler; T. Landelius; V. Lara-Fanego; E. Lorenz; P. Lauret ; L. Martin; M. Mehos; R. Meyer; D. Myers; K.P. Nielsen; R. Perez; C. Fernandez Peruchena; J. Polo; D. Renné; L. Ramírez; J. Remund; J.A. Ruiz-Arias; M. Sengupta; M. Silva; D. Spieldenner; T. Stoffel; M. Suri; S. Wilbert; Stephen Wilcox; F. Vignola; P. Wang; Y. Xie; L.F. Zarzalejo



Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications: Third Edition

Task 16 Webpage

KEY MESSAGE

The 3rd version of the Solar Resource Handbook – the main report of Task 16 - is a comprehensive report including the state of the art and ongoing scientific work.

OBJECTIVE

The main objective is to lower uncertainties in resource assessments and forecasts. Lower uncertenties will result in lower planning, financing and integration costs.

Lower uncertainties are reached by coordination of specific science and description of state of the art methods.

METHODOLOGY

Description of the state of the art methods for measuring and modelling solar resources and forecasts. This includes the basic methods and ongoing scientific work.

A special focus is put on how to use solar data for site assessments, monitoring and control of PV, CSP and solar thermal plants.

Fig.25 - High aerosol loads from Sahara dust over Switzerland obscuring the sun.

Aerosols are the 3rd most important parameter for determining solar radiation (aside clouds – and solar position). The knowledge is still not as good as needed – regarding climatologies, current situation and forecasts. High aerosol loads are seen mainly nearby deserts but can be transported by storms over several thousands of km.

Phase

1. Prefeasibility and planning	• Long-term averages • Monthly data • Solar cadastres/ maps • Simple shading analysis	• TMY • Hourly data • Shading analysis	• Long-term satellite data • Hourly data
2. Feasibility			• Satellite data • Time series (>10 year) • Ground meas. (> 1 year) • Shading analysis • Further site- and technology- specific meteo. parameters (e.g., albedo, soiling)
3. Due diligence and finance		• Satellite data • Time series (>10 y) • Minute data • Shading • Further site- and technology- specific meteo. parameters (e.g., albedo, soiling)	• Satellite data • Time series (>10 y) • Ground meas. (> 1 year) • Minute data • Shading analysis • Further site- and technology- specific meteo. parameters (e.g., albedo, soiling)
4. Operation and maintenance	• Simple monitoring	• Local measurements • Forecasts	• Local measurements • Forecasts

Fig.26 - Data Application Techniques for the Various Stages of Project Development

Not all projects need the same solar resource or forecast data. The needs depend strongly on the size of the system and also on the phase of the project. Not always the best is needed, but the most adequate data. Nonetheless: the trend goes in the direction of higher resolution and multi-year datasets to obtain lower uncertainties.

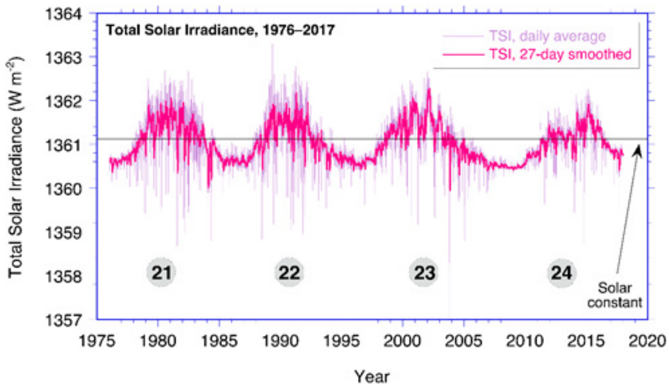


Fig.27 - Four solar cycles show the temporal variations of daily total solar irradiance between 1976–2017

The "solar constant" is variable – and is named now as Total Solar Irradiance (TSI). This example shows, that also basic facts are included in the Handbook – especially if the science has been updated. More accurate definitions show an average level of 1361 W/m2 – compared to 1366 W/m2 in former estimations.

TASK 17

PV AND TRANSPORT

Task Managers: Toshio Hirota (Waseda Uni, Japan); Keiichi Komoto (Mizuho R&T, Japan)

Fig.28 - PV-powered vehicles driving on public road in Japan (photo: courtesy of New Energy and Industrial Technology Development Organization (NEDO), Japan) PV-powered vehicles with around 1kWp PV integrated into the passenger vehicles were developed under the NEDO project in 2019/2020. Since then, these vehicles have been performing demonstration driving for data measurement and performance verification on public roads in Japan.

INTRODUCTION

With widespread electrification of transportation, PV electricity and other renewable energy sources are needed to leverage the EV adoption into even more significant CO_2 emissions reductions. Options for low-carbon charging of electric vehicles include charging from the existing grid network with PV or other sustainable electricity sources, charging from a dedicated charging point with local PV electricity generation, or directly and independently with on-board PV (PV-powered vehicle).

In order to contribute to reducing the CO_2 emissions of the transport sector and to enhance PV market expansions, Task 17 is aiming to clarify the potential of the utilization of PV in transport and to propose how to proceed towards realising the concepts. Task 17's scope includes various PV-powered vehicles such as passenger cars, light commercial vehicles, heavy duty vehicles and other vehicles, as well as PV applications for electric systems and infrastructures, such as charging infrastructure with PV, battery and other power management systems.

→ **Read about the objectives and structure of Task 17 in the Annex**

TASK ACCOMPLISHMENTS

STATE-OF-THE-ART AND EXPECTED BENEFITS OF PV-POWERED VEHICLES

PV-powered vehicles which are driven by on board PV are a high priority concept because of the impact on CO_2 reduction, although it is still a challenging technology to realize in the market.

Task 17 published its first technical report entitled 'State-of-the-Art and Expected Benefits of PV-Powered Vehicles' in 2021.

It was clarified that PV-powered vehicles offer significant benefits to drivers and an important contribution to the energy transition. Short driving range commuter vehicles, ultra-light weight vehicles, and high efficiency electric vehicles are the most realistic concepts to apply PV power for smaller passenger vehicles. As a concept of bridge technology to PV-powered vehicles, it will be possible to consider PV-equipped vehicles for auxiliary components such as air conditioning systems, refrigerators and heating systems. This can already be seen in some passenger vehicles. As well, it was identified that their market introduction would require technical optimisation of PV integration into vehicles. For heavier commercial vehicles such as truck trailers, other goods delivery vehicles, and buses, it was found that on-board PV can make significant contributions to these auxiliary systems and the electric conversion of these systems. Taking into account the area available for PV and the possible use of PV electricity for auxiliary demand, PV-powered refrigerated truck trailers and buses are close to market introduction.

PV-POWERED ELECTRIC VEHICLE CHARGING STATIONS: PRELIMINARY REQUIREMENTS AND FEASIBILITY CONDITIONS

Regarding PV applications for electric systems and infrastructures, V2H, V2G and VPP (Virtual Power Plants) with PV-powered charging stations (PVCS) will be important to improve the utilization factor of PV generation and to reduce the impact of PV generation on the stability of grid.

Task 17 2nd technical report, entitled 'PV-Powered Electric Vehicle Charging Stations: Preliminary Requirements and Feasibility Conditions' published in December 2021, clarified that PV-powered charging stations (PVCS) offer significant benefits to drivers and an important contribution to the energy transition.

It was shown that PVCS have the potential to further decrease the CO_2 emissions impact of electrified transport and accelerate the adoption of EVs overall due to a decreased dependence on the public grid. However, it was also pointed out that their massive implementation would require technical and sizing optimisation of the system, including stationary storage and grid connection, but also change of the vehicle use and driver behavior. PV benefits for EVs charging can be further increased by using algorithm-based communication between operators and end-users. Further, PVCS, will, when combined with a well-designed power management strategy, provide environmental benefits to future V2G / V2H systems when they will deployed at scale.

OUTLOOK

Task17 will go into its 2nd phase for the 2022-2024 period.

Aiming to present the expected benefits of PV-powered vehicles, Task 17 will focus on the following topics:

- PV-powered passenger cars: Technical requirements for VIPV; Possible contributions and benefits
- PV-powered light commercial vehicles: Case study and analysis on amortization time and CO_2 footprint; Requirements, barriers and solution
- PV-powered heavy duty vehicles: Analysis of the energy flow and energy balance of PV generation for different heavy duty vehicle applications; Case study for use of a fleet of HDVs to offer energy services

Task 17 is also aiming to present the benefits of PV-powered charging stations (PVCS). The function of PVCS and the results of a life cycle analysis will be discussed. Expected benefits will be further evaluated and validated from techno-economic, environmental, and societal viewpoints, as well as from those of related industries.

Furthermore, resilience of PV-powered vehicles and charging stations, and business models for 'PV and Transport' will be discussed.

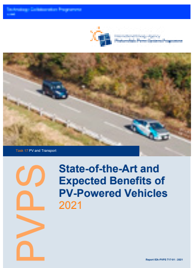
All Task 17's PVPS Publications, including 2 new Technical Reports from 2021, are available here

Fig.29 - PV-powered electric vehicles charging station based on microgrid on parking in Université de Technologie de Compiègne (UTC), France
PV-powered charging station, with around 30 kWp PV integrated, 18 kWh stationary storage, and grid connection, was developed under the UTC project in 2017/2019. Since then, this charging station has functioned as a demonstration site for power flow optimization, power control, and for identifying preliminary requirements and feasibility conditions.

PV POWERED VEHICLES

TASK 17 HIGHLIGHT

K. Araki (Japan); A.J. Carr (The Netherlands); F. Chabuel (France); B. Commault (France); R. Derks (The Netherlands); K. Ding (Germany); T. Duigou (France); N.J. Ekins-Daukes (Australia); J. Gaume (France); T. Hirota (ed.)(Japan); O. Kanz (Germany); K. Komoto (ed.)(Japan); B.K. Newman (The Netherlands); R. Peibst (Germany); A. Reinders (The Netherlands); E. Roman Medina (Spain); M. Sechilariu (France); L. Serra (France); A. Sierra (The Netherlands); A. Valverde (Spain); D. Zurfluh (Switzerland)



State-of-the-Art and Expected Benefits of PV-Powered Vehicles

Task 17 Webpage

KEY MESSAGE

PV-powered vehicles, with on-board integrated PV systems, offer more than just low emissions transport but also options of convenience and autonomy.

OBJECTIVE

This report presents the recent trends in PV-powered vehicles including PV technologies, expected benefits of PV-powered vehicles, estimates of solar irradiance on vehicles, and next steps for realising PV-powered vehicles in the market.

METHODOLOGY

The results were developed by authors through various approaches such as literature survey, simulation using models, measurement in the field, and communications.

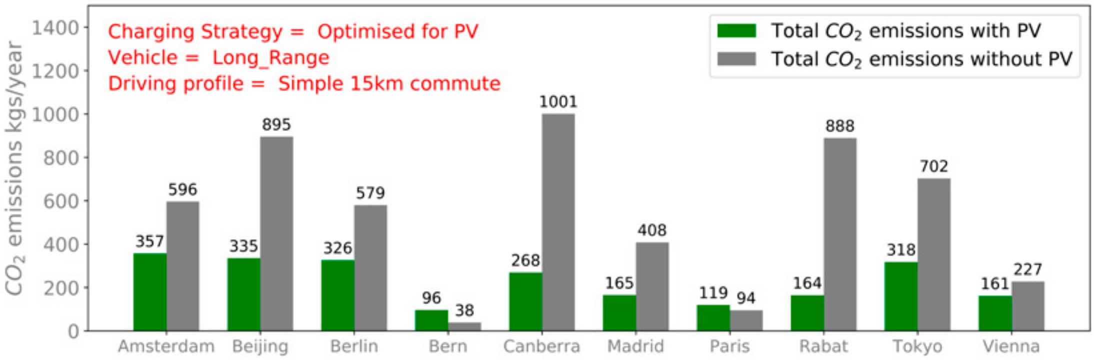


Fig.30 - CO_2 emissions for each location in Task17 member countries by passenger vehicle with/without PV (800 Wp)

CO_2 emissions are reduced during the operation of the vehicle by the on-board PV. However, in some cases, e.g. in countries with relatively clean grid electricity, the embedded CO_2 based on the manufacturing of PV modules might lead to slightly higher lifetime emissions during the operation of the PV-powered vehicle.

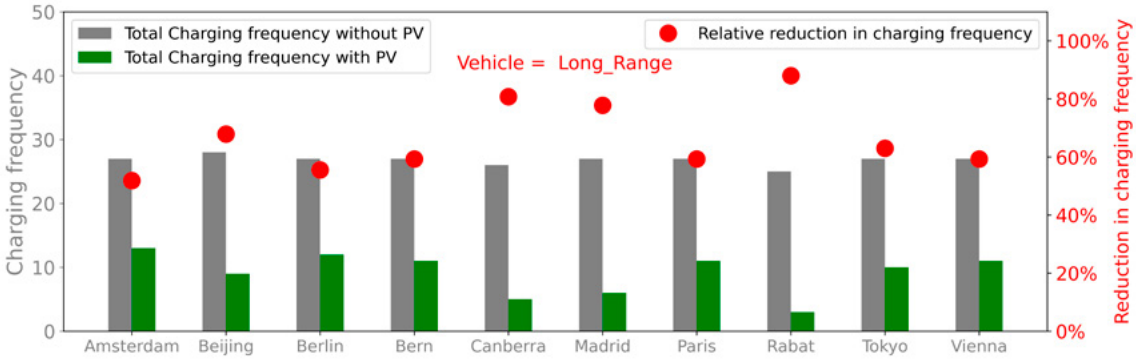


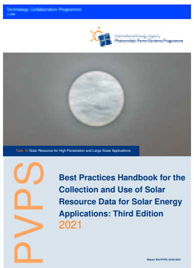
Fig.31 - Charging frequency and the relative reduction in charging frequency for passenger vehicle with/without PV (800 Wp)

Without PV, the number of charging frequency is very similar for all countries. With PV, the locations with higher irradiance, Canberra, Madrid and Rabat see the largest reduction in charging frequency as the PV contributes significantly to the driving energy needed.

PV POWERED VEHICLE CHARGING

TASK 17 HIGHLIGHT

A. Reinders (The Netherlands); A. Sierra (The Netherlands); M. Sechilariu (France); Y. Krim (France); S. Cheikh-Mohamad (France); K. Ben Slimane (France); G. Seiler (France).



[PV-Powered Electric Vehicle Charging Stations Preliminary Requirements and Feasibility Conditions]

[Task 17 Webpage]

KEY MESSAGE

Technical and economic optimization of PV-powered charging stations (PVCS), under local meta-conditions (site, weather conditions, user profile, etc.) and over the lifespan, are strongly recommended to make full direct use of the PV energy and to increase PV benefits.

PVCS can successfully operate for slow charging as well as for fast charging and with less / without reliance on the power grid, also providing additional services via vehicle-to-grid (V2G) and vehicle-to-home (V2H).

OBJECTIVE

This report presents the recent trends in PVCS for passenger cars including system architectures, preliminary requirements and feasibility conditions to increase benefits of PVCS, social acceptance, and proposes steps for realizing PVCS. (Links to related work: [1], [2], [3], [4], [5])

METHODOLOGY

Authors through various approaches such as literature survey, modeling, optimization, algorithm design, simulation using models, real-time control, experimental tests, and surveys, developed the results.

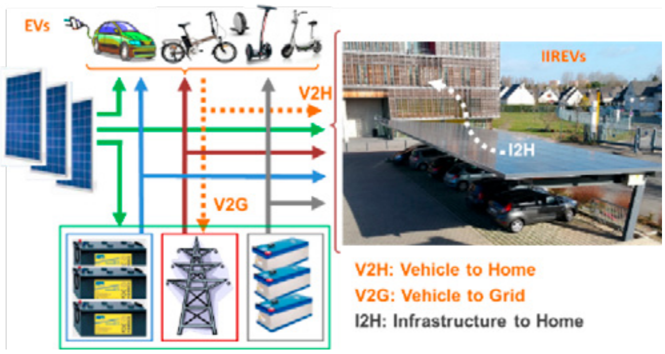


Fig.32 - PV-powered electric vehicles charging station based on microgrid (30 Wp)

To be able to host slow charging and fast charging terminals at a PVCS, the PVCS could be a system based on a microgrid, incorporating stationary storage that is charged exclusively from PV sources, with / without public grid connection, using intelligent power control, optimization system, user application interface, and communication system.

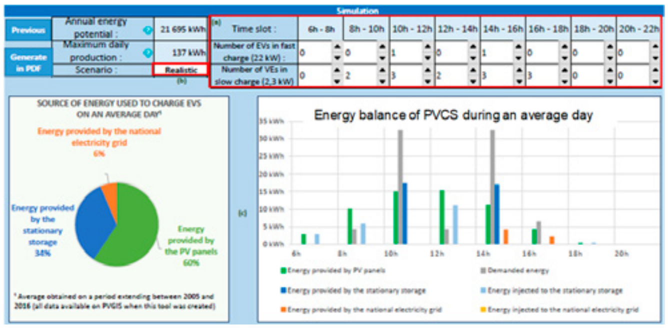


Fig.33 - Assessment of PV benefits for PV-powered electric vehicles charging station based on microgrid

By using a techno-economic tool to identify the best feasibility conditions, the PV benefits are increased for local PVCS. The PV makes a significant contribution to the required charge of electric vehicles (EV). The results show that with the right combination of stationary storage and PV array sizes, the use of PVCS can be a feasible EV charging solution from a technical, financial and environmental perspective in comparison with a grid-charged EV.

Fig.34 - Design methodology of new innovative PV applications for electric mobility systems.

PVCS design is a relevant topic for user acceptance of PV-powered electric vehicles charging station as well as for communicating to users their function and their focus on sustainability.

TASK 18

OFF-GRID AND EDGE-OF-GRID PHOTOVOLTAIC SYSTEMS

Task Managers: Toshio Hirota (Waseda Uni, Japan); Keiichi Komoto (Mizuho R&T, Japan)

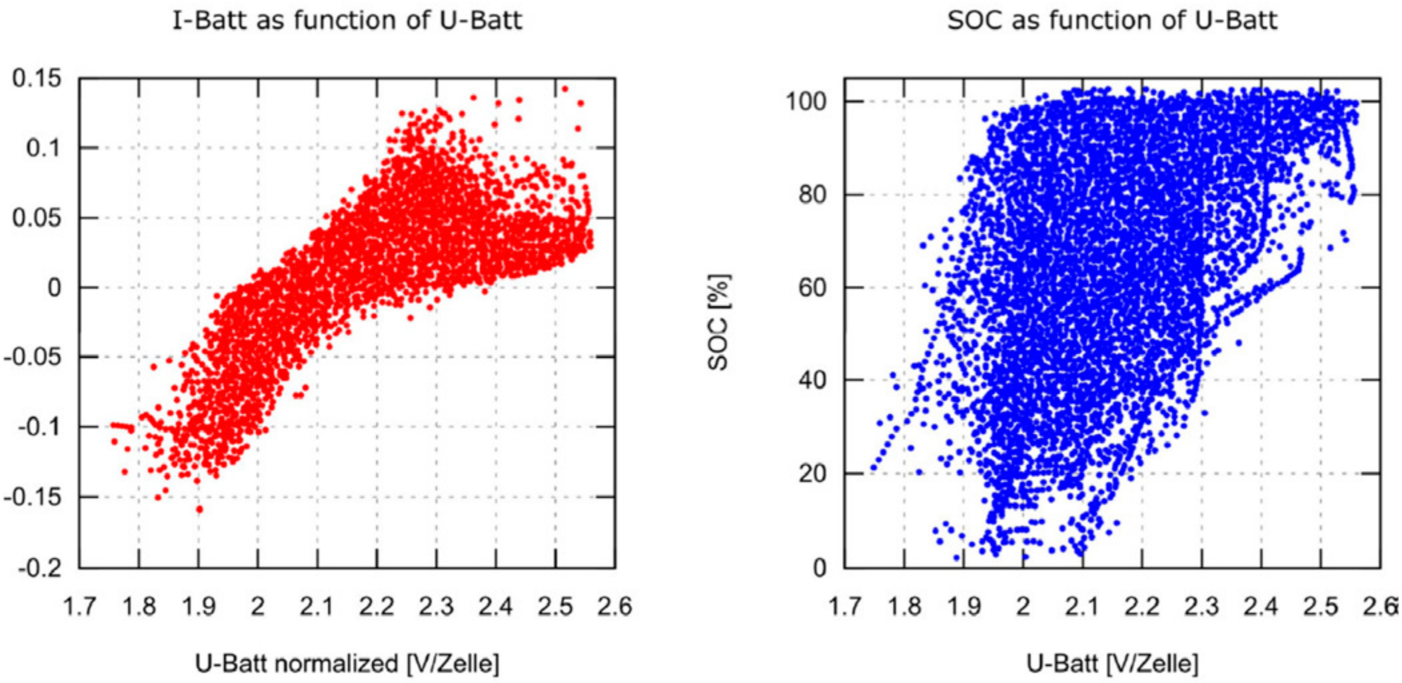


Fig.35 - Charts plotting battery current and state of charge (SOC) against normalised battery voltage

INTRODUCTION

The objective of Task 18 is to find technical issues and barriers which affect the planning, financing, design, construction and operations and maintenance of off-grid and edge-of-grid systems, especially those which are common across nations, markets and system scale, and offer solutions, tools, guidelines and technical reports for free dissemination for those who might find benefit from them.

Within the context of off-grid and edge-of-grid photovoltaic systems, the central discussion points will cover:

- Reliability: A system that can generate and distribute energy to meet the demands of those connected with a high degree of confidence
- Resiliency: A system that can withstand or recover quickly from natural disasters, deliberate attacks or accidents
- Security: A system that is sustainably affordable and provides an uninterrupted supply of energy which adequately meets the associated demand.

→ **Read about the objectives and structure of Task 18 in the Annex**

TASK ACCOMPLISHMENTS

Subtask 2 has published a key report called "Blueprint on How to Conduct Feasibly Studies on Off-Grid and Edge of Grid Power Systems". This report was executed through a literature review which ensured that the expert authors were considering multiple approaches that can and are taken to the performance of a hybrid system feasibility. The report then outlines key considerations of the Blueprint such as ownership, governance, regulations, social aspects, technical design, financial optimisation and multivariant sensitivity analysis. The following is a key insight from the report showing the balance between renewable energy fraction (REF) and net present value (NPV) given varying BESS and PV system sizes. (Highlights from this report are presented in the next pages.)

A second Task 18 report published this year focuses on PV-Hybrid System Data Visualisation Recommendations. This report reviews and recommends methodology for system data logging and representation of the data for its useful interpretation in system operation, diagnostics, maintenance, technical performance and financial performance. The following image shows a key data visualisation representation showing both battery current and state of charge (SOC) plotted against normalised battery voltage.

OUTLOOK

Task 18 will consolidate its efforts onto Activities 1.2 and 1.4 led by Pablo Diaz Villar of University of Alcala, Madrid, Spain and Dr. Pavol Bauer, TU Delft, Netherlands respectively. Activity 1.2 will look at off-grid system compatibility by conducting and international standards review including product and installation guidelines in order to find gaps and commonalities. Activity 1.4 will consider off-grid system digitisation through the use of models which then inform system design and operational dispatch regimes.

All Task 18's PVPS Publications are available here

OFF-GRID FEASIBILITY STUDIES

TASK 18 HIGHLIGHT

L. McLeod, P. Rodden (Ekistica ,Australia); M. Ross (Yukon College, Canada)

[Blueprint on how to conduct feasibility studies on off-grid and edge-of-grid power systems]

[Task 18 Webpage]

KEY MESSAGE

Blueprint on how to conduct feasibility studies on off-grid and edge-of-grid power systems

OBJECTIVE

To provide a blueprint on how to complete an effective feasibility assessment for a photovoltaic (PV) based off-grid or edge-of-grid power system. This report examines the key considerations and processes required to successfully determine the feasibility (or otherwise) of such projects and, through the use of case studies, provide the reader with real world examples of such assessments.

METHODOLOGY

Literature review: A summary of existing litereature, plus a repository to store relevant publicly available feasibility studies.

Blueprint contents: Topics include ownership, governance, regulatory, social aspects, technical aspects, financial aspects, optimisation and sensitivity.

Case Studies: Three real-world examples of feasibility studies explored in detail

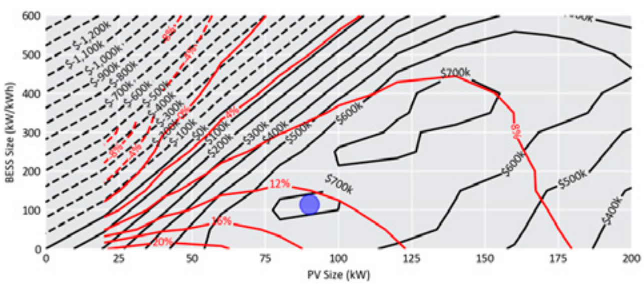


Fig.36 - Feasibility Optimisation Functions – Net Present Value (NPV) and Internal Rate of Return (IRR)

Clients can optimise system sizing given various system parameters. Common examples of this are IRR, NPV and renewable energy fraction. This topological graph shows the system optimisation between IRR and NPV.

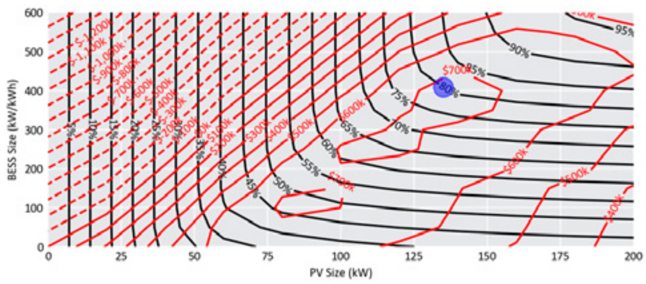


Fig.37 - Feasibility Optimisation Functions – NPV and REF

Whereas IRR may encourage clients to make a lower CAPEX investment, renewable energy fraction may give a client more system resiliency. This topological graph shows the system optimisation between NPV and renewable energy fraction.

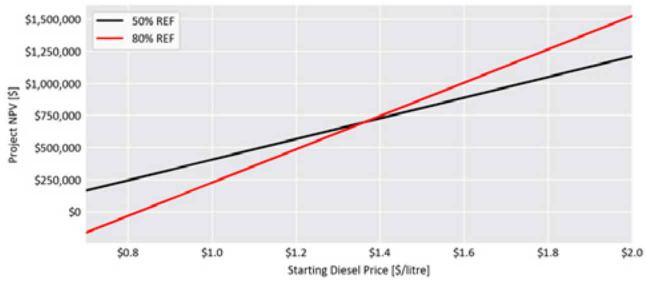


Fig.38 - Feasibly Optimisation Sensitivity

This image shows a simplified sensitivity analysis given 50 % REF and 80 % REF and varying diesel pricing for the hybrid system OPEX.

TASK PARTICIPATION MATRIX

This matrix shows which countries participate in each PVPS task, and names the individual entities involved. Each orange box indicates participation of one entity (row) in one particular task (column).

		T1	T12	T13	T14	T15	T16	T17	T18
AUSTRALIA	Australian Energy Market Operator (AEMO)				■				
	Global Sustainable Energy Solutions								TM
	IT Power Australia							■	
	Murdoch University			■					
	Rolls Royce								■
	Royal Melbourne Institute of Technology (RMIT Uni.)					■			
	Solcast						■		
	University of New South Wales (UNSW)	■	TM	■	■		■	■	
	University of South Australia						■		
	Ekistica			■					■
AUSTRIA	Austrian Institute for Technology (AIT)			■	TM	■			
	Austrian PV Technology Platform (TPPV)	■							
	Austrian Research Institute for Chemistry and Technology (OFI)			■		■			
	ertex Solartechnik GmbH					■			
	Polymer Competence Center Leoben (PCCL) GmbH			■					
	Salzburg University of Applied Sciences					■			
	University of Applied Sciences Technikum Vienna					■			
	University of Applied Sciences Upper Austria					■	■		
BELGIUM	3E			■					
	Becquerel Institute	TM				■			
	Energie Commune	■							
	Energyville					■			
	Interuniversity Microelectronics Centre (IMEC)			■					
	KU Leuven (Catholic University of Leuven)			■					
	LuciSun					■			
	PV Cycle Association		■						
	Tractebel – Engie			■					
	Université Libre de Bruxelles (ULB)					■			
	VITO (Vlaamse Instelling voor Technologisch Onderzoek)		■						

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
CANADA	Canadian Solar Industries Assoc. (CANSIA)	X							
	CanmetENERGY - Natural Resources Canada			X	X	X			
	Concordia University					X			
	Université de Sherbrooke (Québec)					X			
	University of Waterloo					X			
	Yukon Research Centre								X
CHILE	Atacama Module System Technology Consortium (AtaMoS-TeC)			X					
CHINA	China Renewable Energy Society					X			
	Chinese Acadamy of Science	X	X	X	X			X	
	Hunan University					X			
	Jinko Solar Co. Ltd		X						
	Longi Solar	X							
	Public Meteorological Service Center (CMA)						X		
	Zhuhai Singyes Co.					X			
DENMARK	Danish Meteorological Institute (DMI)						X		
	European Energy, Birkerød			X					
	Kenergy	X			X				
	Solar City Denmark					X			
	Technical University of Denmark (DTU)						X		
EU	EU Joint Research Centre (JRC)	X					X		
	European Commission				X				
FINLAND	Aalto University					X			
	Lappeenranta University of Technology	X							
	Turku University of Applied Sciences			X					

		T1	T12	T13	T14	T15	T16	T17	T18
FRANCE	ADEME								
	CSTB								
	Ecole Polytechnique à Palaiseau								
	Electricité de France (EDF R&D)								
	Enedis								
	EnerBIM								
	Hespul								
	Institut National de l'Energie Solaire (CEA-INES)								
	Lab. PIMENT, Université la Réunion								
	MINES ParisTech								
	Polymage								
	Promes-CNRS								
	SAP Labs France								
	Tecsol								
	Univ. des Antilles et de la Guyane								
	Université de Technologie de Compiègne								
GERMANY	DLR								
	Forschungszentrum Jülich GmbH								
	Fraunhofer IEE								
	Fraunhofer Institute for Solar Energy Systeme (ISE)					TM			
	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH								
	Institute for Solar Energy Research Hamelin (ISFH)								
	Technische Hochschule Ulm				TM				
	TÜV Rheinland Energy GmbH (TRE)								
	VDE Renewables (VDE)			TM					
	ZSW (Center for Solar Energy and Hydrogen Research Baden-Württemberg)								
ISRAEL	Green Power Engineering Ltd.								
	Ministry of Energy								

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
ITALY	Electricita Futura								
	ENEA								
	European Academy Bozen/Bolzano (EURAC)								
	Gestore dei Servizi Energetici - GSE S.p.A								
	i-em								
	IMT (Scuola Alti Studi Lucca)								
	Ricerca sul Sistema Energetico - RSE S.p.A.								
	Univ. Tor Vergata / Roma 2								
	University of Catania								
JAPAN	AGC								
	Lixil								
	Mizuho Research & Technologies, Ltd. (MHRT)							TM	
	National Institute of Advanced Industrial Science and Technology (AIST)								
	New Energy and Industrial Technology Development Organization (NEDO)								
	RTS Corporation	TM							
	Tokyo University of Science								
	University of Miyazaki								
	Waseda University							TM	
KOREA	Kongju University								
	Korea Institute of Energy Research (KIER)								
	Korean Institute of Energy Technology (KENTECH)								
	Kyungpook National University								
MALAYSIA	Sarawak energy Berhad								
	Sustainable Energy Development Authority (SEDA)								
MOROCCO	Green Energy Park								
	IRESEN								TM

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
NETHERLANDS	bear-ID					X			
	IM Efficiency							X	
	Rijksdienst voor Ondernemend Nederland (RVO)	X				X			X
	SmartGreenScans		X						
	TNO		X			X		X	
	TU Delft								X
	University of Twente							X	
	University Utrecht			X		X	X		
	Zuyd University of Applied Sciences					X			
NORWAY	Institute for Energy Technology (IFE)			X		X	X		
	Norvegian Water Ressources and Energy Directorate (NVE)	X							
	Norwegian Meteorological Institute						X		
	Norwegian University of Science and Technology (NTNU)					X			
	RI.SE Fire Research					X			
PORTUGAL	University of Lisbon							X	
SPAIN	CIEMAT		X			X	X		
	ESCi (Escola Superior de Comerc Internacional) / Oxford Brookes University		X						
	National Renewable Energy Centre (CENER)			X			X		
	Onyx Solar					X			
	Polytechnic University of Madrid					X			
	Public University of Navarra						X		
	Tecnalia					X		X	
	TTA								X
	Union Española Fotovoltaica (UNEF)	X							
	Univ. Almeria						X		
	Universidad de Las Palmas de Gran Canaria						X		
	University La Laguna				X				
	University of Alcala								X
	University of Jaén			X			X		
	University of Malaga						X		
	University of Seville						X		

		T1	T12	T13	T14	T15	T16	T17	T18
SWEDEN	AFconsult						■		
	Becquerel Sweden	■							
	CheckWatt			■					
	Mälardalen University			■		■			
	Paradisenergi AB			■					
	Research Institutes of Sweden (RISE)			■		■			
	SMHI						■		
	Soltech Energy					■			
	Swedish Energy Agency		■						
	University Uppsala						■		
	White Architects					■			
SWITZERLAND	Berner Fachhochschule (BFH)			■	■				
	Eastern Switzerland University of Applied Sciences						■		
	Engineering Office Muntwyler Berne/ PV LAB BFH-TI							■	
	Institut für Solartechnik (SPF)			■					
	Meteotest						TM		
	Planair SA, Switzerland	■			■				
	Scuola Universitaria Professionale della Svizerra Italiana (SUPSI)			■		TM			
	Solaxess SA					■			
	Swiss Centre for Electronics and Microtechnology (CSEM)			■				■	
	treeze Ltd., fair life cycle thinking		■						
	Viridén + Partner AG					■			
	Zürcher Hochschule für Angewandte Wissenschaften (ZHAW)			■					
TAIWAN	PV Guider Consultancy			■					
THAILAND	King Mongkut University of Technology Thonburi (KMUTT)			■					
	Ministry of Energy (DEDE)	■							

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
USA	Case Western Reserve University (SDLE)								
	Clean Power Research (CPR)								
	Department of Energy (DoE)								
	Envision Digital LLC								
	EPRI								
	First Solar								
	National Aeronautics and Space Administration (NASA)								
	National Renewable Energy Laboratory (NREL)		TM				TM		
	Sandia National Laboratories (SNL)								
	Solar Consulting Services (SCS)								
	State Univ. of New York at Albany (SUNY)								
	Univ. of California San Diego (UCSD)								
	University of Alaska Fairbanks, Alaska Center for Energy and Power (ACEP)								
	University of Oregon								

TM = Task Manager

AUSTRALIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Renate Egan (APVI and UNSW)

Fig.39 - Wemen 110 MWp Solar Farm. Images courtesy of Wirsol Energy Pty Ltd https://www.wemensolarfarm.com.au/

NATIONAL PV POLICY PROGRAMME

With solar increasingly competitive in Australia, National Programmes that support deployment are drawing to a close, being replaced by initiatives that support the integration of storage, demand management, load shifting and grid improvements, among others.

The Large Scale Renewable Energy Target (LRET) of 33 000 GWh of renewable electricity annually over 2020 has now been met, with the installation of close to 9 GW of solar installations with a capacity over 100 kWp. The program is now closed and so will not incentivize future investment, yet interest in large scale solar remains strong.

Support for small-scale systems (up to 100 kWp) will continue through to end 2030, with an uncapped Small-scale Renewable Energy Scheme (SRES) that are able to claim certificates (STCs) up-front for the amount of generation they will be deemed to produce until the end of 2030. This means that the STCs for small systems act as an up-front capital cost reduction. The value of the STCs is decreasing every year toward 2030.

Complementing the National Programmes, the Australian Renewable Energy Agency (ARENA) holds a portfolio of 654 MAUD in solar projects (ARENA Annual Report, 2019). ARENA was established by the Australian Government to improve the competitiveness of renewable energy technologies and increase the supply of renewable energy in Australia. The National Government has committed to extending the program of work by ARENA for a further ten years from 2022. ARENA will focus on Low Emissions Technologies identified in an annual assessment of technology opportunities.

National programmes in support of solar PV are also complemented by State based schemes, that seek to attract new investment in clean energy projects. Examples include Renewable Energy Zones (REZs) that aim to combine utility scale solar with wind, storage and high-voltage transmission to deliver energy to load centres. By co-ordinating investment, connection and location with respect to load, multiple generators and storage the REZ can capitalise on economies of scale to deliver cheap, reliable and clean electricity.

RESEARCH, DEVELOPMENT & DEMONSTRATION

PV research, development and demonstration are supported at the National, as well as the State and Territory level. In 2021, research was funded by the Australian Renewable Energy Agency (ARENA), the Australian Research Council and Co-operative Research Centres.

ARENA is the largest funder of photovoltaics research in Australia. In 2019-20, ARENA committed over 15.1 MAUD for accelerating solar PV innovation, with a focus on end-of-life, advanced silicon technologies and new materials.

In addition, ARENA supported significant investments in lowering the cost of renewable technologies, addressing grid integration challenges to increase the supply of, or improve the competitiveness of, renewable energy in Australia.

Australia is active in all IEA PVPS tasks and takes a leadership role as Co-Operating Agent in Task 12, Sustainability and Task 18, Off-Grid and Fringe of Grid PV. Australia's participation in the IEA PVPS program is supported by ARENA under its international engagement program.

→ **Australian Experts participate currently in 8 PVPS Tasks involving 10 separate entities as listed here**

INDUSTRY & MARKET DEVELOPMENT

2021 saw continued strong PV market with early estimates indicating over 4.5 GW of solar was installed. The average system sizes in the sub-100 kW market grew further to 8.3 kW/system, reflecting both the growth in commercial installations, and growth in the typical size of residential systems as householders prepare their homes for future addition of batteries and electric vehicles.

Average residential solar PV system prices continued to decline in 2021, to less than 1 AUD per Watt after subsidies, or around 1.50 AUD per Watt on average without STC support.

The Australian storage market remained strong in 2021, with the Clean Energy Regulator now tracking and reporting battery installations. Over 11 000 new batteries were installed with small scale solar systems in 2021, increasing the total number of batteries installed to upwards of 42 000 by the end of 2021.

The Australian storage market remains favorably viewed by overseas battery/inverter manufacturers due to its high electricity prices, low feed-in tariffs, excellent solar resource, and large uptake of residential PV.

2022 is expected to see stability in rooftop solar – with continued growth in commercial and industrial installations.

The economic fundamentals for residential and commercial PV are outstanding. Australia's high electricity prices and inexpensive PV systems means

Payback

can commonly be achieved in

3-5 years

a situation that looks set to continue in 2022

Commercial PV deployment is likely to accelerate as solar awareness grows, and corporate interest in solar PPAs is building.

Utility-scale solar new capacity additions were relatively stable at 1.7 GW as the investment market navigates regulatory challenges and transmission limitations. Without a national incentive to support large scale solar deployment, state governments are acting to improve transmission networks. There is a growing awareness 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

Hubert Fechner (Austrian Photovoltaic Technology Platform)

Fig.40 - Ulbrich of Austria's fully automated PV-Ribbon factory. Foto Credit: Ulbrich, Mag. Paul Szimák

NATIONAL PV POLICY PROGRAMME

The energy policy goal in Austria is set at 100 % electricity from renewable energy sources by 2030 and climate neutrality by 2040. Currently - depending on the yearly situation - around 75 % is covered by renewable generation due to the high proportion of hydropower and the contributions from wind and biomass as well as about 3 % from photovoltaics which needs to be increased by 11 GW before 2030.

With the Renewable Energy Sources Expansion Act passed in mid 2021, the funding landscape in photovoltaics and electricity storage will be changed.

From 2022, either a market premium or the investment subsidy can be used to support a PV system. The market premium is the new subsidy for PV electricity fed into the grid and thus replaces the previously available feed-in tariff subsidy (current feed-in tariff contracts remain untouched).

The market premium is applicable for new PV systems/extensions > 10 kWp; it is a surcharge on the reference market value (roughly comparable to the average electricity price traded on the market). As part of the application process, the applicant must report the electricity price necessary to make the PV system economically viable (takes place via a bid in the course of the general tendering round). The subsidy applications are ranked according to the registered electricity price (cents per kWh). This means that the applications are awarded, starting with the project with the lowest registered electricity price, until the funding volume of the tender is exhausted. A maximum value for the registered electricity price is specified by the legislature. Registered bids with a higher electricity price are invalid. The market premium is paid monthly over a period of 20 years. There are at least 2 auction rounds per year with a total annual auction volume of at least 700 MW.

The Investment-support is applicable to new PV systems/extensions up to 1000 kWp as well as electricity storage up to 50 kWh (at least 0.5 kWh/kWp); The amount of the investment subsidy for PV systems varies with the size of the system. The amount of the investment subsidy for electricity storage is fixed. The minimum size of the electricity storage is linked to the performance of the PV system. The fixed subsidy amount is only for PV systems up to 10 kWp. For PV systems above 10 kWp there is a maximum subsidy amount, which can be undercut by the applicant in order to be moved up in the ranking of the listed subsidy projects, thereby increasing the chance of receiving a grant.

The funding scheme of the nine Austrian federal states is ongoing, supplemented by a support scheme from the Climate and Energy Fund (for small systems). The feed in tariff for larger systems (> 5 kWp) ran out at the end of 2021.

An investment subsidy for innovative photovoltaic systems from the Climate and Energy Fund was set up for the first time in 2021 and is intended to build bridges between research and the market and to initiate exemplary and model projects. A high degree of system integration and system usefulness and multiplicability are the goals of the funding. Through monitoring and reporting, a knowledge base should be created for further innovative photovoltaic systems. Standard systems are not supported by this grant. A jury of experts selects projects with a high degree of innovation and reproducibility.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Initially supported by the Ministry of Transport, Innovation and Technology (now the Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology) the Austrian PV-Technology platform acts as a legal body since 2012. The PV Technology Platform brings together about 30 Austrian based industry and commercial entities, active in the production of PV-related components and sub-components, as well as the relevant research community, in order to foster innovation in the Austrian PV sector. The transfer of cutting-edge scientific results to the industry via innovation workshops, trainee programs and conferences, joint national and international research projects, and other similar activities are part of the work program, as well as the necessary awareness raising and effort to further improving the frame conditions for manufacturing, research and innovation in Austria by relevant decision makers. The "Austrian Innovation Award for Integrated PV" is organized by the PV platform on a biannual basis. The target of "PV Integration" now covers all kinds of integration of PV into the building-, mobility- and agricultural sector.

Austrian 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 Program from the Austrian Climate and Energy Fund, as well as the program "City of Tomorrow" from the Ministry of Climate Action cover quite a wide range of research topics on energy technologies including PV. The integration of PV technologies is also covered.

The total expenditure of the public sector for energy research in Austria was about 155 MEUR in 2020, out of that 6 MEUR for photovoltaics†). The national RTD in photovoltaics is focusing on materials research, system integration, and also increasingly on all types of integration; from building integration to the integration into the transport sector (e.g. PV covering of roads) and integrating PV production with agricultural needs. 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 Climate Action.

→ Austrian Experts participate currently in 5 PVPS Tasks involving 8 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

Austria has several dedicated PV module producers, manufacturing standard PV modules as well as modules for specific building integration or solar-lighting. Other local producers in the value chain have a focus on high-quality materials in the module, the mounting or in the entire PV system including storage.

The PV home market is predominately focusing on building adapted systems. Larger ground mounted PV systems are increasingly installed, however legal restrictions and public acceptance are frequently limiting factors. Integration of PV beyond buildings is in a state of infancy: First agricultural solutions and PV systems in the mobility sector are installed.

Local energy communities

are to be implemented by the new energy law, which fulfils the EU Renewable Energy directive RED-II

It foresees the distribution grid level as a boundary condition with some incentives, such as a reduced grid fee (only for the locally used electricity) and reduction in electricity taxes. Several hundred energy communities are under development with PV nearly always as the central energy producer.

Following an increase in the newly installed capacity in 2019 to 247 MWp, significant growth was achieved again in 2020; Photovoltaic systems with a total capacity of 340.8 MWp were newly installed, which corresponds to an increase of approx. 38 % compared to the previous year. At the end of 2020, photovoltaic systems with a cumulative total output of 2 043 MWp were in operation in Austria. This corresponds to an increase of 20 %.‡)

Inverter production is of great importance for the Austrian photovoltaic industry. Energy-, Mobility- and Storage solutions connected with inverter technology from Austrian production are used worldwide. This fact is reflected in export rates of over 90 %.

The Federal Association Photovoltaic Austria (PV-Austria) is the non-governmental interest group of the solar energy and storage industries in Austria. This association promotes solar PV at the national and international level 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 conferences, workshops and industry meetings. By the end of 2020, the association counted 280 companies and persons involved in the PV and storage industries as its members.

† Indinger, Rollings, Energieforschungserhebung 2020 Ausgaben der öffentlichen Hand in Österreich Erhebung für die IEA, Berichte aus Energie- und Umweltforschung 20/2021, Federal ministry for climate action environment energy mobility innovation and technology, 2021

‡ Biermayr, Dißauer, Eberl, Enigl, Fechner et al. Innovative Energietechnologien in Österreich - Marktentwicklung 2020, Berichte aus Energie- und Umweltforschung 18/2021, Federal ministry for climate action environment energy mobility innovation and technology, 2021

BELGIUM

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Benjamin Wilkin (Energie Commune)

Fig.41 - With 60 % of the installed power capacity (98 % of the systems), the residential sector stays the biggest driver of the market in Belgium. It is characterized by a power limit of 10 KVA (inverter power) and primarily a self-consumption market.

NATIONAL PV POLICY PROGRAMME

The first Belgian National renewable energy plan set a target of 1.34 GWp for 2020. It was achieved in 2011.

In December 2019, Belgium introduced a revised version of its Climate-Energy National Plan to the European Commission. The new proposed targets for photovoltaics were 5 GWp by 2020 and 11 GWp by 2030. The 2020 target for PV was reached at the end of 2019. Starting from 7 GWp at the end of 2021, and given that the average annual installed capacity over the past 5 years was 750 MWp/year, surely the 2030 target will also be achieved ahead of schedule.

Considering past Belgian trends, the current cost of solar PV systems, the new evolving business models (individual as well as collective self-consumption), the new paradigm with high electricity prices and requests from the EU to Belgium regarding its Climate-Energy Plan.

We confirm our assumption that Belgium could reach

20 to 22 GWp

in 2030 without big additional efforts

This would represent between 15 to 20 % of the electricity consumption of Belgium at the horizon 2030, depending on the evolution of the electrification of some fueled-based usages (such as cars).

Nevertheless, such a new target still needs to be confirmed and embraced by Belgian politics within the new PACE goals. This work already started in 2021.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The R&D effort in the PV sector is proportionally less focused on PV technologies, but rather diversified in connection with integrated (new) business models such as individual and collective self-consumption, battery storage, power to X transformation (including Hydrogen) and recycling processes.

Specific solar R&D efforts are concentrated on highly efficient crystalline silicon solar cells, thin-film and perovskites. In February 2020 IMEC research institute achieved an energy efficiency of 25 % with a thin-film solar cell. Opening a potential new era for high efficiency solar cells in BIPV or VIPV, due to the thin and flexible characteristics. They are expecting 30 % efficiency within 3 years.

Belgian research centers such as Energy Ville and IMEC, among others, are partners of various PV research projects focusing on different subjects:

- The ANALYST PV project attempts to collect data and analyze the performance of PV systems in order to detect faults in PV plants (end 09/2021).
- The CUSTOM-ART project aims at developing next generation building-integrated and product-integrated (BIPV and PIPV) modules based on earth-abundant and fully sustainable thin film technologies, such as Kasterites-based thin film technologies (end 02/2024).
- The LASERGRAPH project aims to develop an in-situ laser processing for the development of interlayers and transparent conductive electrodes, essential for the commercial success of the tandem solar cells based on perovskite and CIGS thin-film (end 12/2021).
- The PERCISTAND project is the development of all thin-film perovskite on CIS tandem photovoltaics to increase the efficiency of cells above the Shockley-Queisser single junction limit. Target is 30 % at the cell level and 25 % at the module level (end 12/2022).
- The POSITIF project analyses the two-sided poly-Si passivated contact to go towards 24 % efficiency with bifacial Si cells (end 06/2021).

→ **Belgian Experts participate currently in 4 PVPS Tasks involving 11 separate entities as listed here**

INDUSTRY & MARKET DEVELOPMENT

The solar industry in Belgium is like the country: quite small but creative and specific. We have some BIPV companies such as Issol and Sunsoak, active in the architectural PV systems. There is a producer of modules, Evocells, making standard sized and shaped modules. Soltech and Reynaers are the two main companies focusing on embedded applications. Derbigum is specialized in integrated amorphous silicon.

New business models are developing through the emergence of energy communities and collective self-consumption. Their developments are still at too early stages to impact the market, however, their influence should grow in the coming years.

We observe a significant decrease in dynamic in the > 250 kWp segment of installations in 2021 (as in 2020). The residential market is growing again pushed by the pandemic situation and high prices of retailed electricity.

The market shows an increasing trend of the DC/AC ratio in all segments of systems. If a ratio of 1 was the rule until 2015, it increased to reach a 1.3 level, in average for all market segments, from 2017. Above 250 MWp it seems that a ratio of 2 becomes the rule.

The first forecast for the Belgium PV market at the end of 2021 indicates a cumulative installed PV capacity of approximatively 7 GWp. The installations from 2021 (0.85 GWp estimated) seems to have exceeded expectations (around 0.6 GWp forecast one year ago) as there was a main change in the support scheme in the north part of Belgium (Vlaanderen). It appears that the pandemic situation is an opportunity for PV in Belgium as residents with sufficient income to buy a solar system couldn't spend it on travelling and decided to invest.

The total value of 7 GWp is reached considering the upgrade of 2020 official data, the first 2021 partial data and the information collected from the Belgian inverter market. 73 % of the capacity is built in Flanders, 24 % in Wallonia and 3 % in Brussels.

The Belgian PV park is composed of more than 900 000 systems and characterized by a large share (98 %) of small systems (< 10 kVA). With 17 % of households owning a PV system, the total installed capacity reached an average of 612 Wp per inhabitant.

Nevertheless, small systems represent 66 % of the total installed capacity compared to 19 % for the commercial (10-250 kWp), 8 % for industrial (250-750 kWp) and 7 % for utility scale (> 750 kWp).

Belgian solar electricity production represents a share of 6.7 % of the total internal electricity consumption of Belgium (83 TWh) in 2021. The total electricity consumption improved by 1 % compared to 2020.

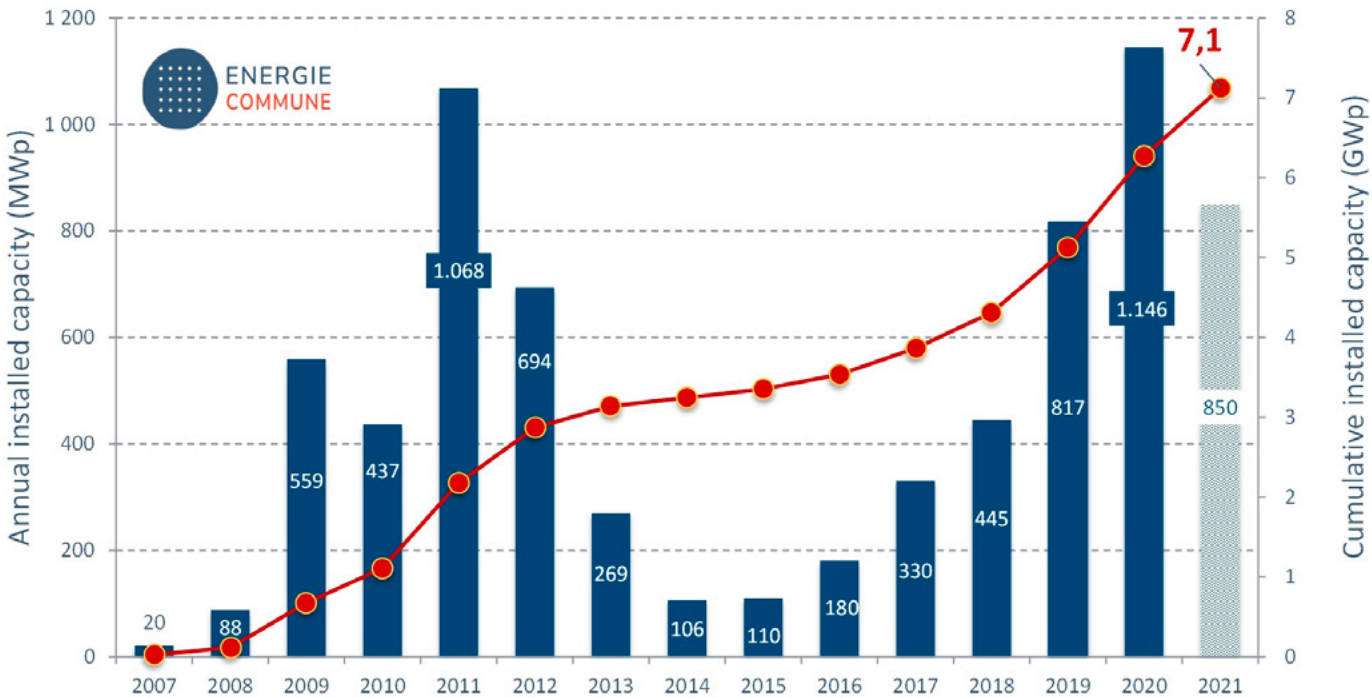


Fig.42 - Solar PV Power Capacity in Belgium, both annual installed (blue bars) cumulative installed (red line)

CANADA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig.43 - Suffield, Alberta, 23 MW PV array consisting of bifacial modules and single-axis trackers. Photo credit: Matt Schuett (BluEarth Renewables).

NATIONAL PV POLICY PROGRAMME

The development of the photovoltaic (PV) sector in Canada fits within the broader context of efforts to decarbonize the economy and address global heating. There are no specific capacity targets for PV set by the federal, provincial, or territorial governments. At the national level, PV is eligible for several federal support programmes including the $964 million Smart Renewables and Electrification Pathways Program (SREP), the $500 million Low Carbon Economy Fund, the $220 million Clean Energy for Rural and Remote Communities programme [1], and the $100 million Smart Grid programme [2]. At the household level, the Canada Greener Homes Grant provides rebates of $1000 per kW for a maximum system size of 5 kW [3]. The provinces and territories also implement their own local support policies such as feed-in tariffs, capital subsidies, self-consumption, and net metering. Several jurisdictions also offer Property-Assessed Clean Energy (PACE) programmes whereby PV system costs are repaid through property taxes. As of December 31, 2020, Canada's PV sector reached approximately 3.65 GW of installed capacity§. Much of the growth is in distribution-connected PV particularly in Alberta, Saskatchewan, Nova Scotia, and British Columbia. According to the Canada Energy Regulator, Canada's future PV capacity is expected to reach 20 GW by 2050 [4].

RESEARCH, DEVELOPMENT & DEMONSTRATION

Fundamental materials research into PV cell or module technology is conducted primarily through university and industry research groups, while research in the deployment and optimization of PV systems tends to be the purview of industry, local utilities and governmental institutions. At the Federal level, PV systems research and deployment occurs mainly through the Renewable Energy Integration (REI) program of CanmetENERGY in Varennes. To this end, the REI program conducts PV research activities related to the performance, durability, and cost of PV systems and components, as well as their integration into buildings and electricity grids. CanmetENERGY in Varennes also studies the integration of PV systems in remote Arctic communities in Nunavut, Yukon, Northwest Territories, and the northern Quebec region of Nunavik. Renewable energy deployment in these communities reduces diesel fuel dependence while working towards increased grid flexibility and energy storage options necessary for the integration of more renewable electricity sources. Other institutes leading PV research in Canada include Nergica, which studies snow accumulation on PV arrays and grid integration of renewable energy.

→ **Canadian Experts participate currently in 5 PVPS Tasks involving 6 separate entities as listed here**

§ All dollar amounts in this report are in Canadian currency (CAD). PV power estimates are in DC. Where conversion from AC to DC was required, a conversion coefficient of 0.85 was used.

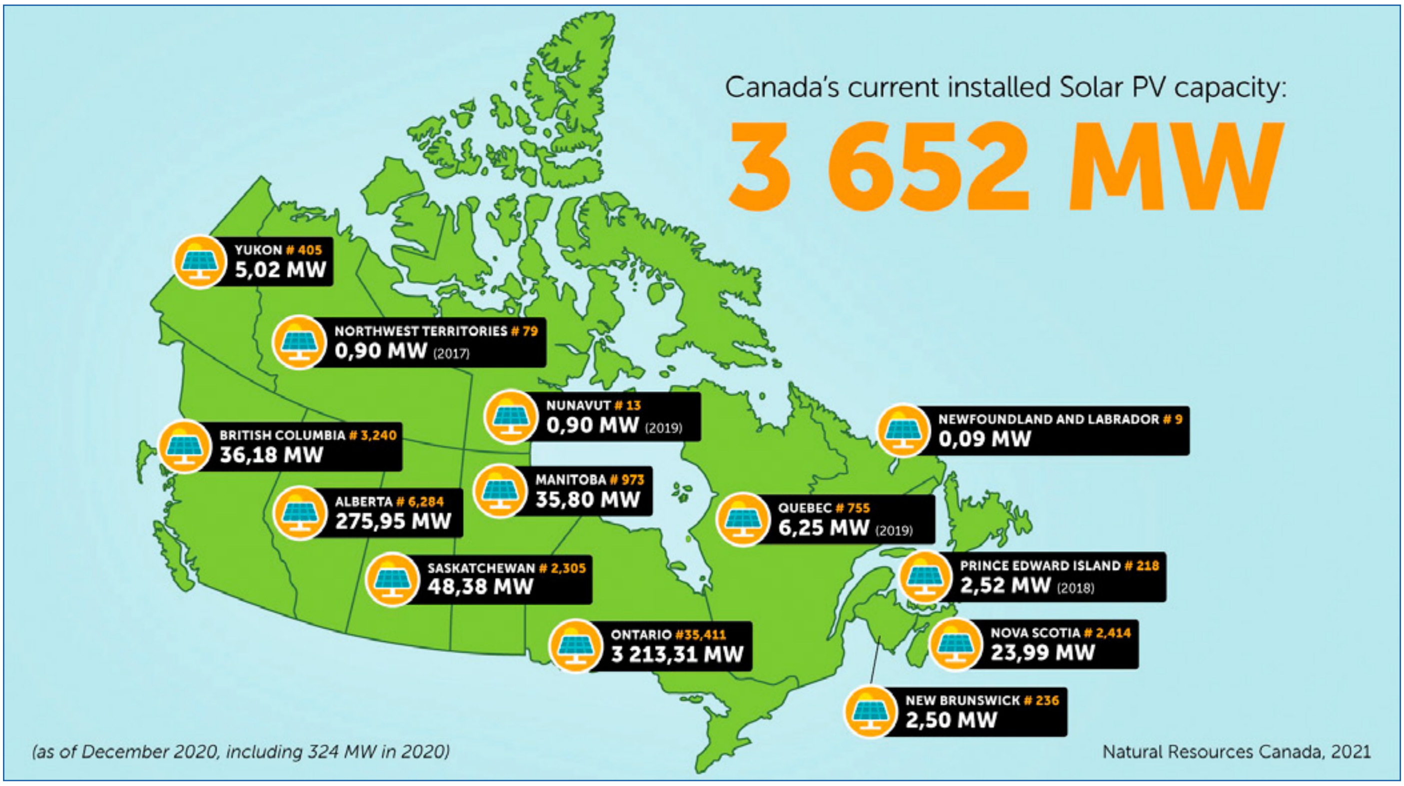

Fig.44 - Map showing PV power capacity (MW) as of December 31, 2020. This map is for illustrative purposes only and sizes or distance scales are approximate. Note: PV data for the Northwest Territories, Nunavut, Quebec, and Prince Edward Island were not available in 2020, and so values from previous years were reported. Estimated accuracy of nationwide capacity is ±3 %.

INDUSTRY & MARKET DEVELOPMENT

Approximately 85 % of Canada's cumulative 3.65 GW PV capacity is connected to the low/medium voltage distribution grid and the remaining 15 % connected to the high voltage transmission grid. A map of cumulative capacity nationwide is given in Figure 44.

The economic value of the Canadian PV industry in 2020 was approximately

$852 million

The combined number of full-time manufacturing, installation, distribution and research employment in this sector was conservatively estimated to be approximately 6000 jobs [5].

Examples of several large PV manufacturers in the Canadian market include Canadian Solar, Heliene and Silfab. Producers in the field of concentrating solar and sun-tracking systems include Stace and Morgan Solar [5]. Turnkey prices per Watt ($/W) in Canada were divided into two categories: rooftop (building-added PV) and ground-mounted systems. For small rooftop PV systems between 10 kW to 100 kW, prices were around 2.00 $/W to 2.50 $/W. Commercial roof-mounted PV from 100 kW to 250 kW in size varied between 1.80 $/W to 2.50 $/W. Small ground-mounted centralized arrays 1 MW to 20 MW in size varied from 1.60 $/W to 1.80 $/W [6]. Lower prices of around 1.25 $/W were achieved for utility scale PV larger than 20 MW.

CHINA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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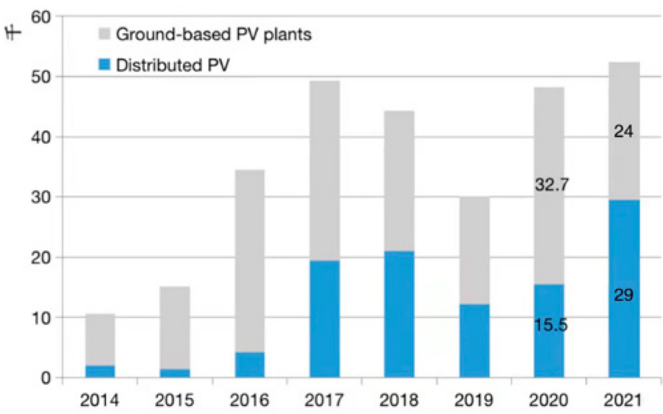

Fig.45 - China's annual new installed PV capacity (GW) [Source: CPIA]

NATIONAL PV POLICY PROGRAMME

At the 75th United Nations General Assembly on September 22nd 2020, President Xi Jinping confirmed China's commitment to peak CO_2 emissions before 2030 and reach Carbon Neutrality by 2060. In order to achieve these goals, China will vigorously develop the new energy industry. In the 14th Five-Year Plan (began 2021) and the following 15th Plan, China's PV and wind power sectors will achieve significant growth.

In June 2021, the National Energy Administration (NEA) began a project to promote roof-top PV in counties. The proportion of the total roof area of government buildings designated to distributed PV installations shall be at least 50 %, on public buildings such as schools and hospitals at least 40 %, on industrial and commercial plants at least 30 %, and on rural residences at least 20 %. In September 2021, the NEA released the list of pilot counties for this project, including 676 counties and cities in 31 provinces. The total scale is expected to exceed 160 GW. Since the policy stipulates a partial completion by 2023 the annual increase of distributed PV installations alone in China are expected to exceed 50 GW in the next three years.

Large-scale power plants will still be the main stream of PV development in China for a long term and will accelerate the energy transformation. Large-scale plants can rapidly expand the fleet of clean energy assets, improve power quality of generation and provide economic benefits, making them an effective way to achieve the carbon peak. Large-scale PV power station projects are mainly financed by several large stated-owned energy enterprises, along with the comprehensive development of wind, solar, hydro-power, thermal power and energy storage. The competitiveness of private enterprises is slightly insufficient. By the end of December 2021, the first batch of projects, about 75 GW of total 97 GW, were started and the remainder are to be started in Q1 2022.

On July 16, 2021, the National Carbon Market was launched in Beijing, Shanghai and Wuhan, and trading officially began. Before this official start, China had carried out 10 years of pilot trading in 7 cities. By June 2021, the cumulative trading volume of the pilot carbon markets had reached 480 million tons of CO_2 equivalent, with a turnover of about 11.4 billion yuan. The present round of carbon trading only includes the power generation industry but the market will expand to include other industries in the next 5 years (steel, nonferrous metals, petrochemical, chemical, building materials, electric power and aviation).

Since 2021, the total PV market quotas are controlled by the National Development and Reform Commission (NDRC) or NEA, and the PV installed capacities are arranged by provincial governments according to the "Mandatary Share of Non-Hydro Renewable Energy Power", issued by the NEA (similar to Renewable Portfolio Standards in western countries).

RESEARCH, DEVELOPMENT & DEMONSTRATION

"Photovoltaic +" has become a key direction for PV applications in China, including "complementary fishery PV", "complementary agricultural PV" and other application scenarios. Agricultural PV complementarity has certain requirements for the transparency of the system and components. Both the system design and the development of new semi-transparent components need to be strengthened.

In December 2021 the Chint Wenzhou 550 MW fishery PV complementary project was connected to the grid. It is a sea surface (Floating PV) technology project with large-scale sea beach and complex construction. The project combines fishery breeding and photovoltaic power to form a new "double-decker" water area development mode with power generation on top and fish culture underneath. It turns intensive and economical sea use into a reality and unifies economic, social and environmental benefits.

The combination of photovoltaics and transportation is also a major application direction of the future, which can take various forms. The usage of photovoltaics on a truck, the so-called "solar automobile" is now in use to energize the Beijing Winter Olympic Games.

China's first snow wax vehicle, made in Shandong, was officially put into use in the competition area of the Chongli cross-country skiing center. The vehicle has been in the full load working state of 24-hour continuous power supply, providing 200-300 pairs of snowboard waxing services every day, and there has never been power failure or interruption of use. The roof of the snow wax car is equipped with photovoltaic modules.

→ **Chinese Experts participate currently in 7 PVPS Tasks involving 7 separate entities as listed here**

INDUSTRY & MARKET DEVELOPMENT

President Xi Jinping's address to the UN in September 2020 stimulated the Chinese market and the installed capacity has increased dramatically since Q4 2020.

According to the NEA, the total PV annual installed capacity reached

53 GW in 2021

which is a 3.86 % increase compared with 2020.

The cumulative installed capacity has reached 306 GW. Both, the new and cumulative installed capacities remain the highest in the world. The Chinese PV market has been ranked world first for nine consecutive years in terms of annual installed capacity and seven consecutive years for cumulative installed capacity.

The new installed capacity of distributed PV reached 29 GW, accounting for 55 % of total new installed capacity. This represented an 87 % increase compared to 2020, showing that distributed PV is the new mainstream application in China. The residential fraction (21.5 GW) of this distributed PV capacity is also growing and becoming a crucial part of China's energy transformation.

In 2021, the cost of PV already fell to the level of grid-parity. This-means that from now on, with the exception of PV home systems which can receive 0.08 yuan/W, no PV projects will receive subsidies, and the grid companies will purchase PV electricity with the price the same as coal-fire power plants. It is estimated that the 2022 annual PV installation in China will be at least 75 GW.

As a result of the proposed new energy industry in the 14th Five-Year plan, photovoltaic companies are performing excellently in the stock market. In 2021, many well-known enterprises raised funds to expand their production, the top three being Tongwei Ltd. issuing 12 billion yuan of bonds, CMC Magnetics Corporation issuing 9 billion yuan of non-public shares and LONGi issuing 7 billion yuan of corporate bonds. China's poly-silicon production has ranked first in the world for 11 consecutive years and likewise with the module production for 15 consecutive years! China's photovoltaic industry is a powerful driving force.

The PERC cell technology is still the mainstream in the market (> 85 % in 2021), however the share of n-type technology is gradually increasing as the PERC cell efficiency reaches its limit. At present, the PERC capacity is reserved for upgrading production lines to the TOPCon technology, while the future expansion capacity mainly focuses on n-type technology.

During the COVID-19 pandemic, each link of the industrial PV supply chain was affected differently, which highlights the importance of scientific supply chain management. The ability to control the supply chain is becoming key to remaining competitive.

Silicon production belongs to the chemical industry and needs long-term expansion. Natural disasters or accidents lead to serious short-term supply shortages and the expansion of the PV industry has exacerbated the supply shortage somewhat. Thus, the price of silicon has continued to rise since 2020. According to China PV Industry Association, in the first nine months of 2021, the maximum price increase reached 165 %. After a short decline at the end of 2021, it will continue to rise in early 2022.

The photovoltaic glass industry, under the dual influence of national macro-control and the expansion of the PV market, is also in a tight balance. Due to the rise and fluctuation of prices in the middle and upper industrial chain, the photovoltaic glass price increased slightly and fluctuated during the second half of 2021.

Affected by the expansion of the PV industry, EVA particle material resources are in tight supply, with suppliers increasing the output of photovoltaic materials through substantial price increases of about 80 %. The EVA is in a tight balance with a price increase of approx. 49 % by the end of September 2021 and unlikely to fall given recent conditions.

TABLE 1

MARKET SECTOR	ANNUAL (MWP)	CUMULATIVE (MWP)	SHARE (%)
OFF-GRID		360	0.12
DISTRIBUTED	29000	107500	35.13
POWER PLANT	24000	198140	64.75
TOTAL	53000	306000	100.00

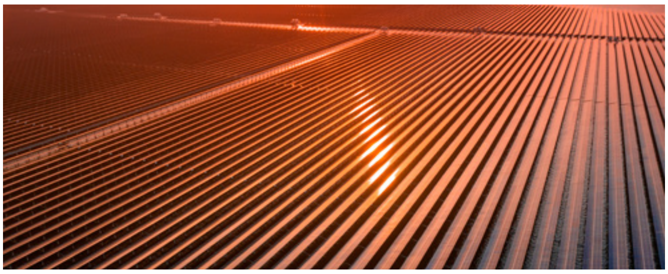

Fig.46 - Chint 550 MW complementary fishery + floating PV project [Source: Chint]

Fig.47 - China's Olympic PV snow wax truck'

DENMARK

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig.48 - Better Energy has built the largest solar park in Denmark. The solar park will supply Bestseller, Normal and Nemlig with new green energy. The plant has a capacity of 207 MWp installed.

NATIONAL PV POLICY PROGRAMME

Denmark has no unified national PV programme, but during 2021 a number of R.D.D. projects has been supported mainly by the Danish Energy Agency's EUDP programme. Some additional technology-oriented support programmes targeting R&D in the green energy transaction have been initiated.

Net-metering was established mid-1998, and is still in existence, however with consequent limitations and restrictions. In 2019, the new requirements for generating plants to be connected in parallel with distribution networks (EN 50549-1) were implemented with national specific requirements.

The number and total capacity of PV installations that do not apply for additional support but rather operate in the economically attractive "self-consumption mode" or sell electricity via the commercial market or PPAs is growing. Several commercial PV developers also have activities in deploying PV across the EU and internationally. The main potential for deployment of PV in Denmark are ground-based centralised PV systems in the range of 3 to > 200 MW and this segment has been growing dramatically. Mostly, the projects are based on commercial PPAs or selling power at the actual market price (Nordpool). The government's technology neutral auction scheme has given a push to this trend, although public concerns regarding large scale ground mounted PV parks are rising. In 2021 the technology neutral auction was cancelled, because no entities in the PV sector found it attractive to participate.

The Danish PSO system, has so far financed the grid investments in renewable energy capacity. Now a political decision to phase out this system has opened a discussion of the future financing of the grid in the green transition. Developers of both wind and PV projects claim that it will reduce the implementation of new capacity dramatically and set the targets of the green transition under pressure. Negotiations about this question are ongoing.

Five years ago, the Danish Energy Agency forecasted PV to reach 1.75 GW by 2020 (5 % of the annual electricity consumption) and more than 3 GW by 2025. These figures are periodically revised. The national TSO, Energinet.dk, has informed, that about 5 GW of PV can be grid connected in Denmark with only minor network problems, but they are aware of 18 GW PV plants already in planning. In Figure 49 the Prognoses from the Danish Energy Agency for the future PV deployment shows an estimate of 11 GW by 2035.

In 2020 a capacity map was launched as a website. It is a dialogue tool that supports optimal placement of new renewable energy systems in relation to the electricity grid. The capacity map shows with a Production Map the currently available capacity in the electricity grid for connection and full integration of new electricity production in the 50-60 kV and 132-150 kV grid. Figure 50 shows with the green areas where there is available capacity in the grid for new RE to be connected.

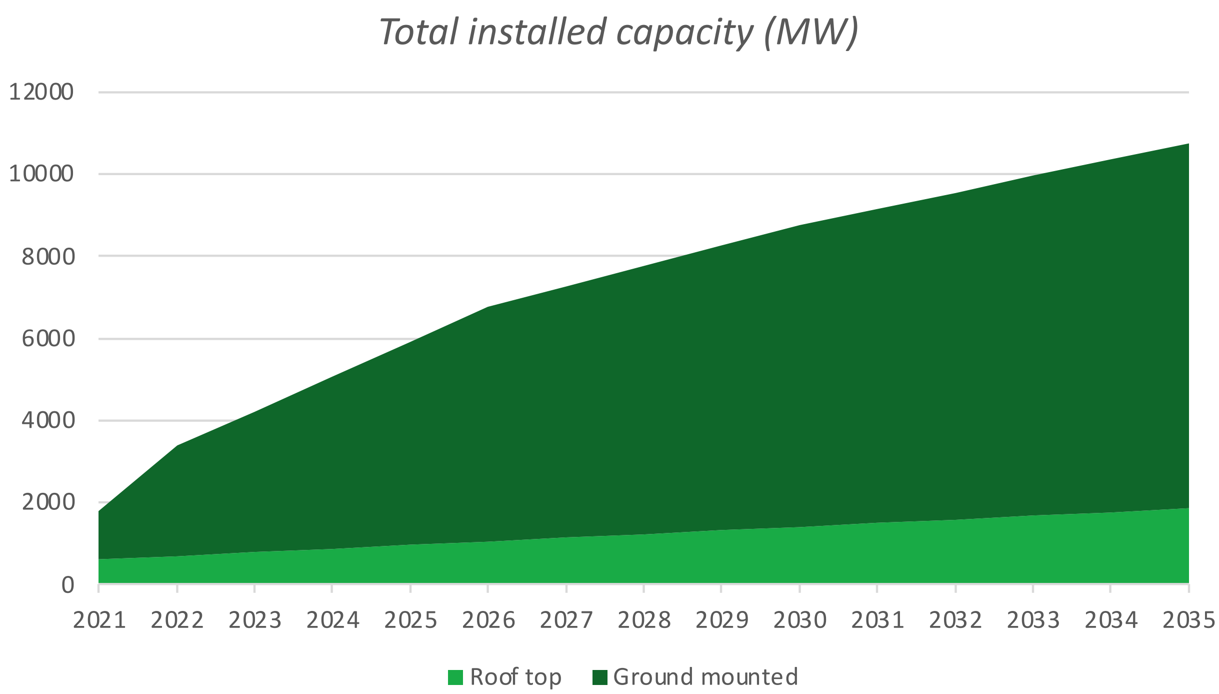

Fig.49 - 2022 Prognoses from the Danish Energy Agency

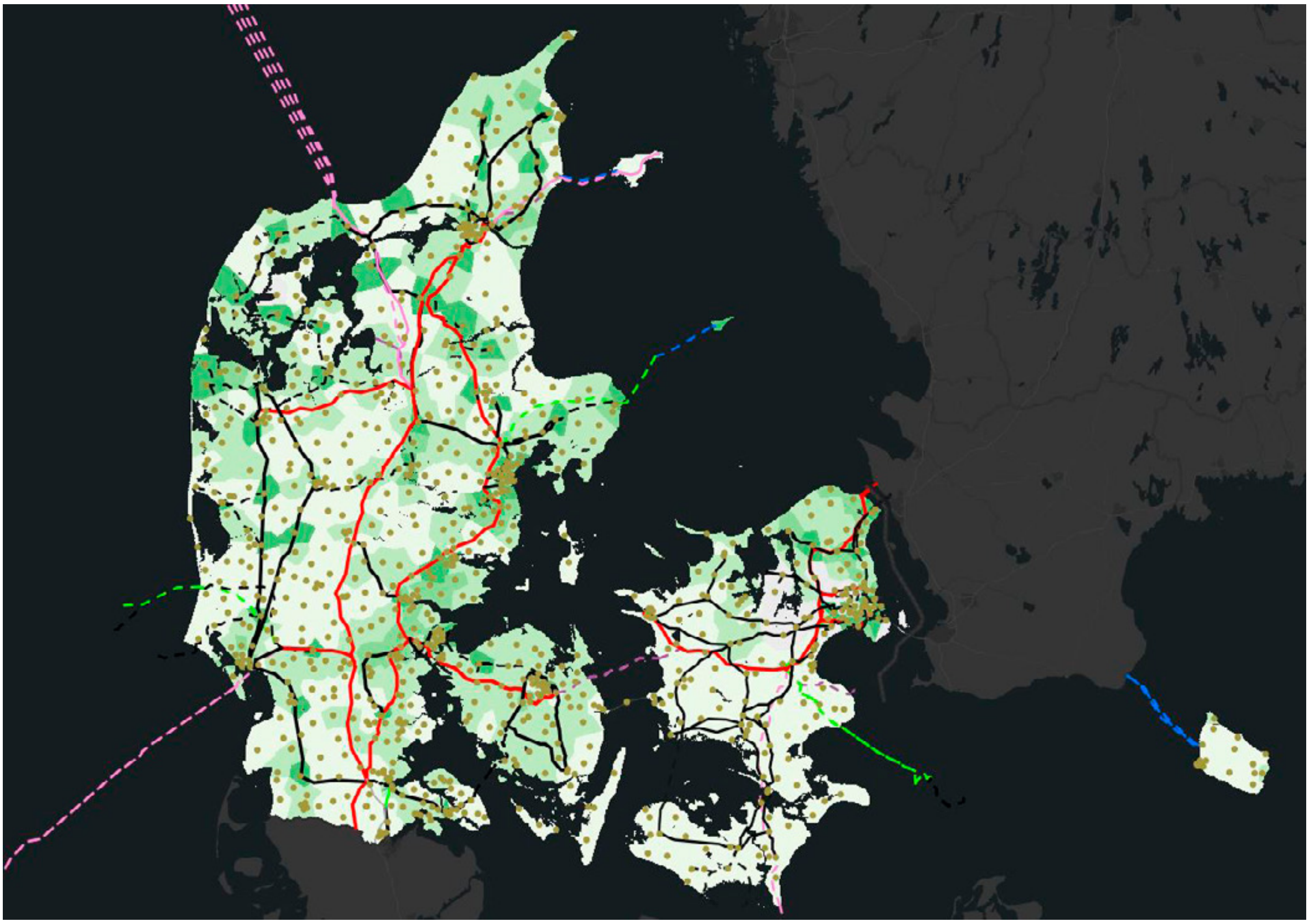

Fig.50 - Capacity map.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The national Energy Research and Development Programmes have a webside https://energiforskning.dk/en where general information about three programs can be found as well as the link to the specific R,D&D support scheme. It is also possible to see information about ongoing and former R&D projects.

The Energy Technology Development and Demonstration Programme (EUDP) under The Danish Energy Agency funds work by enterprises and universities on demonstration of new green energy technologies. The program supports different PV related projects each year. The R&D program as well as the ongoing and ended PV related projects can be found at the EUDP webpage https://www.eudp.dk/en/om-eudp.

The strategic innovation topics in the EUDP program are:

1. More green electricity and for more purposes
2. Increased energy efficiencies
3. Personal and light freight transportation
4. Heavy transport and Power-to-X in large scale
5. Heat and heat storage
6. Green process energy
7. Flexible use of electricity, grid extension and digitalization
8. Carbon capture, storage and use

ELFORSK - DANISH ENERGY ASSOCIATION

ELFORSK supports projects that ensure a more efficient use of electricity by end-users. The projects are located in a wide range within the value chain from applied research through development forward to deployment.

Innovation Fund Denmark under the Ministry of Education and Research creates a framework for entrepreneurs, researchers and businesses so they can develop innovative and viable solutions to society's challenges.

→ **Danish Experts participate currently in 5 PVPS Tasks involving 5 separate entities as listed here**

Fig.51 - Haarup Maskinfabrik. The installed 1 MW PV system can supply all the electricity needed in the factory. Batteries with a capacity of 943 kWh improve the self-consumption from the solar plant. For more detailed information see Green transition (haarup.com)

INDUSTRY & MARKET DEVELOPMENT

The Danish PV Association, established late 2008 with approximately 30 members, has provided the emerging PV industry with a single voice and is introducing ethical guidelines for its members.

In 2020, the association formulated a new and ambitious strategy based on the political

target for 2030

with a reduction of the CO_2 emissions by 70 %

In this plan, green electricity will play an important role and therefore the Danish PV Association expects the cumulative capacity of PV in 2030 will be ten times more than in 2019.

A few Danish PV manufacturing companies exist, for example producing tailor-made modules such as window-integrated PV cells. A Li-Ion battery manufacturer and a vanadium redox flow battery (VFB) manufacturer are now engaged in the PV market and are offering storage solutions. A few companies develop and produce power electronics for PV, mainly for stand-alone systems for the remote-professional market sector such as telecoms, navigational aids, vaccine refrigeration and telemetry. A growing number of companies are acting as PV system developers or integrators designing, developing and implementing PV systems for the home market and increasingly at the international level.

Danish investors have entered the international PV scene on a rising scale acting as international PV developers/owners of large scale PV farms. In 2021 six of these PV developers established Dansk Solkraft as an organization with the main focus on the utility scale market. Some the members of this organization have activities inside and outside Denmark and do also have activities in the wind sector and in the power to gas sector.

Consultant engineering companies specializing in PV applications in emerging markets report a gradually increasing business volume.

The political target of 70 % reduction in carbon emissions by 2030 has pushed the PV system market forward. The dramatic increase in electricity prices for all consumers during 2021 has further boosted the market.

The national green transition and the ambitious governmental target for CO_2 reductions have the consequence of doubling the forecast for Danish electricity consumption in 2030. This placed pressure on the grid operators due to connection of several GW capacity wind and solar parks as well as establishing thousands of electric vehicle charging systems, which demanded significant resources, both monetary and personnel.

The latest official market statistic in Denmark is from 1st October 2021, at which point the total installed capacity was 1.532 GW. With a DC/AC capacity factor of 1.3 the estimated total power is approx. 2 GW.

EUROPEAN COMMISSION

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Maria GETSIOU (European Commission, Directorate-General for Research & Innovation); Giulio VOLPI (European Commission, Directorate-General for Energy)

NATIONAL PV POLICY PROGRAMME

2021 marked a shift in the European Union from setting out a comprehensive vision for the transition to climate neutrality (e.g. the European Green Deal) and its supporting sectoral strategies, to proposing and implementing the resulting initiatives. Key moments in this regard were the adoption of the European Climate Law in June and the presentation of the "Delivering the European Green Deal" (so-called 'fit for 55') package in July 2021 [1]. The adoption of the European Climate Law established a clear binding framework to achieve climate neutrality by 2050, which fully enshrines the 2030 target of at least 55 % greenhouse gas reductions presented in the 2030 Climate Target Plan and relies on Member States' National Energy and Climate Plans (NECPs). Supporting the path set out in the Climate Law, the pioneer "Delivering the European Green Deal" package presented a set of interconnected proposals across the economy increasing the 2030 ambition, among others, by setting new targets for GHG emissions reduction and for renewables and energy efficiency.

In that context, the European Commission proposed to raise the

EU 2030 target

for renewable energy from the current

32 % to at least 40 %

of the Union's gross final consumption of energy [2]

while promoting renewable energy deployment across all sectors of the economy. The Commission also proposed raising energy efficiency targets at EU level and making them binding, to ensure overall reductions of 36 % for final energy consumption and of 39 % for primary energy consumption by 2030.

Increasing ambition and delivering on decarbonisation is also about achieving the existing 2020 target for renewables. Member States are to submit by 30 April 2022 data on whether the 2020 renewable energy targets were achieved. The latest available data (2019) and current projections indicate that the EU as a whole, and the majority of Member States individually, were on track to achieve the renewables targets, thanks partly to the lowering prices for key technologies such as wind and solar over the last 10 years. In particular, the cost of PV modules has decreased dramatically in recent years. Analysing the global evolution of module price vs. cumulative production,

A price decrease of 25 %

is inferred for each doubling of cumulative production.

In the period from

2011 to 2020

an 85 % price decrease

has been recorded

Overall investment in renewables grew substantially in the EU to 48.8 BEUR in 2020, from 32.9 BEUR in 2019. However, the picture varied across the different technologies: annual additional capacity declined from 8.4 to 7.1 GW for onshore wind, but increased from 1.5 GW to 2.5 GW for offshore wind and from 16.3 GW to 18.6 GW for solar photovoltaic (PV) energy.

To further support innovation and deployment in solar technologies, the Commission will work in 2022 on an EU Solar Energy Strategy. The work will focus on the existing barriers that are hampering the deployment of solar energy capacity required by 2030 and by 2050 and the conditions that will enable such deployment.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Horizon Europe is the new EU Framework Programme for research and innovation (2021-2027) [3] with a budget of 95.5 BEURO. The first Work Programme 2021-2022 on "Climate, Energy and Mobility" under the "Destination" Sustainable, secure and competitive energy supply includes inter alia activities in the area of renewable energy. Under this destination, R&I on Photovoltaics concentrated on the following research priorities with a budget of 167 MEURO.

1. Novel tandem, high efficiency Photovoltaic technologies targeting low cost production with earth abundant materials, developing novel concepts that optimise cell architecture, decrease losses and target very high efficiencies.
2. Stable high-performance Perovskite Photovoltaics, to research and resolve the degradation issues/mechanisms and produce stable and highly efficient perovskite PV architectures with the aim to increase the commercialisation potential of perovskite PV.
3. Innovative foundations, floating substructures and connection systems for floating PV and ocean energy devices to improve overall life time, reliability, installability, operability and maintainability of marine substructures for ocean energy and offshore floating PV.
4. Demonstration pilot lines for alternative and innovative PV technologies (Novel c-Si tandem, thin film tandem, bifacial, CPV, etc.) to promote a considerable pipeline of new and advanced versions of existing technologies from lab to fab production, enabling robust continued performance increase, opening up new applications and facilitating further cost reduction.
5. Advanced manufacturing of integrated PV to demonstrate flexible automated manufacturing for differentiated product designs at competitive costs in conformity with codes and standards of IPV use.
6. Novel Agro-Photovoltaic systems to increase land-use efficiency and enable PV capacity to be expanded solving the problem of energy poverty in the agricultural sector, while still retaining fertile arable areas for agriculture.
7. Novel Thin Film (TF) technologies targeting high efficiencies based on environmentally benign processing and architectures aiming at high efficiencies with flexibility for specific applications.
8. Recycling end of life PV modules to develop recycling technologies depending on the typologies of solar modules and reverse logistics, increase recyclability and reduce the environmental impact of PV.

In addition, a "Clean Energy Transition Partnership" was launched to support collaboration among Member States and Associated Countries on research programmes supporting clean energy technologies and their integration.

→ EU Experts participate currently in 3 PVPS Tasks involving 2 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

The EU is a global leader in several parts of the photovoltaic value chain: research and development, polysilicon production, equipment and machinery for PV manufacturing. The EU hosts one of the leading polysilicon manufacturers. Furthermore, EU companies are more competitive in the downstream part of the value chain with key roles in the monitoring and control, and balance of system segments, especially inverter and solar trackers manufacturing. European companies have also maintained a leading position in the deployment segment. A recent study [4] shows that the EU has the best performance in terms of the energy produced compared to that used in manufacturing and operating photovoltaic systems, followed by China and the US. Similarly, the EU also has the lowest carbon intensity for the energy produced by PV systems, followed by USA and then China. The EU also has the highest energy return on carbon. This latter indicator reflects the carbon intensity of the production cycle of the electricity used in the manufacturing processes.

In 2018, 109 000 direct and indirect jobs in photovoltaics are reported in the EU, with a 42 % increase between 2015 and 2018 [5]. The preliminary results of a more recent study indicate about 123 000 direct and 164 000 indirect full-time jobs in the EU PV industry, in 2020, for a total of 287 000 jobs [6]. From the job skills perspective, the photovoltaic sector employs a highly educated work force in the areas of R&D, polysilicon and wafer production and cells and module manufacturing. EPC (engineering, procurement and construction), O&M (operation and maintenance), decommissioning and recycling are also demanding activities in terms of skills required.

With the increase of PV system installations, the trade deficit for the EU for the import of solar modules has started to increase again since 2016, after it had declined between 2011 and 2016, due to a shrinking deployment of PV systems. It has grown to more than EUR 5.7 billion in 2019. This imbalance reflects the volume of the imports, as the exports have not changed dramatically over the years. EU solar photovoltaic imports are strongly dependent on Chinese and other Asian companies [7]. The polysilicon, ingots, and wafer production together with the solar cells and modules manufacturing currently have a global value of about 57.8 BEURO. The EU's share (12.8 %) corresponds to 7.4 BEURO. This share is mostly due to the polysilicon production. Almost all of the growth in manufacturing of photovoltaic cells and modules has taken place outside the EU [8]. With market demand accelerating in Europe and around the world, and new production technologies emerging, European manufacturers are showing a renewed interest in setting up production capacity within the EU based on the latest technologies. Several projects are already taking off in the EU for manufacturing wafers, solar cells and modules.

REFERENCES

[1] Delivering the European Green Deal
[2] Q and A on Making Energy System Fit
[3] Horizon Europe Work Programme 2021-2022
[4] F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 11123
[5] JRC 2021, based on EurObserv'ER data
[6] Solar Power Europe, Solar PV job market study for the European Union
[7] EU Energy Technology Trade
[8] JRC PV Snapshot 2021

FINLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Karin Wikman (Innovation Funding Agency Business Finland)

Fig.52 - LUT two-axis tracking solar PV system (Photo: Teemu Leinonen)

NATIONAL PV POLICY PROGRAMME

Finland has an objective to become a greenhouse gas neutral society by 2035. In the energy sector, the challenge of transformation is particularly great. Approximately three-quarters of all greenhouse gas emissions in Finland come from heating, power generation, and direct fossil fuel consumption, when energy use in transportation is included. One of the main solutions to achieve the objective is direct and indirect electrification of energy use with emission-free electricity. In addition, actions to increase the amount of negative CO2 emissions by forest-based carbon sinks are considered.

There is no specific national strategy nor objectives for photovoltaic power generation in Finland. Instead, 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, wind power and solar PV are currently the least cost options for the electric power generation in Finland. To support PV installations, the Ministry of Employment and the Economy and Business Finland grant investment subsidies to renewable energy production. In 2020, a total of 6.6 MEUR investment subsidies for 308 PV installations were granted. The support is only intended for companies, communities and public organizations, and it is provisioned based on applications. The subsidy level has been 20 % 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 up to 40 % of the total work cost, including taxes resulting up to about 1015 % of the total PV system's costs.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In Finland, the research and development activities on solar PV are spread out over a wide array of universities.

- Academic applied research related to solar economy, solar PV systems, grid integration, power electronics, and condition monitoring is conducted at Aalto University, Lappeenranta-Lahti University of Technology and Tampere University, as well as at Metropolia, Satakunta and Turku Universities of Applied Sciences.
- There is 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.
- There are research groups working on perovskite solar cells, organic photovoltaic (OPV) and atomic layer deposition (ALD) technologies at Aalto University and the Universities of Helsinki and Jyväskylä.

The research work at universities is mainly funded by the Academy of Finland and Business Finland, which also finance 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.

→ **Finnish Experts participate currently in 3 PVPS Tasks involving 3 separate entities as listed here**

INDUSTRY & MARKET DEVELOPMENT

For a long time, the Finnish PV market was 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 an off-grid PV system 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 ground-mounted solar PV plant, with the total power of 6 MW, was built in Finland during years 2017-2019 in Nurmo.

By the end of **2020**,

the installed grid-connected PV capacity was estimated to be approximately

300 MW **and the number of PV plants**

more than 30 000

In 2020,

hourly net-metering and energy communities were legislated in Finland. These both are expected to impact positively on the number of PV installations in coming years.

FRANCE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Melodie de l'Epine, Damien Salel (Association HESPUL for ADEME)

NATIONAL PV POLICY PROGRAMME

The framework for developing photovoltaic policies in France falls within the long term National Low Carbon Strategy (SNBC, 2050 horizon) and the 10-year Energy Programme Decree (PPE). The current PPE, published in 2020, targets 3 GW to 5 GW per year new capacity, to reach 20 GW by 2023 and 35 GW to 44 GW by 2028. The PPE authorizes competitive tenders as the preferred mechanism to reach these goals if market forces are insufficient.

The government has signalled a real desire to meet the PPE targets, publishing an Action Plan in November to accelerate the development of photovoltaics. This plan includes a possible feed in tariff for ground based systems under 500 kW on wasteland, 1 000 projects on public land and buildings, a reduction in upfront grid connection costs and simplifications to administrative procedures.

The Climate and Resilience Law passed in August 2021 included dispositions for the regionalization of the PPE targets by local authorities, in coherence with other climate planning documents. In 2021, photovoltaics contributed between 2 % and 3 % of electricity production in France.

This law also tightened the mandatory solar or living roofs rules on new buildings, starting at 500 m2, down from the previous year's 1000 m2. It now applies to previously exempted buildings such as offices, heavily renovated buildings and some parking areas. Solar parks were also classified as permeable surfaces, exempting them from restrictions on the creation of new impermeable surfaces.

A new series of competitive tenders was launched – called the PPE2 tenders – with a total of 17.35 GW to be called through to 2026 (see Table 2). Remuneration is in the form of feed in premiums (or a self-consumption bonus). Bonus points are awarded to projects with crowdfunding or citizen investment, making them more competitive in the process. Eligibility conditions include having planning permission and a carbon footprint for modules below 550 kg CO_2/kWc (450 kg CO_2/kWc in the Innovation tender).

Announced as far back as 2020, the publication in early October of the much-awaited feed in tariffs for systems up to 500 kW on buildings, greenhouses and parking canopies led to a 100 % quarter on quarter increase in requests for grid connection. The new framework includes differentiated tariffs depending on system size and lump sums for smaller self-consumption systems as well as specific building integrated products. Systems may now participate in collective self-consumption projects, and changes have improved access to tariffs for systems on publicly owned buildings. France continues to push low impact modules, with a 550 kg CO_2/kW maximum carbon footprint for modules in systems over 100 kW. See Table 3 for feed in tariff levels.

TABLE 2: COMPETITIVE TENDERS, ELIGIBLE SYSTEMS AND VOLUME CAPS

SYSTEM TYPE AND SIZE	BUILDING MOUNTED SYSTEMS INCLUDING GREENHOUSES AND PARKING CANOPIES	GROUND BASED SYSTEMS	SELF CONSUMPTION*	BUILDING MOUNTED INNOVAIVE SOLAR SYSTEMS	GROUND BASED INNOVAIVE SOLAR SYSTEMS	TECHNOLOGY NEUTRAL*
INDIVIDUAL SYSTEM SIZE LIMITS	From 0.5 MW No upper limit	0.5 MW to 30 MW No upper limit on degraded sites	0.5 MW to 10 MW	0.1 MW to 3 MW	0.5 MW to 3 MW	
VOLUME	4.2 GW to 5.6 GW in 14 calls of 300 MW to 400 MW	9.25 GW in 10 calls of 925 MW	0.7 GW in 14 calls of 50 MW	0.4 GW in 5 calls of 80 MW	0.3 GW in 5 calls of 60 MW	2.5 GW in 5 calls of 500 MW
MOST RECENT AVERAGE TENDER PRICE	2021: 76.66 EUR/MWh	2021: 56.65 EUR/MWh	2021: 10.45 EUR/MWh			

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

RESEARCH, DEVELOPMENT & DEMONSTRATION

Research and Development for photovoltaics in France ranges from fundamental materials science to pre-market development and process optimization, to social sciences.

The National Alliance for the Coordination of Research for Energy (ANCRE) is an alliance of 19 different research or tertiary education organizations, with the goal of coordinating national energy research efforts and ensuring alignment with the National Energy Research Strategy. Members include the CEA (Atomic Energy and Alternative Energies Commission) and the CNRS (National Centre for Scientific Research), whilst the research financing agencies ADEME (Agency for Ecological Transition) and ANR (National Research Agency) are members of the coordination committee.

France's public financing of Research and Development for photovoltaics increased to 76 million euros (+12 % in 2020) after decreasing steadily from 2015 to 2019, with a similar budget reserved for storage and general electricity subjects, but equivalent to only 10 % of the budget going to research on nuclear energy (fusion and fission).

The "Institut Photovoltaïque d'Ile-de-France" (IPVF) and the "Institut National de l'Energie Solaire" (INES), the major research centers, are equipped with industrial research platforms and collaborate with laboratories and industrials across France and Europe.

IPVF works across a number of fields both industrial and upstream, including a solar-to-fuel program, work on perovskite, on silicon tandem modules, III/V on silicon tandem cells.

INES works with industrial partners on subjects ranging from building integration components to grid integration and storage technologies and smart management, as well as fundamental research on silicon and cell technologies and applied research on module technologies. Recent work includes the commissioning of a linear (vertical) PV system on the Rhône banks with CNR, scaling up Enel's bifacial heterojunction manufacturing lines and creating the first bio-based and 100 % recyclable photovoltaic panels with an industrial partner.

The principal state agencies that are financing research are:

- The National Research Agency (ANR), which finances projects through topic-specific and generic calls and also through tax credits for internal company research.
- The French Agency for Ecological Transition (ADEME) runs its own calls for R&D on renewable energies and supports PhD students. They are the French relay for the IEA PVPS and SOLAR-ERA.net pan-European network.

→ **French Experts participate currently in 6 PVPS Tasks involving 16 separate entities as listed here**

3 GW commissioned in 2021 for a cumulative

total of 16 GW

New feed in tariffs up to 500 kW and new competitive tenders launched

400 % **quarter on quarter Q4 increase in new projects from**

100 kW to 250 kW

INDUSTRY & MARKET DEVELOPMENT

Current applications for photovoltaics in France are mostly segmented between systems on buildings (from residential to industrial), parking canopies and ground based systems. The Innovation competitive tenders have enabled the development of products and expertise by local industry in growing markets such as floating PV and agrivoltaics.

Majors players include local multi-energy giants such as Engie, TotalEnergies and EDF but also independent RES operators such as Technique Solaire, and cross-overs from the wind industry. The competitive cost of photovoltaics, easier permitting (compared to wind) and rising demand for long-term power purchase agreements to safeguard rising electricity costs has reinforced financing and brokering services, and seen the development of the country's first multi-MW ground-based systems with no form of public support.

Social housing clusters and local authorities led experimental collective self-consumption programs to test business models and project methodologies, and obtained legislative changes facilitating projects. Complex energy tax laws are still seen as a barrier to a more widespread deployment.

As project volumes rise, growing tensions have appeared on the labour market, with a dearth of trained personnel in prospection, design, installation and operations and maintenance. Regional public/private training initiatives have been developed, accompanied by the reinforcement and creation of regional networks, but are not expected to be sufficient to meet demand.

Overall grid-connected volumes grew by an estimated 3.3 GW DC (1300 MW DC in 2020 and 1100 MW DC in 2019). Nearly 70 % of the newly installed capacity was for systems over 250 kW, with a further 15 % in the 36 kW to 100 kW segment. Total installed capacity is expected to top 16 GW DC, with 3.5 GW DC for the year, nearly triple the roughly 1 GW per year seen since 2014. Industry actors cite a number of factors – last commissioning deadlines for winning bids in the 2017 competitive tenders, catch-up on projects delayed due to the first COVID shutdowns, the steady rise in material costs that incentivized fast-tracking projects and a structural rise in investments.

Grid connection requests (i.e. late stage projects) also rose, especially in the 4th quarter for systems between 100 kW and 250 kW – where project volumes increased fivefold. This increase was largely due to the backlog of projects waiting on the publication of the new support mechanism (switch from competitive tenders to a feed in tariff with no volume caps). These projects do not seem to have impacted volumes in other segments, mobilizing previously unexploited buildings. The stock of projects with ongoing grid requests remains high, from 8 to 11 GW depending on the source, so similar volumes – 2.5 GW to 4 GW - are expected in 2022 – if no major supply issues are encountered.

TABLE 3: FEED IN TARIFFS FOR INSTALLATIONS UNDER 500 KW

POWER OF PV INSTALLATION (KW)	FEED IN TARIFF NO SELF-CONSUMPTION (TA,B,C)	FEED IN TARIFF FOR PARTIAL SELF-CONSUMPTION AND BONUS (PA,B)	BONUS FOR CERTIFIED BUILDING INTEGRATION PRODUCTS (PINT)
≤3 kW	178.9 EUR/MWh	100 EUR/MWh (+0.38 EUR/W installed)	0.238 EUR/W installed
3 kW to 9 kW	152.1 EUR/MWh	100 EUR/MWh (+0.29 EUR/W installed)	
9 kW to 36 kW	108.9 EUR/MWh	60 EUR/MWh (+0.16 EUR/W installed)	
36 kW to 100 kW	94.7 EUR/MWh	60 EUR/MWh (+0.08 EUR/W installed)	
100 KW to 500 KW	98 EUR/MWh	98 EUR/MWh	< 250 kW : 0.235 EUR/W installed < 500 kW : 0.233 EUR/W installed

REFERENCES

[Data has been compiled from Enedis Opendata, French government and ministerial data services (SDES, Data Lab).

Official French market volume data is collected in AC power. For the purposes of this report and in keeping with IEA PVPS practice it has been converted to DC power using a standard ratio of 1.2. Energy prices and competitive tender volumes have been left as reported in France. National reporting indicates 2.8 GW AC new volume in 2021 for a cumulative total of 14 GW AC.

GERMANY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Klaus Prume; Christoph Hünnekes; Projektträger Jülich (PtJ); Forschungszentrum Jülich GmbH

NATIONAL PV POLICY PROGRAMME

The new German government announced an immediate action climate protection programme. By 2030, a near tripling of the current pace of emissions reductions must be achieved to meet the climate targets [1]. The implementation of this climate protection programme allows shaping the energy transition in an economically growth-friendly and socially responsible way. However, the target triangle of security of supply, environmental compatibility and affordability remains the guiding principle of energy policy [2].

As Germany will stop nuclear power production in 2022 and is ready to phase out all coal-fired power plants

by 2030

renewable electricity from wind and solar power plants will become the central building block for an energy system

without fossil fuels

Against this background, the new German government is undertaking its joint mission to drastically accelerate the expansion of renewable energies and to remove all obstacles and barriers. In photovoltaics, the goal is to increase the installed capacity from the current level of approximately 54 GW to 200 GW by 2030.

Furthermore, a core element for a green energy system is the availability of hydrogen produced from renewable energy sources like solar and wind. The German government foresees a hydrogen demand of approx. 90 to 110 TWh by 2030 [3]. To meet a significant part of this demand by domestic production, renewables with a total capacity of up to 5 GW are to be built in Germany by 2030. This corresponds to a green hydrogen production of up to 14 TWh and a required renewable electricity volume of up to 20 TWh [3].

As a main backing of the development, the European Commission has largely approved the amendment to the Renewable Energy Sources Act (EEG 2021). Thus, tenders for wind turbines and solar installations can take place from 2022 onwards with significantly increased tender volumes. In 2021 the solar tender volume was nearly 2 GW of capacity and will increase to 4.8 GW.

Renewables are now more competitive than ever before and hence the number of large ground-mounted systems proceeding without support of an EEG subsidy is increasing. The electricity generated by these systems is marketed directly via PPAs (Power Purchase Agreements). Approximately 0.5 GW capacity of PPA-marketed systems are already in operation and approx. 4 GW capacity of new plants are currently under planning.

A further adjustment to the EEG enables plant operators to pay local municipalities a bonus. The aim is to foster greater acceptance of ground-mounted photovoltaic systems among citizens and municipalities. To this end, the plant operator can voluntarily pay up to 0.2 EURcent/kWh generated to the municipalities in which a plant is erected and which are directly affected by its construction (§6 EEG 2021).

RESEARCH, DEVELOPMENT & DEMONSTRATION

The 7th Energy Research Programme entitled "Innovations for the Energy Transition" [4] came into force in September 2018. It still defines the guidelines for energy research funding. In the context of the programme, the Federal Government earmarked around 6.4 BEUR for research, development, demonstration and testing of sustainable energy technologies and concepts.

In conjunction with the Energy Research Programme, the BMWK (Federal Ministry for Economic Affairs and Climate Action) released in June 2021 an updated call for tenders, which reflects the targets of the programme. Concerning PV, the call still addresses five specific focal points, which are all connected to applied research:

- Efficient production and process technologies to increase performances and reduce costs for Silicon wafer and thin film technologies
- Quality and reliability issues of PV components and systems
- New PV materials and cell concepts (e.g. tandem Silicon / Perovskite solar cells)
- Cross-cutting issues like Building Integrated PV (BIPV), Vehicle-integrated PV (ViPV) or avoidance of hazardous materials and recycling of PV systems,
- Innovative system technologies for both, grid-connection and island PV plants.

Within this broad approach, the 2021 focus areas were again on silicon-perovskite tandem solar cells, technology development for the industrialization of bigger silicon wafer formats and operation and maintenance of PV plants.

The development of funding activities over recent years is shown in Figure 53. In 2021, the BMWK support for R&D projects on PV amounted to about 84 MEUR shared by 494 projects in total.

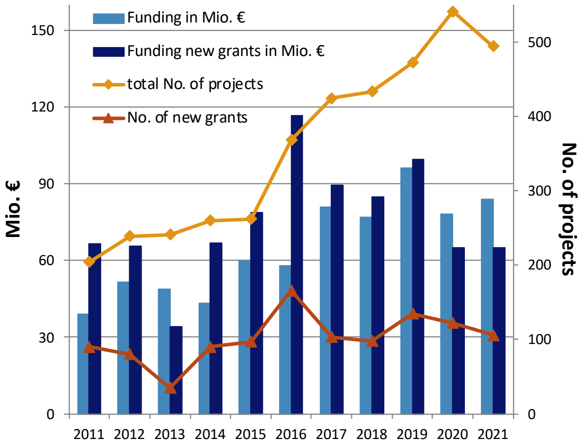

Fig.53 - R&D support and quantity of PV projects funded by BMWK in the 6th and 7th EFP.

Fig.54 - PV Park built on a landfill site.

That year, 106 new grants were contracted. The funding for these projects amounts to 65 MEUR in total. Highlights of research projects can be found on the programmes webpage [5].

The funding activities are complemented by strategic measures: A consultation process to review the focus of the funding measures took place in 2020 / 2021 within the BMWK research network on renewable energies. The results were presented at a workshop with participants from industry and research institutes in January 2021. From March 2021 onwards, an additional working group within this network was formed to focus on nontechnical topics. Finally, a workshop with industry and research addressed issues of the service life and reliability of PV inverters end of 2021.

→ German Experts participate currently in 8 PVPS Tasks involving 12 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

In 2021, renewable energies covered around 42 % of electricity consumption in Germany - less than in the previous year, which was special because of COVID-19 pandemic effects.

Nevertheless, the market of photovoltaic systems in Germany has grown steadily over the past seven years. In 2021, a total of 5.2 GW of photovoltaic capacity was newly installed, which corresponds to a total capacity of 59.4 GW of PV power plants.

The levelized cost of electricity (LCOE) of photovoltaic systems in Germany ranges from 3.12 to 11.01 EURcent /kWh, depending on the system type and location, while the specific peak power systems costs range from 530 to 1600 EUR/kW, depending on the system type [6]. This corresponds very well with the surcharge prices for tenders for free-field power plants (1.6 GW, 5.0 EURcent/kWh) and large rooftop plants (0.3 GW, 6.9 EURcent/kWh).

The low LCOE and the sharp rise in electricity prices have led to an increase in the number of utilities building PV systems without subsidies or opting out of subsidies. Furthermore, the use of "green" electricity is increasingly becoming a locational advantage for various companies in Germany.

In line with this positive market development is the opening of two factories for cell and module production by Meyer Burger (Germany) GmbH in May 2021 with an initial annual capacity of 0.4 GW of both solar cells and modules. An expansion of Meyer Burger's production capacity to 4.2 GW is planned by 2025.

September 2021 has seen the opening of two new PV module factories. Solar module manufacturer Solarwatt commissioned Europe's largest production facility for glass-glass solar modules in Dresden, with an annual production capacity of 0.3 GW. And Heckert Solar GmbH opened a new 0.4 GW high-efficiency PV module factory.

REFERENCES

[1] Press release BMWK (in German)
[2] Climate Action Programme 2030 of the Federal Govt.
[3] The national hydrogen strategy
[4] The 7th Energy Research Programme "Innovations for the Energy Transition"
[5] Research on sustainable power generation tech.
[6] Fraunhofer ISE study on LCOE in Germany:

ISRAEL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Yael Harman (PhD Head of the R&D division in the Chief scientist office at the Ministry of Energy)

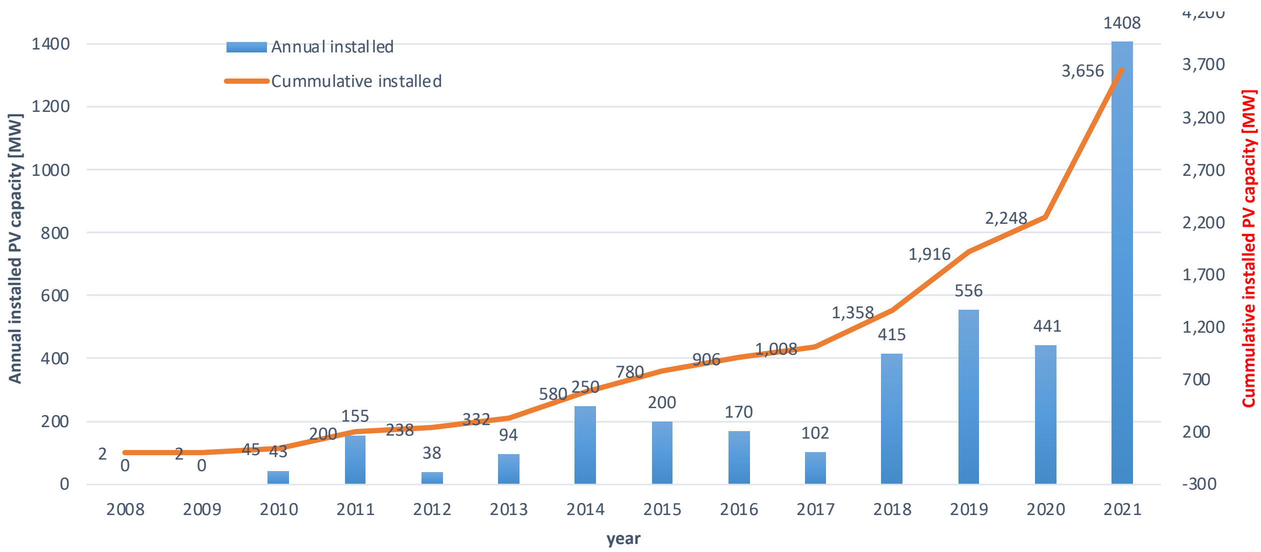

Fig.55 - Development of grid connected PV capacity in Israel through 2021

NATIONAL PV POLICY PROGRAMME

In November 2021 the Israeli Prime Minister announced Israel's target for net zero carbon emissions by 2050, and also that 80 % of Israel's electricity will come from renewable sources. Previously, in July 2020 the Minister of Energy had announced that the renewable energy target in electricity generation for 2030 would be raised from 17 % to 30 %, most of which will come from PV combined with energy storage.

Previously, in July 2020 the Minister of Energy had announced that the renewable energy target in electricity generation for 2030 would be raised from

17 % to 30 %

most of which will come from PV combined with energy storage.

In 2021, the total RE capacity in Israel was increased by

1 408 MW to a total capacity of

3 656 MW

Overall, by the end of 2020 Israel reached a level of 9.5 % RE electricity generation measured in potential terms

(meaning taking the installed capacity at the end of 2020 and multiplying it by the average hourly production per installed MW). PV systems are still the most abundant RE resource in Israel, accounting for approximately 99 % of the installed capacity. Due to the COVID-19 crisis many PV installations were postponed.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Chief Scientist Office (CSO) at the Ministry of Energy supports R&D through three national programs and two international programs:

- 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 Pilot and Demonstration projects - support is 50 % for commercial deployment of novel technologies.
- Horizon 2020 – The CSO operated several joint programs with the European Union and publishes annual calls for proposals. Among the joint programs are Water JPI, Solar, CSP, SES & Digitalization Era-Nets.
- The Bird Energy fund is a Binational Industrial Research and Development (BIRD) Foundation that supports joint US-Israel projects in the energy field.
- The US-Israel energy center of excellence is a Binational 5 year program to support research in 4 core areas: Energy Storage, Cyber Security for infrastructure, Water and Energy, Natural Gas. It is operated by the BIRD foundation.

In 2021 the Office of the Chief Scientist invested over 35 MUSD in energy related R&D projects.

→ Israeli Experts participate currently in 2 PVPS Tasks involving 2 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

In 2021, the price of electricity further decreased by

2.3 % to 0.4313 ILS

excluding VAT (0.137 USD), per KWh, one of the lowest in the developed world.

TABLE 4: ISRAEL'S ELECTRICITY PRICES BETWEEN 2016 AND 2021 IN ILS [SOURCE]

2016	2017	2018	2019	2020	2021
45.58	47.26	46.19	47.16	44.84	43.30

In 2021 the Israeli Public Utility Authority (2-PUA Reports) had published one competitive bid for PV with dual use of land. 815 MW were accepted at a tariff of ILS 0.1705 (0.053 USD) per KWh.

In 2021 the PUA promoted a fixed tariff of small and medium PV instillations in dual use of land in order to accelerate their establishment.

A new tender for high voltage +storage is expected to be published in early 2022.

100 MW was granted for experiments in AgroPhotoVoltaics which are expected to be installed in late 2022 or early 2023.

ITALY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Ezio Terzini (ENEA); Salvatore Guastella (RSE)

NATIONAL PV POLICY PROGRAMME

In Italy, the amount of PV installations in 2021 was slightly higher than the recent years. The PV installations were 0,916 GW in 2021 (Figure 56), which leads to a total cumulative installed PV capacity of 22,6 GW at the end of 2021. In 2021 the PV energy produced was 25.1 TWh/y, which corresponds to 7.8 % of electric consumptions. This highlights that a consistent acceleration of PV installations is still needed to reach the objectives of the Integrated National Plan for Energy and Climate (PNIEC) which foresees a cumulate installed power of 51 GW by 2030.

Moreover, this target must be revised according to the "fit for 55" indications carried by the new EU climate law, approved on 24 June 2021. This further acceleration of decarbonization policies leads to an estimate of about 64 GW of cumulative photovoltaic power required in Italy by 2030.

In support of this ambitious goal, it is worth mentioning the launch of the National Recovery and Resilience Plan (PNRR) which allocated resources for a total of 2.6 billion euro for the development of photovoltaics in the agricultural sector. Of this, 1.5 billion euro relate to an investment called "Agrisolare Park". This measure aims to incentivize the installation of 0.43 GW on infrastructures serving agricultural activities. The remaining 1.1 billion euro is strictly dedicated to the development of agrivoltaic. The objective is the installation of a production capacity from agrivoltaic plants of 2 GW with a reduction in greenhouse gas emissions of approximately 1.5 million tons of CO_2. As a related action, the recent decree-law n. 77/2021 admits the agrivoltaic plants to benefit from the incentives for renewables energy, while other PV plants on agricultural land are not admitted.

The PNRR has a parallel goal of developing international industrial and knowledge leadership in photovoltaics, promoting the development of a competitive supply chain, also by supporting the realization of a high-tech gigawatt-scale factory.

The further measure, intersecting the PNRR's actions, is the transposition of the RED II Directive. This decree, issued in December 2021, among other measures having effect on photovoltaics, reorganizes and simplifies the current legislation on configurations for self-consumption to encourage the establishment of Energy Communities and the agreements for collective self-consumption.

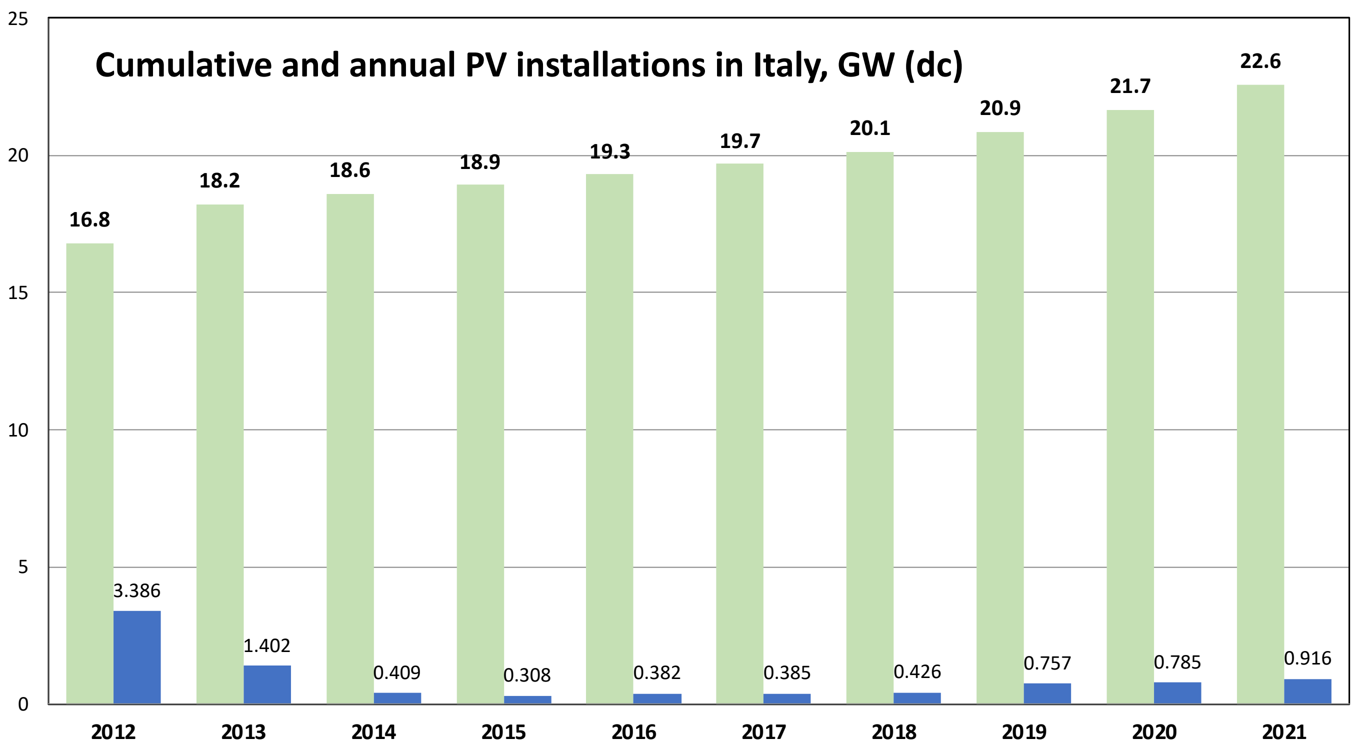

Fig.56 - Trend of cumulative PV installation in Italy (Source: TERNA)

RESEARCH, DEVELOPMENT & DEMONSTRATION

ENEA is the most relevant research public organization in the energy sector in Italy. In the PV field its activity is focused on both solar cell fabrication technologies and system development. A notable achievement is an efficiency of 20.08 % on a single perovskite solar cell as part of the High Efficiency Photovoltaic Project, funded by the Program Agreement on Research of the Electricity System between ENEA and the Ministry of Economic Development.

In the frame of Agrivoltaics development ENEA has set up a task force called "Sustainable Agrivoltaic @ENEA" with the aim of giving technical and scientific support to the National Network for Sustainable Agrivoltaic, also launched by ENEA, which gathers various partners (academia, trade associations, institutions, local bodies and licensing institution) to respond to the most significant questions that agrivoltaic systems installation raises in the national context.

RSE is carrying out activities on Concentrating Photovoltaic technology, from the development of high efficiency multi-junction (MJ) solar cells to the setup of new solar tracking strategies. In particular, RSE is pursuing original research on: i) monolithic integration of SiGe(Sn) and III-V-based materials for high efficiency - low cost- MJ solar cells, ii) design of innovative CPV/PV hybrid modules and set up of new characterization methodologies for CPV solar cells and modules.

Furthermore, RSE's research is focused on exploring the development of PV plants to contribute to their optimal production in the Italian territory, by advanced O&M strategies through improved diagnostic and predictive techniques. Finally, RSE is performing Life Cycle Assessment (LCA) of most promising innovative PV technologies.

CNR is active in PV research, mainly on the evaluation of the two types of innovative low-cost processes for thin film cells: standard DSSC and GIGS-LTPED.

Eurac Research, through its Institute for Renewable Energy, is active in research activities focused on the calculation of degradation rates in PV performance and in assessing uncertainties in yield assessments. Moreover, Eurac is engaged on the digitalization of the PV plants to increase their performance and reliability thanks to the use of Digital Twins creation. Another research area is focused on “BIPV field”, managing a database for BIPV products and BIPV case studies.

Moreover, a network of **PV Researcher Institutes and Operators** (“Rete nazionale del Fotovoltaico per la Ricerca, lo Sviluppo e l’Innovazione”) has been established in Italy with the the aim of sharing PV project initiatives and research infrastructures across the whole country. The approach has been supported by research and innovation coordination activities on a European scale, such as EERA (European Energy Research Alliance) and ETIP-PV (The European Technology and Innovation Platform for Photovoltaics) and was guided by the action to promote the objectives of the ''Implementation Plan” of the SET Plan that Italy signed in November 2017 after a phase of extensive consultation with the aforementioned Network.

→ Italian Experts participate currently in 6 PVPS Tasks involving 9 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

The main Italian PV module manufacturer is Enel Green Power, whose 3SUN factory in Sicily is one of the biggest in Europe. Its present 200 MW capacity of Silicon Heterojunction Technology (HJT) cells and modules, which achieved record efficiencies (25.0 % for HJT cells based on M2 wafer and 20.5 % for modules) have reached a module power more than 400 W and a very high bifacial factor (>90 %).

EGP has started the project to increase consistently its module production, through a

“Gigafactory”

which aims to increase the HJT cells and module production

up to 3 GW/year

Fig.57 - 3SUN Enel Green Power factory of HJT bifacial cells and modules [EGP courtesy]

Fig.58 - Fimer inverter for utility-scale PV plants [Foto by Fimer]

Two other PV module manufacturers are planning to start construction in Italy of large factories by the end of 2022, supported by the "Recovery Fund" initiative, while other minor operators are active in this field.

The Italian PV industry includes also the production of PV inverters, maintaining a leading position around the world. Among them, the company Fimer has incorporated the inverter production of ABB Inverter branch.

Lastly, Italian EPC Contractors and System Integrators are active in PV installations in Europe and in emerging market areas; among them, the biggest company is Enel Green Power, which is active especially in the field of utility scale plants in various countries around the world.

REFERENCES

This work has been financed by the Research Fund for the Italian Electrical System in compliance with the Decree of April 16, 2018.

JAPAN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Mitsuhiro Yamazaki (New Energy and Industrial Technology Development Organization (NEDO)); Osamu Ikki (RTS Corp.)

Fig.59 - Canopy type PV system at Global Zero Emission Research Center (GZR), AIST in Tsukuba City, Ibaraki Prefecture, Generation capacity: 6.9 kW, PV glass: Sunjoule® by AGC, ©RTS Corporation

NATIONAL PV POLICY PROGRAMME

In Japan, the Sixth Strategic Energy Plan was approved by the Cabinet in Oct. 2021, under which the new energy mix for 2030 was determined to achieve the national target of 46 % GHG reduction by 2030 [1,2]. An ambitious upward revision was made on the renewable energy (RE) ratio in the energy mix from 22-24 % to 36-38 %. PV is expected to account for 14-16 %, and the target PV installed capacity by 2030 was set at 117.6 GW(AC). The target was set with the engagement of relevant ministries and agencies. While Ministry of Economy, Trade and Industry (METI) is in charge of energy policy, hereafter, Ministry of the Environment (MoE), Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and Ministry of Agriculture, Forestry and Fisheries (MAFF) joined METI, to be responsible for PV introduction by mobilizing laws, systems, policy, regulatory reforms and budgets administered by each of them.

METI will work on establishing an environment that smoothly promotes the expansion of RE deployment through the Renewable Energy Promotion Act, the Electricity Business Act, the Energy Conservation Act, etc. METI will keep the FIT program [3] for residential and small-sized PV systems as locally-used power sources. As for medium-sized and larger PV systems, METI will not only promote the introduction under the FIP program, but also enhance measures to expand RE deployment such as expansion of use of off-site corporate PPAs without FIT/FIP support, development of next-generation solar cell technologies, promotion of understanding in local communities, and overcoming grid constraints.

MoE will take the lead in introducing RE with the highest priority and to the maximum extent, based on the revised 'Law Concerning the Promotion of the Measures to Cope with Global Warming' and the 'Plan for Global Warming Countermeasures'. Specifically, MoE will take initiative in PV introduction in buildings of the national/local governments, PV introduction in harmony with communities led by local governments via positive zoning, supporting businesses to introduce PV systems for self-consumption, and creating leading areas in decarbonization under the local decarbonization roadmap.

Based on the MLIT Environmental Action Plan, MLIT will promote net zero energy houses (ZEH) and buildings (ZEB), and expand PV introduction using infrastructure spaces (public rental housing, government facilities, roads, airports/ports, parks and sewerage, etc.)

Based on the 'Act for Promoting Generation of Electricity from Renewable Energy Sources Harmonized with Sound Development of Agriculture, Forestry and Fisheries' and the 'Green Food System Strategy', MAFF will promote introduction of AgroPV and review restrictions on farmland conversion to expand PV introduction.

The Cabinet Office's Task Force for comprehensive review of regulations on RE will advance regulatory reforms to expand PV introduction by comprehensively inspecting regulations on RE across relevant ministries and agencies as well as the Cabinet Office.

Japan added 6.5 GW(DC) in 2021 (preliminary), mainly under the FIT, including non-FIT systems for self-consumption.

RESEARCH, DEVELOPMENT & DEMONSTRATION

As for R,D&D activities concerning PV, technology development for commercialization administered by METI has been conducted by the New Energy and Industrial Technology Development Organization (NEDO). Fundamental R&D is administered by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and has been promoted mainly via projects of the Japan Science and Technology Agency and the project to subsidize the scientific research fund. NEDO made an additional public offering in FY 2021 for the Development of Technologies to Promote Photovoltaic Power Generation as a Main Power Source (FY 2020-FY 2024) and selected 5 themes. These themes include development of technologies to evaluate generation amount to support the next-generation O&M, as well as technologies to forecast solar irradiation for a short-term forecast of generation amount. A demonstration experiment to ensure safety of PV systems on slopes, AgroPV and floating PV systems is also conducted.

In 2021, the government established a

2 TJPY, 10-year fund

called the Green Innovation Fund (GIF) as part of NEDO for development of decarbonization technology and R&D on social implementation to realize

carbon neutrality by 2050

Projects across 18 areas, the important areas for which implementation plans were formulated under the Green Growth Strategy by METI, will be conducted between FY 2021 and FY 2030. As part of the GIF project, NEDO started the Next-Generation Solar Cell Development Project in 2021 [4] as the 10-year project between FY 2021 and FY 2030 with total budget of 49.8 BJPY. In FY 2021, 6 themes were selected to develop fundamental technologies of film-type perovskite solar cells with the performances equivalent to existing solar cells as well as technologies for commercialization. Sekisui Chemical, Toshiba, EneCoat Technologies, Aisin, Kaneka and the National Institute of Advanced Industrial Science and Technology (AIST) were selected. Demonstration tests are also planned to be conducted in FY 2023 onwards, aiming to achieve social implementation of these cells. Furthermore, the project of Hydrogen production with water electrolysis using electricity derived from renewable energy, etc. was also started under the GIF project.

METI, NEDO and MoE are conducting demonstrations on PV utilization technology. METI is conducting demonstration projects on power grid control including PV and storage batteries. In 2021, 3 projects were selected for RE aggregation demonstration, in which 50 companies including electric companies and VPP operators participate. In the aggregation demonstration project of distributed energy resources (DER) such as storage batteries, 2 projects with the participation of 31 companies in total were selected. METI and MoE are also collaborating on the project to support the demonstration of ZEB. MoE is demonstrating the reuse and recycling of PV modules. In 2021, MoE started a demonstration project on the collection of residential PV modules in Saitama Prefecture, which has the second largest installed capacity of residential PV systems by prefecture in Japan.

→ Japanese Experts participate currently in 6 PVPS Tasks involving 9 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

While the majority of PV system installations in Japan were supported by the FIT, new business models and services have been launched. As for residential PV systems, a service with a third-party ownership (TPO) model in which PV systems and storage batteries are installed at no initial cost in cooperation with electric companies was launched, and efforts to promote ZEH have progressed. Sekisui House has been promoting ZEH in newly built detached houses and rental housing, and achieved its plan for FY 2022 ahead of schedule. In public and industrial applications, the introduction of PV systems on the roofs of factories and logistics facilities with the PPA model has advanced. ORIX installed a 2.2 MW PV system at a factory of Kaihara, whereas Tokyo Gas Engineering Solutions installed a 3.8 MW PV system at Honda Motor's Kumamoto Factory with the on-site PPA model. Proposals for solar carports for parking lots of stores, etc. are also being made. In addition to on-site PPA, off-site PPA initiatives have progressed, mainly by businesses that are members of an international initiative RE100, etc. addressing climate change, and consumers have been actively procuring renewable energy. Nippon Telegraph and Telephone (NTT) will develop a new non-FIT PV power plant as a dedicated power source for Seven & i Holdings, and will supply renewable electricity for a long period of time. As efforts to develop small-scale PV power plants advance, Itochu Corporation signed a capital and business alliance agreement with Clean Energy Connect, planning to build small-scale PV power plants at 5 000 locations of idle land nationwide by 2025. Efforts using the self-wheeling system are being carried out as well. Sony, FD and DIGITAL GRID jointly started self-wheeling with PV systems in April 2021. The conventional energy industries are increasingly making large-scale investments in renewable energy, and ENEOS acquired Japan Renewable Energy (JRE).

Fig.60 - PV system for regional microgrid at Odawara Kodomo no Mori Park Wanpaku Land in Odawara City, Kanagawa Prefecture, Generation capacity: 50 kW, c-Si PV modules: Kyocera, ©RTS Corporation

According to PV module shipment statistics released by the Japan Photovoltaic Energy Association (JPEA), the total shipments of PV modules from January to September 2021 was 3 859 MW, of which imports accounted for 86 % with 3 308 MW. Foreign manufacturers are assumed to have occupied the highest ranks in the shipment volume as in the previous year. Panasonic and Solar Frontier, which had been leading Japanese PV manufacturers, withdrew from PV production, but have continued to work on the PV business. In anticipation of the future market expansion, Japanese companies have made progress in their efforts to recycle PV modules.

In the BOS industry, overseas business expansion is becoming more active. In the area of inverters, Toshiba Mitsubishi-Electric Industrial Systems (TMEIC) delivered inverters to a large-scale project in Vietnam, and Fuji Electric started production in India. In the area of storage batteries, efforts by major companies such as automakers are progressing, and Toyota Motor partners with JERA to develop a technology to reuse used in-vehicle batteries as stationary storage batteries. Tesla Motors Japan will enter the Japanese market in the area of grid-scale storage batteries.

REFERENCES

[1] Cabinet Decision on the Sixth Strategic Energy Plan https://www.meti.go.jp/english/press/2021/1022_002.html

[2] The 6th Strategic Energy Plan https://www.enecho.meti.go.jp/en/category/others/basic_plan/

[3] FIT Program (in Japanese) https://www.enecho.meti.go.jp/category/saving_and_new/saiene/index.html

[4] Call Starts for Applicants for Next-Generation Solar Cell Development Projects https://www.meti.go.jp/english/press/2021/1001_006.html

KOREA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Donggun Lim (Korea National University of Transportation)

Fig.61 - 100 MW PV system at Shinan-gun, Jeollanam-do, Korea

NATIONAL PV POLICY PROGRAMME

The Korean government has steadily increased its renewable energy targets during the past years. The first significant step was in 2017 when the renewable energy target for 2030 was increased from 7 % up to 20 % (under the so-called Implementation Plan for RE 3020). Then in 2019 a further target of 30-35 % renewable energy by 2040 was introduced (under the 3rd Energy Master Plan). Most recently in 2020 the target was tightened again to 42 % renewable energy by 2034 (under the 9th Basic Plan for Electricity Supply and Demand).

TABLE 5: ENERGY MIX ACCORDING TO THE "9TH BASIC PLAN FOR ELECTRICITY SUPPLY AND DEMAND"

	2020	2022	2030	2034
COAL	35,8GW	38,3GW	32,6GW	29,0GW (6,8GW↓)
LNG	41,3GW	43,3GW	55,5GW	59,1GW (17,8GW↓)
NUCLEAR	23,3GW	26,1GW	20,4GW	19,4GW (3,9GW↓)
RENEWABLES	20,1GW	29,4GW	58,0GW	77,8GW (57,7GW↓)

Table 5 shows the projected changes in energy supply mix. Nuclear power will be gradually phased out as no further extensions will be made to the lifespan of aged reactors and no new reactors will be constructed. Simultaneously, coal-fired power generation will be drastically reduced to within the range necessary to secure a stable supply and demand. Natural gas, which emits the least amount of greenhouse gas and fine dust amongst fossil fuels in addition to its relatively low geographical risks compared to oil, will continue to play a greater role in the future. Korea will transform its energy mix by prioritizing the public's requests for a clean and safe environment.

In 2020, the Korean government also announced a "Korean-style Green New Deal Plan" to move toward carbon-neutral society. It is planned to invest 73.4 trillion KRW (~ 67 billion USD) in the energy sector to transform the fossil fuel-dependent economy into an eco-friendly economy. The projects could create around 659 000 jobs and also help to cut 12.2 million tons of carbon emission by 2025. The government declared the leapfrog toward low-carbon and eco-friendly nation by disseminating 42.7 GW of PV and wind by 2025.

In Oct. 2021, the Korean government finalized its policy roadmaps to achieve the goal of carbon neutrality by 2050. The first roadmap aims to scrap all thermal power production using fossil fuels such as coal, LNG and oil to have zero emissions in the electricity generation sector. The second roadmap calls for abolishing coal-fired power generation but will keep LNG as a flexible power source. However, the second plan seeks to boost carbon capture and storage and direct air capture capabilities so as to fully neutralize carbon emissions from natural gas-fired power plants. Under both roadmaps, the portion of coal and LNG in the country's electricity mix will be lowered to 21.8 % and 19.5 % in 2030, respectively, compared with 41.9 % and 26.8 % in 2018, respectively. In contrast, share of renewable sources would jump to 30.2 % in 2030, from 6.2 % in 2018, while nuclear would edge up to 23.9 % in 2030, compared with 23.4 % in 2018.

1. RPS Programme – The Renewable Portfolio Standard (RPS) requires power producers to supply a certain fraction of their generation by renewable energy. The RPS was introduced in 2012 as a key programme to replace the FIT. In Korea, 23 obligators (electricity utility companies with electricity generation capacity of 500 MW or above) are now required to supply 10 % of their electricity from renewable energy sources by 2022, up from 2 % in 2012. Annual installations under this scheme have increased exponentially from 244 MW in 2012 up to 3 997 MW in 2021. By the end of 2021, the total installed capacity was 17 254 MW. The RPS is expected to be the major driving force for PV installations in the next few years in Korea. To promote community energy projects under this scheme, the Ministry of Trade, Industry and Energy (MOTIE) launched a REC weighting scheme that gives up to a 20 % increased weighting when community residents are involved in projects.

2. Home Subsidy Programme – This programme was launched in 2004 to continue the existing 100 000 solar-roof installation programme. The plan focuses on various resources such as PV, solar thermal, geo-thermal, and small wind. Detached and apartment houses can benefit from this programme, whereby 60 % of the PV system cost is covered for single-family houses, and 100 % for public multi-family rental houses. The maximum PV capacity allowed is 3 kW. In 2021, 66 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 non-residential buildings. In addition, the government supports maximum 80 % of initial cost for special purpose demonstration and pre-planned systems in order to help the developed technologies and systems to diffuse into the market. In 2021, 40 MW was installed under this programme.

4. Regional Deployment Subsidy Programme – This aims to balance energy supply & demand as well as develop regional economies by supplying region-specific PV systems via projects conducted by local governments. Up to 50 % of the installation cost is covered for NRE (including PV) systems owned and operated by local authorities. In 2021, 11 MW was installed under this programme.

5. Convergence and Integration NRE Subsidies – This programme is designed to help diffuse the NRE into socially disadvantaged and vulnerable regions such as islands, remote non-grid-connected areas, long-term rental housing district, etc. Consortiums of either local authorities or public enterprise with NRE manufacturer can apply. In 2021, 120 MW was installed under this programme.

6. Public Building Obligation Programme – New buildings of public institutions with floor area exceeding 1 000 m^2 are obliged by law to use more than 30 % (in 2020) and up to 40 % (by 2030) of their total expected energy usage from newly installed NRE resource systems. In 2021, 91 MW was installed under this programme.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Korea Institute of Energy Technology Evaluation and Planning (KETEP) controls the biggest portion of the MOTIE-led national PV R&D budget and managed a total of 92.4 Billion KRW in 2021. In the PV R&D budget, 56.4 % was invested in c-Si topics and 16.5 % was invested in perovskite topics. See Table 6.

→ Korean Experts participate currently in 4 PVPS Tasks involving 4 separate entities as listed here

TABLE 6: ANALYSIS OF PV R&D BUDGET IN KOREA IN 2021

TYPE	2021	
	BUDGET (BILLION KRW)	SHARE (%)
C-Si	52.1	56.4
Perovskite	15.3	16.5
Organic/Compound	4.8	5.2
DSSC	1.0	1.1
Others (Inverter, BOS)	19.2	20.8
TOTAL	**92.4**	**100.0**

Fig.62 - 99 MW PV system at Gunsan-si, Jeollabuk-do, Korea

INDUSTRY & MARKET DEVELOPMENT

Hanwha Solutions has a capacity of 4 500 MW and 1 600 MW in the c-Si solar cells and modules, respectively. LG Electronics has a capacity of 1 847 MW and 1 475 MW in the c-Si solar cells and modules, respectively. Hyundai Energy Solutions has a capacity of 650 MW and 750 MW in the c-Si solar cells and modules, respectively. See Table 7 for total manufacturing capacities.

TABLE 7: CAPACITY OF KOREAN PV PRODUCTION CHAIN IN 2021

WAFERS (MW)	CELLS(MW)	MODULES(MW)
166	7 002	9 970

Approximately

4 225 MW

of photovoltaics were installed in Korea during 2021

The RPS scheme was the main driver for the PV installation in 2021, whereby a remarkable fraction of 3 997 MW was recorded. At the end of 2021, the total installed PV capacity was about 19 564 MW.

Fig.63 - 41,5 MW Floating PV system at Hapcheon-gun, Gyeongsangnam-do, Korea

MALAYSIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Siti Aishah Mohammad (SEDA Malaysia)

Fig.64 - 60 MWac Floating solar plants in Tasik Danau Tok Uban, Pasir Mas, Kelantan by Cypark Estuary Solar Sdn Bhd (30 MWac) & Cove Suria Sdn Bhd (30 MWac) soon to be commissioned under the LSS

NATIONAL PV POLICY PROGRAMME

In December 2021, the Minister of Energy and Natural Resources of Malaysia announced the Malaysia RE Roadmap (MyRER), which details the country's development plans for the transition towards a low-carbon energy system in the short- and medium-term. MyRER has set the target to achieve the national aspiration of 31 % Renewable Energy capacity in 2025 and 40 % in 2035. MyRER outlines a strategic framework to achieve the country's RE development vision, namely 'Towards a Low Carbon Energy System', through the implementation of four technology-based pillars of solar, bioenergy, hydro and new sources.

Under the Ministry, two statutory bodies are responsible to monitor all PV programs in Malaysia: The Energy Commission as the custodian for all Large Scale Solar (LSS) and self-consumption (SELCO) programs, and Sustainable Energy Development Authority (SEDA) overseeing the Feed-in-Tariff (FIT) and Net Energy Metering (NEM) programs. These programs, however, are not applicable to the state of Sarawak as it is governed by the state's own electricity supply ordinance.

Following the COVID-19 pandemic that hit the country in early 2020, the government has pushed for initiatives to lower the cost of doing business through generation surplus utilisation. The new Net Energy Metering 3.0 programme was introduced to provide more opportunities for electricity consumers to install solar PV systems on their roofs to save on their electricity bill. The enhancement of the NEM policy has given focus to commercial and industrial users through the Net Offset Virtual Aggregation (NOVA) Program to enable generation excess to be sold at market price or System Marginal Price (SMP). A virtual NEM is also featured under this program where generation surplus can be shared/distributed through virtual aggregation of up to 3 different electricity bill accounts under the same name. A special quota is allocated for the residential sector under NEM Rakyat (the word Rakyat means 'people/citizen' in Malay) and growth of rooftop PV generation is also expected to increase in 2022 through the one-to-one NEM GoMEn, a program targeting rooftop PV installation on government entity/agency buildings.

The government has introduced the Green Electricity Tariff (GET) in December 2021. This GET programme is a part of the nation's initiatives to achieve net-zero GHG emissions by the year 2050 and to provide the option of green electricity coming from renewable energy supply to any electricity consumer to reduce their carbon footprint. GET subscribers will be supplied with green electricity coming from Solar and Hydro generators. On top of that, the green electricity is backed by Malaysia Renewable Energy Certificates (mREC) which is based on international REC standards.

FiT Update: Under Malaysia's RE Act 2011, a 1.6 % surcharge is imposed on electricity bills of all users in Malaysia that will go to the RE Fund. Since 2012, a FIT program has been funded through this scheme; 322.5 MW_{ac} of PV installations has been fully operational in 2021 where non-individual PV projects constitute the largest portion at 244.8 MW_{ac}, 69.4 MW_{ac} of individual installations including MySuria Program from B40 category and 8.3 MW_{ac} from community sector. In total, this program has benefited 10 269 feed-in holders with 89.9 % from the individual category. Now that the FiT's quota has been fully subscribed, new PV projects in Malaysia will mainly be driven by the three other programs – LSS, NEM and SELCO (cumulative SELCO capacity in 2021 was 137 MW_{ac}).

LSS Update: The Large Scale Solar (LSS) program was implemented in 2016 and has seen a total of 2 457.3 MW_{ac} cumulative capacity awarded with 909.5 MW_{ac} fully operational at the end of 2021 and another 1 547.7 MW_{ac} expected to operate between 2022 and 2023.

In 2021, the new PV capacity added under LSS was only 52.8 MW_{ac}. This low take up rate was due to a government-enforced order from June 2021 to postpone development/construction projects.

NEM Update:

Due to an overwhelming response from the PV industry, the

500 MW

quota under the NEM 2.0 was fully subscribed by 31st December 2020.

To boost the development of the local RE industry the government has released an additional 500 MW solar quota under NEM 3.0, which was announced December 2021, plus an additional 300 MW under the NEM NOVA program announced October 2021. The NEM quotas will run until 2023. The additional NEM NOVA quota is expected to benefit between 60-300 commercial and industrial consumers and create more business opportunities for over 100 solar local players. At the end of 2021, cumulative capacity approved under the NEM was 786.4 MW_{ac}, with 426.9 MW_{ac} already operational. Another 359.5 MW_{ac} is expected to operate in 2022. Between 2017 and 2021, despite the impact of the pandemic, the operational capacity spiked from 1 MW_{ac} up to 426.9 MW_{ac}, corresponding to an annual growth rate of 358 %.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Malaysia has a vast solar potential to support its initiatives to reach the MyRER targets (e.g. 40 % RE by 2035); according to MyRER Malaysia has vast solar PV technical potential, able to support at least 269 GW_{ac} of solar PV installations in the country. This technical potential is dominated by ground mounted configurations as the major portion of the pool at 210 GW_{ac}, followed by rooftop space and floating solar at 42 GWac and 17 GW_{ac} respectively.

Following the new RE target announcement, the MyRER which was mandated to SEDA will be implemented from 2022 to 2035. Action plans to achieve the new target have been outlined to cover all initiatives and strategies with the aim of striking a balance between environmental targets, preserving affordability and economic benefits, and maintaining system stability by mitigating the impact of variable renewable energy (VRE) especially solar.

To support the national RE target, two studies will be conducted by the Grid System Operator (GSO) of Malaysia to gauge the impact of high solar deployment to the national grid. The first study will determine the grid solar penetration limit so that the higher solar capacity can be deployed successfully in future. Another study will focus on exploring battery energy storage system integration as feasible framework to improve grid management and flexibility.

A study on the true cost of solar integration to the power system network of Peninsular Malaysia will also be conducted by Single Buyer to address concerns of additional system cost due to solar PV integration by considering limitation of solar PV in term of energy and dispatchability.

The Solar energy pillar is built upon existing programmes (i.e; NEM and LSS auctions) but is to be complemented with the introduction of new business models including corporate PPAs, third party access framework and providing greater avenues for distributed generation, as well as monetization of environmental attributes through Renewable Energy Certificates (RECs).

→ **Malaysian Experts participate currently in 2 PVPS Tasks involving 2 separate entities as listed here**

INDUSTRY & MARKET DEVELOPMENT

Malaysia's PV industry has not been spared the impacts of the global pandemic since 2020, affecting local PV manufacturers and assemblers (LMA) and service providers. In 2021, the total of polysilicon manufacturing nameplate capacity was at 10 GW with employment of 605. For ingot, wafer, solar cells and PV modules manufacturing, the total estimated nameplate capacity was 23 GW with employment of 10 794. Total number of jobs in Malaysia's PV industry dropped from 15 180 to 11 399 with a significant number of LMAs ceasing production. The table shows the major PV manufacturing statistics in Malaysia in 2021. Within the PV industry, there were 198 PV registered service providers active in the market in 2021 (see list).

TABLE 8: STATISTICS OF MAJOR PV MANUFACTURING IN MALAYSIA 2021

NO	COMPANY NAME	TECHNOLOGY	CAPACITY (GW)	JOBS
Metal Si/ Poly Si Feedstock			2021	
1	OCIM Sdn Bhd	poly-Si	10	605
Cell			2021	
1	Jinko Solar Technology Sdn Bhd & Jinko Solar (Malaysia) Sdn. Bhd.	sc-Si	6.0	2 700
2	Longi (Kuching) Sdn Bhd & Longi Technology (Kuching) Sdn Bhd	Mono c-Si	4.8	1 795
Module			2021	
1	Jinko Solar Technology Sdn Bhd & Jinko Solar (Malaysia) Sdn. Bhd.	sc-Si	6.0	2 800
2	Longi (Kuching) Sdn Bhd	Mono c-Si	0.9	369
3	First Solar Malaysia Sdn. Bhd.	CdTe	2.7	1 800
4	Hanwha Q CELLS Malaysia Sdn. Bhd.	sc-Si	2.2	995
Ingot/Wafer			2021	
1	Longi (Kuching) Sdn Bhd	Mono c-Si	0.6	335

MOROCCO

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Ahmed BENLARABI (Green Energy Park, IRESEN); Amin BENNOUNA (Cadi Ayyad University, Senior Advisor to the Green Energy Park, IRESEN)

Fig.65 - Morrocan Green Energy Park

NATIONAL PV POLICY PROGRAMME

Since 2009, Morocco has developed an ambitious renewable energy program aimed at increasing the share of renewable energies in the national energy network to 52 % by 2030. In 2020, Morocco reached a share of 31 % of renewable power, which corresponds to a capacity of 3400 MW, whereby solar has a capacity of 707 MWp and 240 MWp is photovoltaic plant. This major deployment of renewables is backed with a huge potential in terms of available solar and wind resources, totaling ~ 500 TWh.

The Moroccan Agency for Solar Energy (MASEN) is developing national programs aiming to achieve the

52 % renewable energy

target by 2020

So far 53 renewable energy projects (cumulating 52.2 billion Dirhams of investments) are under development aiming to achieve more than 1760 MWp of solar energy whereby over 1500 MWp will be photovoltaic. The Moroccan government, through MASEN, is launching a new program dedicated to mainly national SMEs, by the launching of different tenders for small and medium size PV plants with capacities varying between 5 and 40 MWp. This program will contribute to the deployment of 400 MWp additional capacity based on solar photovoltaics, and on the other hand, will enhance the development for Moroccan SMEs in the field of photovoltaics. It will also support the creation of new job opportunities as well as the diversification of the Moroccan industrial fabric. Forty seven companies have already manifested their interest to participate. The future PV plants are expected to be commissioned by 2022. The Moroccan government is projecting to achieve 100 % of the scheduled planned capacity by the horizon 2023.

The Ministry of Energy Mines and Environment (MEME) is launching a program aiming to upgrade public buildings in terms of energy performance by equipping them with renewable energy sources, mainly photovoltaic systems. This program, while focusing solely on public buildings, seeks to encourage the private sector to follow a similar approach.

The Moroccan government has set up a new roadmap for the certification of photovoltaic solar components (modules, inverters and batteries) aiming to protect the local market against fraud and reinforce its surveillance. Green Energy Park's testing laboratory has been designated as a qualified laboratory by the National Certification Body to perform the tests according to the Moroccan standards based on the IEC 61215 and IEC 61730. The MEME also introduced the label "Taqa-pro" in 2018 for the certification of EPCs based in Morocco.

The National Regulation Authority has established a grid code, while the MEME is establishing a new process for the certification of electricity provided from renewable sources and injected into the grid. A new law is under approval by the Head of the Government that will manage the modalities of injection of renewable energy in middle voltage grid. This law will allow the injection of around 10 % of the produced capacity in the grid.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In Morocco, the Research Institute of Solar Energy and New Energies (IRESEN) and its research platforms lead the R&D activities regarding solar technologies. Created in 2011, the IRESEN is at the heart of the national energy strategy in The Kingdom of Morocco, by its position in the fields of applied research and innovation. Its funding agency strives to meet the priorities defined within the framework of the national energy strategy. Thus, all the topics addressed are aligned with renewable energy and energy efficiency sectors in Morocco with a need for applied R&D.

IRESEN and Mohammed VI Polytechnic University (UM6P) initiated in 2016 the creation of a research platform throughout the kingdom, with Green Energy Park being the first member.

The platform is dedicated to

solar energy

and is unique of its kind in Africa.

The platform allows, on the one hand, the creation of synergies and the pooling of infrastructures of several Moroccan research institutes in order to create a critical mass and achieve excellence, and on the other hand, the acquisition of knowledge and know-how by the universities and Moroccan industries.

In the same approach, the network initiated by IRESEN and UM6P have created the new testing, training and research platform "Green & Smart Building Park". It is an innovative platform dedicated to research and development in the field of green buildings; energy efficiency and smart grids with the aim of creating the ecosystem in which future sustainable Moroccan and African cities will develop thanks to the integration of renewable energies and digitalization, which will enrich the value chain of the building sector.

Another platform specialized in Power-to-X and the production of Green Hydrogen and Green Ammonia is under study. Green H2A is a research platform that aims to be a national, regional and continental (Africa) reference for R&D and Innovation, dealing with topics related to the "Power-To-X" (PtX) sector, in particular Power-to-Hydrogen and Power-To-Ammonia. The objective of this platform is to offer capacity building and to stimulate the use of green raw materials in fertilizer production in particular, and in the industry more generally.

→ Moroccan Experts participate currently in 3 PVPS Tasks involving 2 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

PV INDUSTRY FEATURES, CURRENT SITUATION AND TRENDS

Three PV module manufacturers have established facilities in Morocco as photovoltaic module assembly lines. With its 250 MWp, Almaden Morocco holds the production line capacity in North Africa. Nonetheless, further module producers ranked among the tier 1 manufacturers are willing to install their production units in the country. All other related industries dedicated for the Balance Of System (BoS), the solar cabling sector, electrical components (DC breakers, fuses, etc.), PV modules structures as well as engineering expertise are already well developed where more than 40 EPCs exist already in the EnF solar database.

Finally, the Ministry of Industry, Trade and Investment and the Digital Economy, has launched the Acceleration Plan to enhance the investment in high potential production lines, some of them being dedicated to the following:

- Solar Photovoltaic modules assembly
- Inverters
- Batteries
- Solar Heaters

This new step will support the diversification of the industrial landscape, creating new job opportunities for local citizens.

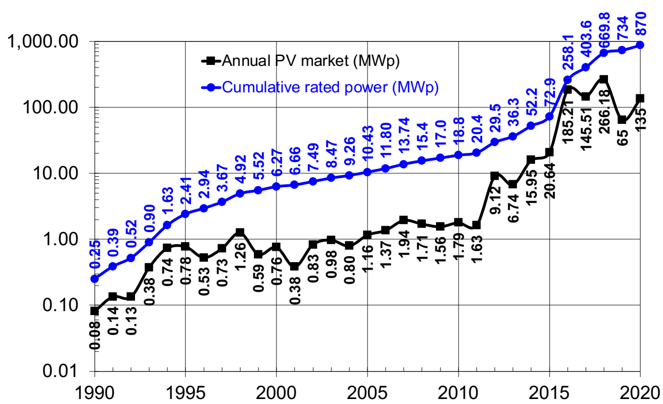

Fig.66 - Evolution of the PV Market

KEY MARKET

Isolated photovoltaic installations for domestic electrification have become a minority on the market and, apart from large photovoltaic power plants financed by PPA, other decentralized installations dominate the market: to meet the demand for photovoltaic agricultural pumps (grid-connected or not) and grid-connected generators for domestic or industrial self-consumption.

ROLE OF PV IN THE POWER MIX

Isolated photovoltaic installations for domestic electrification have become a minority on the total national market (shown in Figure 66 which has cumulated 870 MWp in 2020 [1][2]. The other decentralized installations mentioned above have reached 634 MWp in 2020 and now dominate the market and, with 240 MWp cumulated in 2020, large photovoltaic power plants with a PPA take a substantial part. The evolution of the electric power mix is shown in Figure 67 and reaches 10 856 MW in 2020¶. Despite the rapid growth shown of large photovoltaic power plants with a PPA, large photovoltaic power plants, with their 240 MWp in 2020 do not represent more than 2.2 % of national electricity production capacity in 2020.

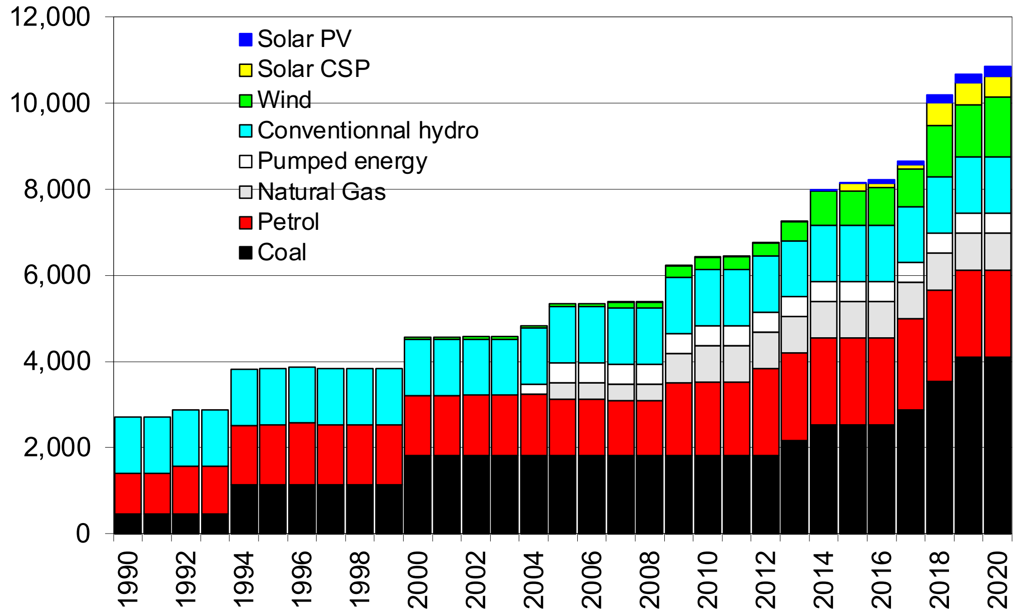

Fig.67 - Evolution of the Power mix

REFERENCES

[1] A. Bennouna, "The increasingly important role of decentralized solar energy in Morocco", Applied Journal of Environmental Engineering Science (ISSN: 2509-2065), 7-1 (2021) Pages 18-41.

[2] A. Bennouna, "Trois décennies d'énergie solaire photovoltaïque au Maroc", EcoActu, 04 December (2019),

¶ A. Bennouna, "Monographie 2020 de l'énergie au Maroc", In press1

NETHERLANDS

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Otto Bernsen (Advisor Netherlands Enterprise Agency (RVO), part of the Netherlands Ministry of Economic Affairs and Climate, team Energy Innovation)

Fig.68 - Installers from Dutch Start-Up "Solar Duck", which provide ocean-based floating solar solutions.

NATIONAL PV POLICY PROGRAMME

The Netherlands have a liberalized and privatised energy market in which network operators and energy retailers are unbundled. Only the grid infrastructure remains in the public domain, which is operated by seven different regional grid operators and one national operator Tennet.

The national goals established in 2019 with the "Climate Agreement" are set on 49 % emission reduction by 2030 and 95 % by 2050. The innovation policy does not mention goals for specific technologies as the principle is to achieve these goals in the most cost efficient way while maintaining energy security and a reasonable energy price. At the moment all three objectives are under pressure.

The Netherlands have a fast-growing solar market and several support schemes are in place such as;

- SDE plus for solar systems larger than 15 kWP
- Net metering, until at least 2023.
- Postal code (tax reduction) adjusted to SCE (subsidy cooperative energy).
- Tax return VAT small PV systems
- ISDE for SME's up to 125€/kWp
- Cheap loans in many municipalities if signed up to a national fund

While the policy framework has not changed over the last year, the steady growth of solar PV over the years has led to a change of focus in the implementation and innovation programs towards system integration, societal integration of solar PV and its carbon footprint. Grid congestion has become widespread and has led to a backlog of solar power plants and led to forced curtailment in the domestic market. For an overview of present congestion see the capacity map provided by the Dutch grid operators.

Space is scarce in the densely populated low countries and a preference has been formulated by parliament for installing solar panels first on the available roof tops, although this market segment only counts for one third of the solar market. The overall result is a slowing down of the roll out of solar energy to about half the amount the market is capable of without these restrictions. To achieve the ambitious climate goals, additional measures have to be taken.

Investments in grid reinforcement are underway but given the longer lead times, compared to the development of solar parks, grid operators will not catch up with the existing backlog in the coming decade. Alternative ways are being explored to make use of the existing electricity network including frequency management, cable polling etc. Several studies have been conducted over the last year into societal costs & benefits of solar parks, the ecological impact, multiple land use in the agricultural sector and adding battery storage to solar generation. The electricity demand for heating & cooling in the built environment and industry is also increasing and expected to double by 2030, which will enhance the role of solar energy as a cornerstone of the energy transition.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In 2021 the mission oriented R&D program was prolonged with a total budget of 13 MEUR for the topic "electricity on land", of which solar PV formed the lion's share. It focused on sub-themes such as: system solutions for the new value chain, increasing integration and flexibility of the energy system, upscaling and specific applications for integration of solar PV. A similar program also existed for the built environment in which solar topics were also represented with a focus on renovation and home energy systems.

In addition, relatively large budgets were available in the subsidy scheme for demonstration and pilot projects, with an aim to accelerate market introduction, and the HER plus subsidy scheme for CO_2 reduction.

In the R&D programs the focus is not only on expanding the integration of solar panels but also on higher efficiencies close to and over 30 % and a longer life span by limiting degradation of the cells.

Higher technology readiness levels are managed in separate programs for fundamental research by the national organisations NWO and STW. The research activities themselves are dispersed over several universities and research institutes like AMOLF, DIFFER, Solliance and TNO (the national institute for applied research). A clear trend is for higher professional education to offer courses in solar technology and installation.

The above programs are expected to be prolonged in 2022 with slightly modified topics and budgets. Most notable is the expected inclusion of the topic "offshore floating solar" in 2022.

In 2021 a one time call was launched for the design and production of circular solar panels. In that call projects were granted about lightweight, flexible solar panels and fully recyclable panels.

The Top consortium for Knowledge and Innovation (TKI) concerning solar, under the flag of Urban Energy, drives innovation by forming partnerships and match making.

→ Dutch Experts participate currently in 7 PVPS Tasks involving 9 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

In 2021 the Dutch solar PV market continued growing at the same pace with an estimated added installed capacity just over 3.6 GWp installed (preliminary figures) which leads to a total cumulative installed capacity of 14.3 GWp.

These figure are based on a market survey by DNE Research in the Solar Trend Report 2022. See updated chart from the RVO.

The official figures are provided and updated regularly in the Electricity Balance Sheet published by Central Bureau for Statistics (CBS).

A shift has taken place over the years from more installations in the market segment of domestic roof top systems towards larger solar systems both ground and roof mounted, which now account for over half the total annual installed capacity. Most of these larger solar parks are still below 50 MWp but some are now built well over the 100 MWp installed capacity.

As mentioned before the different market segments for integrated solar panels are developing quickly in the Netherlands and national consortia are formed around solar in the landscape, infrastructure, on the water (floating) and BIPV.

A special mention is deserved for the experiments with off shore solar parks

that take advantage of the Dutch sea going experience. Although a major contribution of these to the national goals is not expected until 2025, the potential is huge.

An example is the start up Solar Duck, who were interviewed by the TKI (the interview is in Dutch but the pictures speak for themselves).

An overview of the entire Dutch solar sector and industry can be found in this NL Solar Guide 2020.

The forecast is that the solar market in the Netherlands will continue to grow at a stable rate of over 3 GWp per year notwithstanding the increasing pressure on the electricity grid and land resources. Creative ways are being found to avoid and solve these issues while working on higher efficiencies and integration of solar PV.

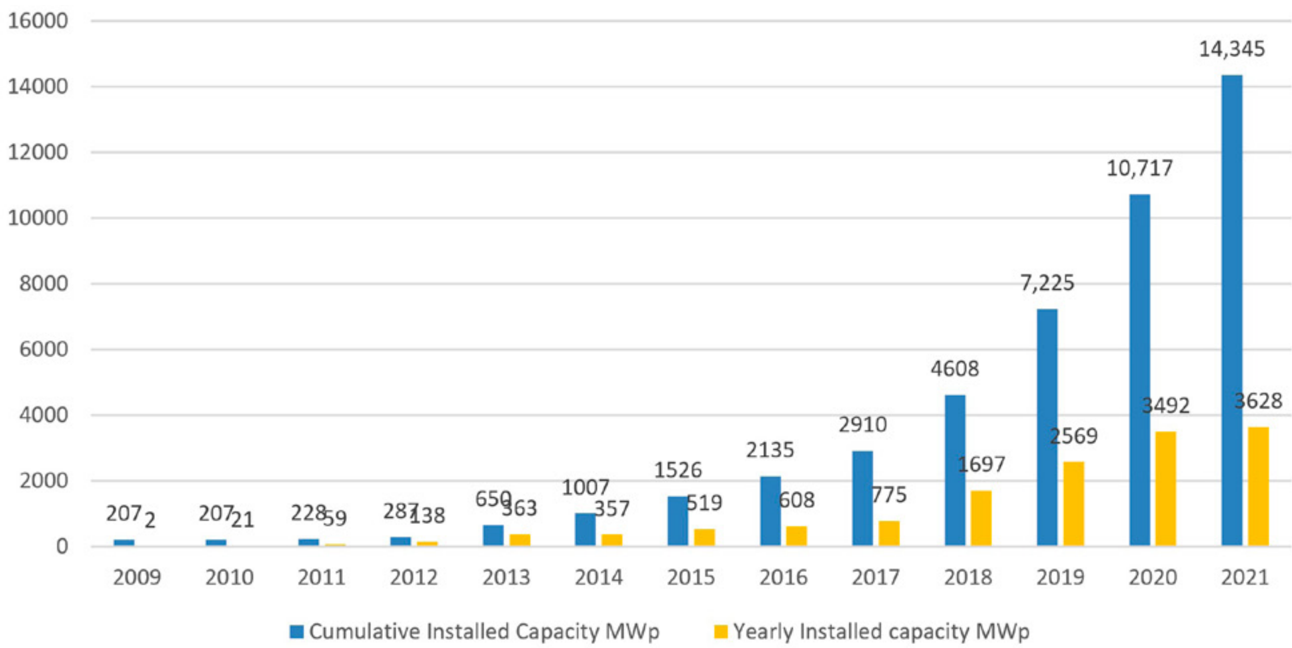

Fig.69 - Dutch PV installed capacities, both annual and accumulated in MWp. [Source: RVO]

NORWAY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Trond Inge Westgaard (The Research Council of Norway)

NATIONAL PV POLICY PROGRAMME

Norway's programmes in the energy sector focus generally on the promotion of renewable energy and increasing energy efficiency. Support for implementation of PV is integrated into these programmes.

The public agency Enova SF subsidized, until January 2022, up to 35 % of the installation costs for grid connected residential PV systems at a rate of 7500 NOK per installation and 1250 NOK per installed kW rated capacity up to 15 kW.

In early February 2022, these support levels were increased to 2000 NOK per installed kW up to a

maximum of 20 kW

which will positively impact the outlook for PV installations

This programme also incorporates leisure homes with grid connection, but apartment buildings are in practice excluded from the programme.

The government agency Innovation Norway supports investments in PV systems in the agricultural sector. This support is contingent on a consideration of the role of the PV system in the commercial operation of the actual farm.

Surplus electricity from small, privately operated PV systems can be transferred to the grid at net electricity retail rates (i.e., excluding grid costs, taxes, and fees). Small suppliers are exempt from grid connection fees that are charged from electricity suppliers. Such installations are not allowed to exceed a limit of 100 kW electric power feed-in to the grid. Current rules for grid transmission fees are unfavourable with respect to transmission between separately metered installations. This is of concern for residential apartment buildings and for building clusters with common infrastructure for local electricity supply. There is an ongoing process to establish a better framework for these situations.

RESEARCH, DEVELOPMENT & DEMONSTRATION

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. The PV related part of the portfolio consists of R&D projects on the silicon chain from feedstock to solar cell research, on novel solar cell concepts, novel applications, and on applied and fundamental materials research.

Leading national research groups and industrial partners in PV technology participate in the Research Center for Sustainable Solar Cell Technology, which is funded by RCN and Norwegian industry partners. The research activities are within silicon production, silicon ingots and wafers, solar cell and solar panel technologies, and use of PV systems in northern European climate conditions. The total center budget is 240 MNOK (27 MUSD) over its duration (2017–2025).

There are six main R&D groups in the university and research institute sector of Norway, which all participate in the Research Center:

- Institute for Energy Technology (IFE): Focus on polysilicon production; design, production, and characterization of silicon solar cells; and the effects of material quality on solar cell performance.
- University of Oslo (UiO): 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: Materials science, micro- and nanotechnology relevant for solar cells.
- SINTEF Trondheim and Oslo: Focus on silicon feedstock, refining, crystallisation, sawing and material characterisation.
- Norwegian University of Life Sciences (NMBU): Fundamental studies of materials for PV applications and assessment of PV performance in high-latitude environments.
- Agder University (UiA): Research on silicon feedstock. Renewable Energy demonstration facility with PV-systems, solar heat collectors, heat pump, heat storage and electrolyser for research on hybrid systems.

→ **Norwegian Experts participate currently in 4 PVPS Tasks involving 5 separate entities as listed here**

INDUSTRY & MARKET DEVELOPMENT

The Norwegian PV industry is divided between "upstream" materials suppliers and companies involved in the development of solar power projects.

REC Solar Norway operates production plants for solar grade silicon with an annual production capacity of approximately 8 000 metric tons. **NorSun** manufactures high performance monocrystalline silicon wafers. The annual production capacity is equivalent to 1 GW of solar panel capacity. **Norwegian Crystals** produces monocrystalline silicon ingots and wafers. The ingot production capacity of the factory is equivalent to 0.5 GW per year. The products supplied by all 3 companies have a low carbon footprint compared to the industry average.

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 is a renewable power producer. A major part of its operations is development and operation of PV power plants. The present portfolio of PV power plants has a capacity of approximately 2 GW, located in Africa, Asia, South America, and Europe.

In recent years new companies have been formed for developing new services or solutions for the PV markets. Examples are companies offering BIPV products, floating solar power plants, or PV system supervision.

The Norwegian PV market is small on an international scale. Norway's electricity supply is dominated by

hydropower (91 %) and wind (8 %).

It is estimated that 45 MW of PV capacity was installed in 2021, while the total PV generation capacity installed before 2021 was approximately 160 MW. The moderate installation volume is due to a combination of very season dependent solar resources in Northern Europe, relatively low electricity prices in the summer season, and moderate financial support.

High electricity prices in the second half of 2021 caused

increased demand

for PV installations.

The Norwegian Energy Regulatory Authority (NVE-RME) had approved new rules for grid connection tariffs that would have taken effect from January 1, 2022. However, this was postponed at the political level because the new rules were considered, in general, to have unpredictable effects for consumers. If introduced, these new rules were expected to have negatively affected the economics of PV installations.

PORTUGAL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Ricardo Aguiar (Directorate-General of Energy and Geology)

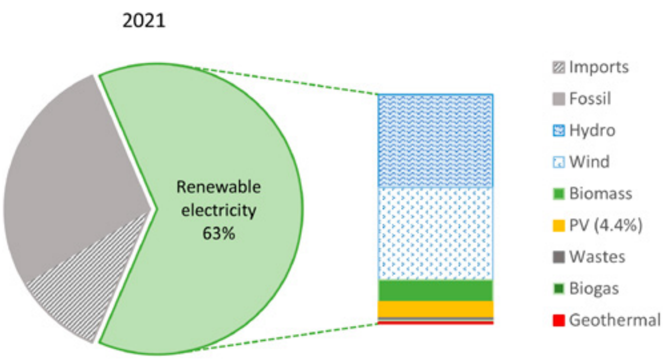

Fig.70 - Installed PV capacity in Portugal, 2014-2021 (Source: DGEG 1).

NATIONAL PV POLICY PROGRAMME

Following signature of the Paris Agreement in 2015, Portugal was the first country in the world to make a commitment to achieve carbon neutrality by 2050, and the first to approve a roadmap with specific measures to reach that goal. The **Carbon Neutrality Roadmap** for 2050 (RNC, Ministerial Resolution No. 107/2019) performed cost-optimal studies specific for the country, regarding the energy and domestic transportation sectors. These pointed to a strategy whose main features are the extensive electrification of all end uses of the economy and the production of energy from renewable sources – mainly hydro, solar and wind.

Shortly after, the **National Energy and Climate Plan** (NECP, Ministerial Resolution n° 53/2020), presented a shorter term path with goals and measures coherent with the RNC for the period 2021-2030. The NECP main target is a 47 % share of renewable energies in the final energy consumption by 2030; the respective subgoal for electricity is 80 %. The NECP scenario sets the role of PV by 2030 at 10 GW (30 % of installed power capacity), or 63 PJ (25 % of the electricity production).

However, some aspects of the RNC and NECP were gradually sensed as not providing the desired high level of security and flexibility for the energy system, besides not addressing effectively hard to abate emissions at some sectors, especially in industry and in international transportation. This was addressed by the **National Hydrogen Strategy** (EN-H2, Ministerial Resolution No.63/2020), that introduces several hydrogen value chains in the vision of a future sustainable Portuguese energy system. It relies only on renewable hydrogen –from biomass, from thermoelectrochemical processes, but mostly from electrolysis. Updating the RNC, renewable electricity still dominates but part is assigned to production of hydrogen and other synthetic fuels. EN-H2 therefore calls for additional installed capacity – about 2/3 from PV. The vision of the role of PV by 2030 is thus upgraded to 13 GW installed, or 105 PJ produced (35 % of installed power capacity, or 39 % of the overall electricity production).

Future needs for PV capacity are now seen as even larger, due to the interest of producing renewable hydrogen for non-energy uses such as plastics and fertilizers.

These targets are ambitious but do seem feasible, as there are about 20 GW of projects queuing for access to grid. The Government policy is to allow existing feed-in tariffs to reach the end of the supporting period, and conduct auctions for new capacity, seeking discounts on the market price of electricity. The design of these auctions varies, but some already value PV plants with integrated storage.

As for distributed production, major developments are expected by early 2022, including regarding storage, prosumers and energy communities.

The public perception was initially neutral on PV projects. However, as large power plants spread, concerns are now being raised about visual and ecological impacts. As part of an effort to mitigate these concerns, auctions are being prepared for non-conventional surfaces, such as water reservoirs and road margins.

RESEARCH, DEVELOPMENT & DEMONSTRATION

R&D on PV in Portugal has experienced a steady development since the 1980's, but in the last few years the pace has been accelerating.

As regards academic research,

University of Minho is working on thin-films, amorphous/ nanocrystalline silicon solar cells; silicon nanowire solar cells; oxygen and moisture protective barrier coatings for PV substrates; and photovoltaic water splitting;

University of Porto (at FEUP) is working on Solar PV cells and modelling processes;

University of Aveiro is working on semiconductor physics: growth and characterization of thin-films for photovoltaic applications;

University of Coimbra (at FCT) is 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 is working on materials for solar cells, solar resource measurement and forecasting, and PV systems' modelling (at FCUL); and on organic cells (at IST);

Nova University of Lisbon (at FCT, CTS, UNINOVA and CENIMAT) is working on thin-film technologies, including tetrahedrite-based materials, tandem cells with perovskites and kesterites.

As regards public research groups,

National Laboratory of Energy and Geology is working on tetrahedrite-based materials, PV/T modules and PV prosumers;

International Iberian Nanotechnology is working on solar fuel production; inorganic-organic hybrid solar cells, sensitized solar cells, perovskite solar cells, Cu_2O, Cu(In, Ga)Se_2 solar cell devices and materials, quantum dot solar cells, thin-film Si, encapsulation barriers, and Si-NW solar cells;

Directorate-General of Energy and Geology makes studies for public policies promoting PV, including national energy plans and roadmaps, technical legislation, and design and implementation of specific support measures.

As regards private companies operating in Portugal,

MagPower continues to improve the design of its CPV modules and trackers;

EFACEC works on inverters, storage, automation and control for PV plants;

FusionFuel is developing a technology for hydrogen production that combines a high-efficiency solar cell and a CPV solar panel to capture both the electrical and thermal potential of solar energy.

Other companies like **Voltalia** (former Martifer Solar) and **Open Renewables** also perform research and innovation activities related to PV technologies.

→ Portuguese Experts participate currently in 1 PVPS Task involving 1 entity as listed here

INDUSTRY & MARKET DEVELOPMENT

Regarding electricity, the year 2021 was marked by two major features: the end of production from coal in Portugal, and the steep rise of the price in the integrated Iberian market throughout the year.

This diverted the public attention from other relevant features, including the remarkable increase of

60 % **in PV capacity over the year**

The COVID-19 pandemic seems to continue taking its toll on electricity demand, although the -1.4 % drop in 2021 was smaller than the -3.9 % drop in 2020 (DGEG provisional data [1]). Indeed, and despite a GDP growth of +4.8 %, the gross electricity production plus imports in Portugal during 2021 declined from 53.0 TWh to 52.2 TWh.

Renewable energy technologies were responsible for 32.8 TWh, 2.4 % up from the 2020 value of 32.0 TWh, although the weather was drier than usual and caused a 2.0 % decrease of the hydroelectric systems' production. GHG emissions from the power sector at mainland Portugal declined from around 8.0 M tonne CO_2 in 2020 to 6.2 M tonne CO_2 (provisional estimates), this being due to the progress of renewables but mostly to the closure of the last two coal power plants, Sines and Pego. This resulted in a decline of the specific CO_2 intensity of electricity from about 159 kg/MWh in 2020 to only 132 kg/MWh in 2021.

As can be appreciated in Figure 70, the PV capacity continues to increase at an accelerated pace. The additional capacity installed during 2021 was 931 MW, corresponding to 701 MW at power plants and 230 MW of small systems, a remarkable 60 % rise over last year. The installed PV capacity now totals around 2.5 GW.

Although fossil (27 %), hydro (26 %) and wind (25 %) technologies still dominate the electricity production mix, as can be seen in Figure 71, the penetration of PV continues to rise, from 3.3 % in 2020 to 4.4 % in 2021.

Meanwhile, the average daily market price of the Iberian Electricity Market where Portugal operates, raised from 34,0 €/MWh in 2020 to 111.5 €/MWh in 2021, i.e. about a 70 % increase (OMIE data [2]). As can be appreciated from Figure 72, it is unlikely that such a huge increase can be explained as a simple consequence of the yearly or even seasonal patterns of the electricity demand and the production from renewables. In a similar way to other European countries, it seems that the increase of natural gas price, coupled to an inadequate market design for the ongoing energy transition, played here the largest role. Nevertheless, for 2022 the price of electricity for consumers is expected to go down again, perhaps to around 87 €/MWh according to estimates from the market regulator. This is because several income sources will revert to lowering the final electricity price, including auctions of guarantees of origin from power plants that receive State support, auctions of GHG emission licenses (whose price has been rising much) and, last but not least, because more cheap renewable's production will kick in, notably from PV technologies.

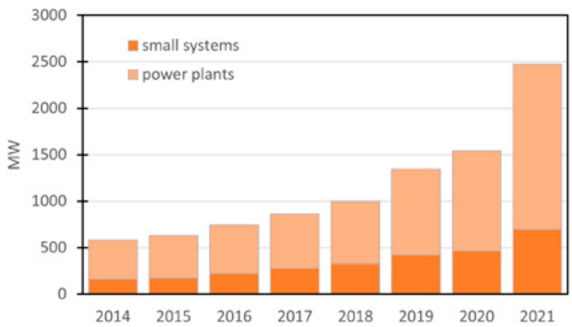

Fig.71 - Electricity generation by type of energy source in Portugal, 2021 (Source: DGEG 1).

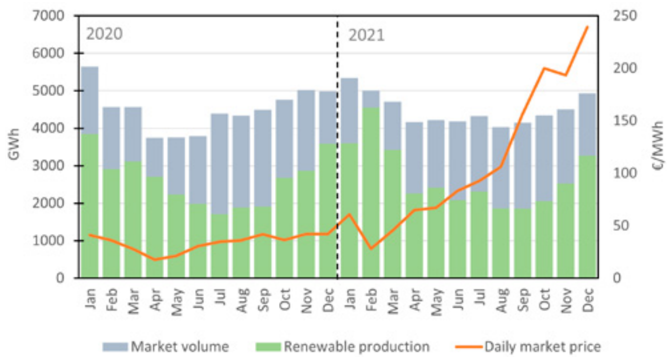

Fig.72 - Renewable Electricity Production and Iberian Electricity Market Volume and Price for 2020-2021 (Sources: DGEG 1, OMIE 2).

REFERENCES

[1] Official statistical data from DGEG https://www.dgeg.gov.pt/pt/estatistica/energia/

[2] Statistical Data from OMIE, the nominated electricity market operator for managing the Iberian Peninsula's day-ahead and intraday electricity markets.

SOLAR POWER EUROPE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Walburga Hemetsberger, Claire Couet, Rafaele Rossi (SolarPower Europe)

Fig.73 - The European Solar Initiative aims to recevelop 20 GW of PV Manufacturing in Europe. © SolarPower Europe

PV POLICY PROGRAMME

SolarPower Europe worked relentlessly in 2021 to shape the best possible policy and business environment, which will enable our sector to grow even further, and contribute to a green recovery for the EU. The efforts were translated in some major successes:

- The European Commission has confirmed an EU solar strategy for our clean energy technology in 2022 which is set to boost the European solar industry, and remove barriers to deployment.
- In a clear advantage for the sector, and European consumers, the European Council has agreed to allow governments to introduce reduced or zero VAT rates for solar panels used on rooftops.
- New EU State Aid rules will allow technology-specific tenders such as solar and storage, or agri-solar and floating solar. It will also maintain the exemption from tendering processes for rooftop PV projects up to 1 MW, when and where they are owned by SMEs or renewable energy communities.
- Finally, the different proposals put forward by the European Commission in the 'Fit for 55 package' provide a very positive basis for the further negotiations, improving the framework for renewables to thrive.

The **Sustainability Workstream** continued to position SolarPower Europe as the leading stakeholder on the Sustainable Product Policies initiative led by the EU Commission, which plans to introduce Ecodesign and Energy Label policy tools to solar modules, inverters, and systems. The group published an Expert Input Paper to review the results of the EU Commission's work and provide recommendations for the next regulatory discussions. In 2021, it has contributed to the publication of the Solar Sustainability Best Practices Benchmark, the first report of its kind to illustrate sustainability challenges and solutions in the solar industry. In addition, a new working group was created to work on solutions to increase PV supply chain transparency and address sustainability challenges.

On the **Communication** side, SolarPower Europe and Google launched the #SolarWorks awareness campaign, shining a light on growing solar job opportunities in Europe. This programme shows the diverse range of careers in the solar sector and aims to connect potential solar workers with the right training to get them started. The video series on some major solar markets (France, Germany, the Netherlands, Poland and Spain) is aimed at students, job seekers and people looking for reskilling opportunities. The campaign performed extremely well, significantly surpassing our forecasted targets across all metrics. Our main focus was Facebook, which also showed the best performance with 45 376 clicks to the campaign website and 78 536 video completions (watching the video 100 %). The final results show 81 214 video completions and we reached 457 709 users on all channels combined.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In May 2021, the **Agrisolar Workstream** developed the first edition of the SolarPower Europe Agrisolar Best Practice Guidelines. This landmark report defines 19 best practices in the EPC and the O&M of agrisolar projects to maximize the sustainability of agrisolar projects, from an agronomical, ecological, and financial perspective. The report also outlines key barriers for agrisolar and how to overcome them.

The **Lifecycle Quality Workstream** published an industry-first Lifecycle Quality best practice guidelines, focusing on the core concepts of quality assurance throughout an asset's lifecycle. Building on the successful launch of the first edition of the Engineering, Procurement, and Construction (EPC) guidelines in 2020, 2021 saw the development of the second edition along with the fifth edition of the P&M Best Practice Guidelines, incorporating more industry experience into more streamlined documents. The workstream, along with 20 partners, participated in TRUST-PV, a 4-year research project with over €12 million in grant value from the EU's Horizon 2020, aimed at improving the performance and reliability of solar power plants.

2021 saw the launch of SolarPower Europe's **Renewable Hydrogen Workstream** which strives to develop market and business intelligence on solar-to-hydrogen and renewable hydrogen. In close cooperation with high level industrial actors from across the EU, as well as with the Renewable Hydrogen Coalition, the Workstream develops recommendations from the solar industry to promote renewable hydrogen in key European policy files. With the ongoing negotiations on the Renewable Energy Directive and the Hydrogen and Decarbonised Gas package, 2022 will be a pivotal year for the Renewable Hydrogen Workstream.

The **Solar Buildings Workstream** continued its activities to mainstream solar within the EU's Renovation Wave and scale-up BIPV in Europe. The Solar Buildings workstream provided input to SolarPower Europe's contributions to the New European Bauhaus initiative. The workstream also advocated for an ambitious Recast

Energy Performance of Buildings Directive which should favours the deployment of decentralised energy resources in new buildings.

The **Solar & Storage Workstream** has closely followed the legislative process of the EU Battery Regulation, which is poised to introduce new sustainability and safety provisions for a broad range of batteries sold in the EU single market. The Workstream provided feedback to the draft policy proposals brought forward by the EU Commission and the EU Parliament, and published a position paper highlighting the industry's key priorities on this file.

INDUSTRY & MARKET DEVELOPMENT

2021 has been a challenging year with the ongoing pandemic, supply chain disruption, severe effects of the climate crisis and unprecedented high energy costs. More than ever before, solar is coming to the fore as the solution to some of our most pressing issues. In 2021, solar has not only grown, it has thrived, demonstrating once again its resilience, innovation and flexibility. According to SolarPower Europe's EU Market Outlook for Solar Power 2021-2025, the European Union has seen 25.9 GW of new solar PV capacity connected to the grid. This growth makes 2021 the best year in European solar history.

A highlight of 2021 was the launch of the European Solar Initiative together with EIT InnoEnergy which aims at redeveloping solar PV manufacturing in Europe. For the first time, the alliance sets an aspirational objective for the development of the industry:

Reestablishing

20 GW-worth

of solar PV manufacturing production in Europe, from polysilicon to module.

The endorsement of the strategic importance of solar PV manufacturing in Europe by both Commissioner Thierry Breton (responsible for industrial strategy) and Energy Commissioner Kadri Simson at the launch of the European Solar Initiative was a major milestone.

Related to the European Solar Initiative, the Industrial Strategy Workstream held a series of workshops to draft a Strategic Action Plan for the redevelopment of 20 GW of manufacturing. The alliance also creates an industrial platform aiming at structuring the industrial community and fostering the development of projects and a financing platform to de-risk and accelerate investments into new manufacturing projects. A briefing on the solar PV value chain was organized for the European Commission and the JRC.

The Emerging Markets Workstream wrote a solar investment opportunities report for Algeria, and participated in the EU-Algeria Energy Dialogue meeting. Members also published a regional investment opportunities report on the Middle East, with engagement ongoing in 2022. International cooperation was further enhanced through the signing of a partnership agreement with IRENA. The workstream published the South African edition of the O&M Best Practice Guidelines, combining their experience with that of South African stakeholders to spread industry best practices.

SolarPower Europe has increased its market intelligence output to a significant extent. In addition to the award-winning Global Market Outlook 2021-2025 and the EU Market Outlook 2021-2025 – the association's flagship reports on solar PV markets – our team has published two more reports, the European Market Outlook for Residential Battery Storage 2021-2025 and the EU Solar Jobs Report 2021, which are going to be released on an annual basis from now on.

2022 is set to be a phenomenal year for solar. For the first time, the world will reach Terawatt scale solar installation. In Europe, we expect to hit the 30 GW installation level. Yet, the challenge is clear: we need to speed up to meet the Paris Agreement objective to limit temperature rise to 1.5 degrees Celsius. We must transform to a 100 % renewables-based energy system and reinforce the goals of the European Green Deal. We don't have time to wait. At SolarPower Europe, we are working tirelessly to ensure the right framework empowering solar to reach its full potential – we can and must reach 870 GW by 2030!

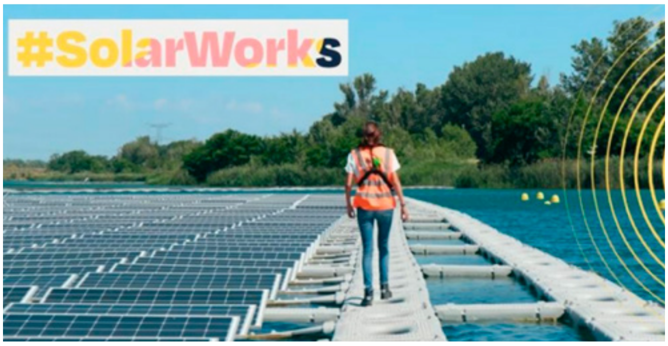

Fig.74 - #SolarWorks is an online awareness campaign launched by SolarPower Europe and Google to promote growing solar job opportunities in Europe. © SolarPower Europe

SPAIN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Ignacio Sánchez Manero (National Renewable Energy Centre of Spain, CENER); Eugenia Zugasti Rosende (National Renewable Energy Centre of Spain, CENER); Jaione Bengoechea Apezteguía (National Renewable Energy Centre of Spain, CENER)

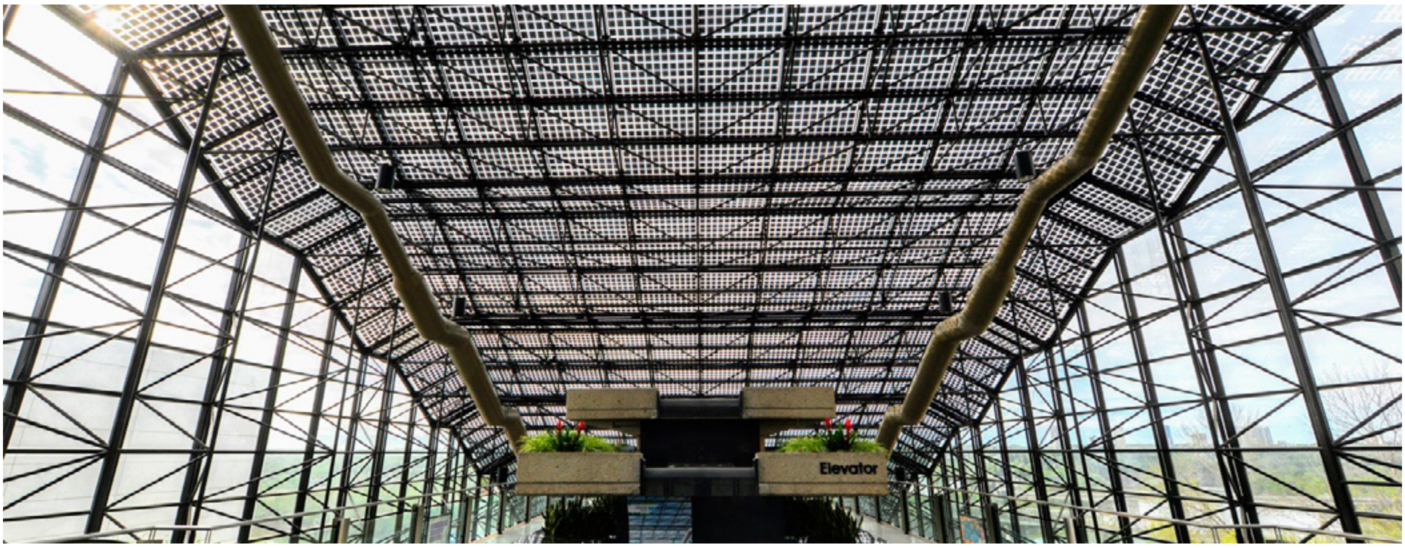

Fig.75 - Skylight Convention Centre Edmonton Canada. Courtesy of Onyx Solar.

NATIONAL PV POLICY PROGRAMME

In 2020, the Spanish government approved the "Integrated National Energy and Climate Plan" (INECP 2021-2030), that reflects Spain's commitment to achieve climate neutrality in 2050. Spain's INECP identifies the challenges and opportunities within the five dimensions of the Energy Union, such as decarbonisation (including renewable energy), energy efficiency, energy security, internal energy market, and research, innovation and competitiveness. Spain's objectives for 2030 include: 23 % reduction in greenhouse gas (GHG) emissions with respect to 1990 levels; a 42 % share of renewables in energy end-use; a 39.5 % improvement in energy efficiency; and a 74 % share of renewables in electricity generation. These shorter-term results will pave the way to the achievement of the longer-term objectives, namely the GHG emission neutrality in Spain by 2050.

This plan foresees a total installed capacity in the electricity sector of 161 GW for 2030, of which 39 GW will be provided by solar photovoltaic (PV) technology. In 2021, following the trend of the previous 2 years, Spain has been focused on an impressive deployment of renewable energy, essentially solar and wind in order to be able to meet the objectives defined in its agenda for energy and climate. In this regard, the announcement and deployment of PV plants has been continuous along the year 2021, with key national and international PV companies participating in them. In this regard, according to the Spanish National Association of Photovoltaic Energy Producers (ANPIER) Spain should limit the size of new solar plants and facilitate the deployment of smaller PV projects, closer to consumers.

As a reference, Spain hosts Europe's largest PV plant, the

500 MW project

from Iberdrola, Núñez De Balboa

After the previous Royal Decree 244/2019, Spain approved in 2021 the Royal Decree 477/2021, regulating the aids for the implementation of various incentive programmes related to self-consumption and storage, with renewable energy sources, and the implementation of renewable thermal systems in the residential sector. Spain's Ministry of Ecological Transition also supported distributed PV deployment allocating up to 140 MW of distributed solar PV capacity in the country's next auction (for year 2022). The government is also working on the National Floating PV Strategy, which is expected to be approved in the first quarter of 2022.

Finally, by the end of the year, the Spanish Government passed the Strategic Project for the Recovery and Economic Transformation of Renewable Energies, Renewable Hydrogen and Storage (PERTE ERHA). This initiative will mobilise resources worth 16.37 BEUR, of which 6.92 BEUR will come from the Recovery Transformation and Resilience Plan and more than 9.45 BEUR from the private sector, aiming at renovating the Spanish production model around the energy transition.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Ministry of Science and Innovation defines the framework for action in the field of research, development and innovation in two key documents: the Spanish Strategy for Science, Technology and Innovation 2021-2027 (EECTI) and the State Plan for Scientific and Technical Research and Innovation with a total budget of 10 357 MEUR which regular budget has been complemented with extraordinary 6 060 MEUR from the Plan for the Recovery, Transformation and Resilience.

R&D activities in Spain cover the whole value chain of the photovoltaic technology, from the development of PV cell technology up to the demonstration of different possibilities of application of PV systems. The projects funded by CDTI (Centre for the Development of Industrial Technology) in the first half-year of 2021, ranged from the investigation of lifetime of perovskite PV technology, to the inspection and optimization of PV plants, and distributed PV applied to the industrial sector, among others.

Besides, several H2020-funded projects, such as PROBONO, coordinated by ACCIONA *Ingeniería Especializada Obra Civil e Industrial* SA, and OPENLAB, with participation of several Spanish entities, aimed at demonstrating Positive Energy Neighbourhoods (PEN) through Living Labs (LL) all over Europe, for which photovoltaics remains a key technology. Regarding floating PV (FPV), several participants from the Canary Islands take part in the project BOOST targeted to develop a new FPV solution.

Perovskite PV is also a key emerging technology that is a focus of research in several Spanish organizations including VIPERLAB H2020-funded project, which facilitates and coordinates access to the best European perovskite virtual and physical infrastructures, as well as academic and industrial researchers. Other relevant projects include PrOperPhotoMiLe, Self-Power and APOLO. Finally, it is worth mentioning the research focused on development and demonstration of different recycling and reuse alternatives for photovoltaic components. Examples are the project ICARUS with the participation of CIDETEC, also the project PEACOC coordinated by TECNALIA and with the participation of CEINNMAT or PHOTORAMA with the participation of Mondragon Assembly and IDENER.

In addition to the many R&D projects, other innovative solar PV projects are paving the way in the Spanish landscape. In this regard, Spain's first community Agrivoltaics project, located in the Valencia region, was announced early in the year 2021. Also, the role of photovoltaics in the production of green hydrogen received increasing interest last year. As an example among many others, the Power to Green Hydrogen Mallorca (P2GH2M) announced a large-scale green hydrogen production. Finally, SENER Renewable Investment launched Solgest-1, the first hybrid concentrated solar power with storage (molten salt) and photovoltaic plant. With an installed power of 150 MW, the plant will be located in the province of Sevilla.

→ Spanish Experts participate currently in 8 PVPS Tasks involving 16 separate entities as listed here

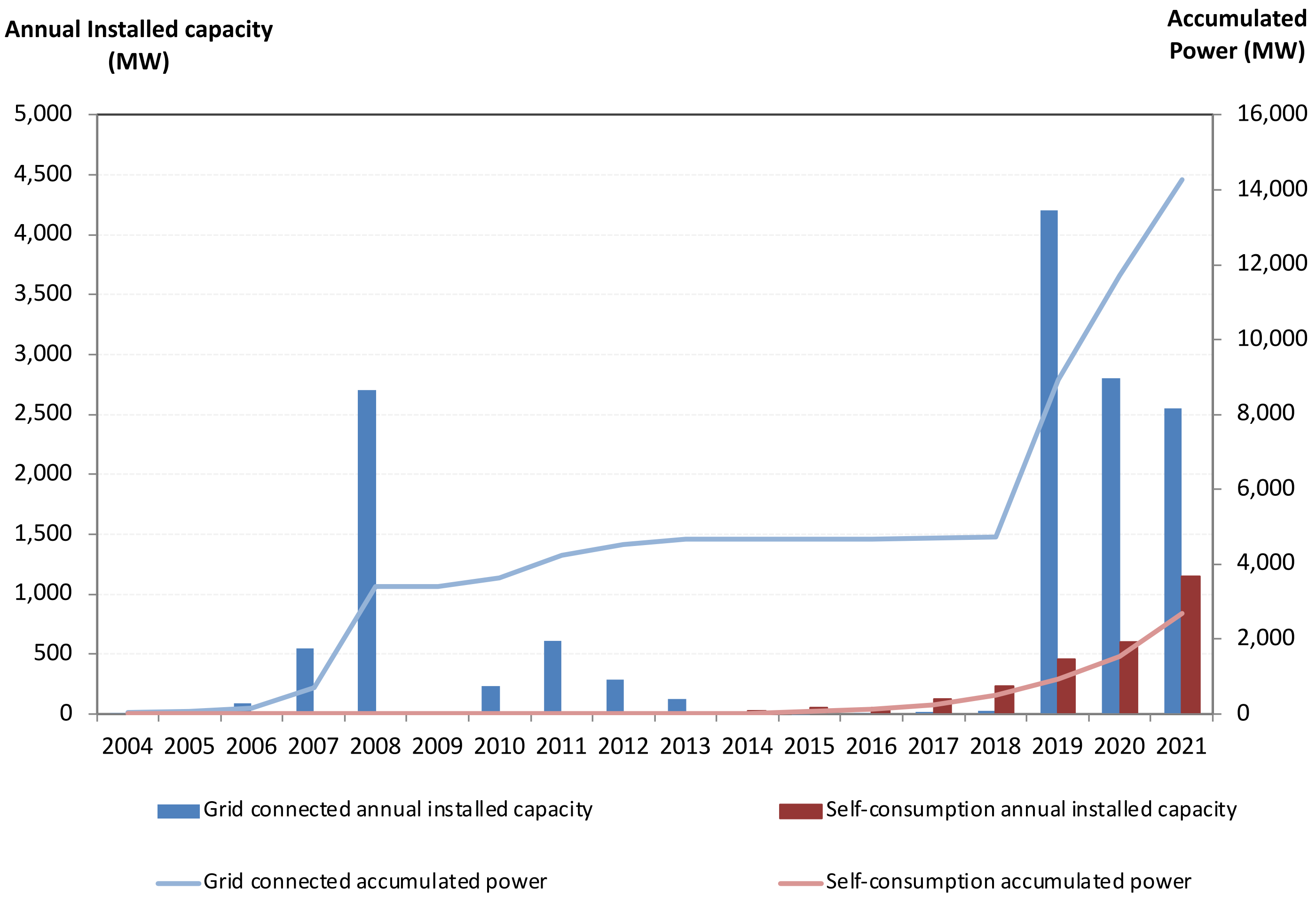

Fig.76 - Evolution of installed PV 2005 – 2021, including grid-connected and self-consumption.

INDUSTRY & MARKET DEVELOPMENT

Spain has been able to develop and maintain a strong role in the PV manufacturing chain with its own technology in elements with the highest added value such as power electronics, trackers, structures, EPCs, promoters and O&M companies. This sector has witnessed in 2021 important events such as the acquisition of the tracker manufacturer *Soluciones Técnicas Integrales* Norland (STI-Norland), by the USA-based Array Technologies. Besides, the certification company Applus+ completed last year its acquisition of Enertis, the Spanish engineering, consulting and inspection services provider for the PV industry.

Regarding the manufacturing of PV modules, Spain's industrial base of existing companies such as BSQ Solar, Atersa, and Onyx, as the BIPV tailored-solution provider (see Picture 1), was reinforced by new players, such as Escelco. In this respect, it is also worth mentioning Mondragon Assembly, the European leader in the production of technological equipment for the manufacturing of PV modules, providing turnkey production lines.

On top of this, the plans were announced last year by new PV manufacturing start-up, Greenland, to build a 5 GW integrated PV manufacturing plant in Sevilla. This is the first integrated PV plant to be installed in Spain in many years.

For another consecutive year, Spain has continued the growth trajectory of PV installed capacity initiated in 2019. More specifically, a total of 2 549 MW grid-connected have been added (see Picture 2; preliminary data out of the operator Red *Eléctrica de España*, REE) and 1 151 MW as self-consumption, amounting to a total accumulated installed capacity of 17 GW. Despite the COVID-19 health crisis and its financial impact, the sector has demonstrated its ability to overcome adverse circumstances and keep pace. The share of the peninsular electricity demand coverage positions PV with slightly more than 8 %, increasing from 6.1 % in year 2020 (see Figure 77). The information provided here corresponds to consolidated values up to 2020, provided by the grid operator REE.

The high prices of the spot electricity in this year, with an annual average price of 111 €/MWh, due mainly to elevated prices in the natural gas market, have stimulated the installation of PV self-consumption solutions for industry, neighborhood communities, shared electric consumption communities, and private households.

Looking forward, there are several factors to continue this tendency in the future. European funds for recovery "Next Generation EU" represent an important step for the green transition and therefore a support to the renewable energies, including photovoltaic and self-consumption.

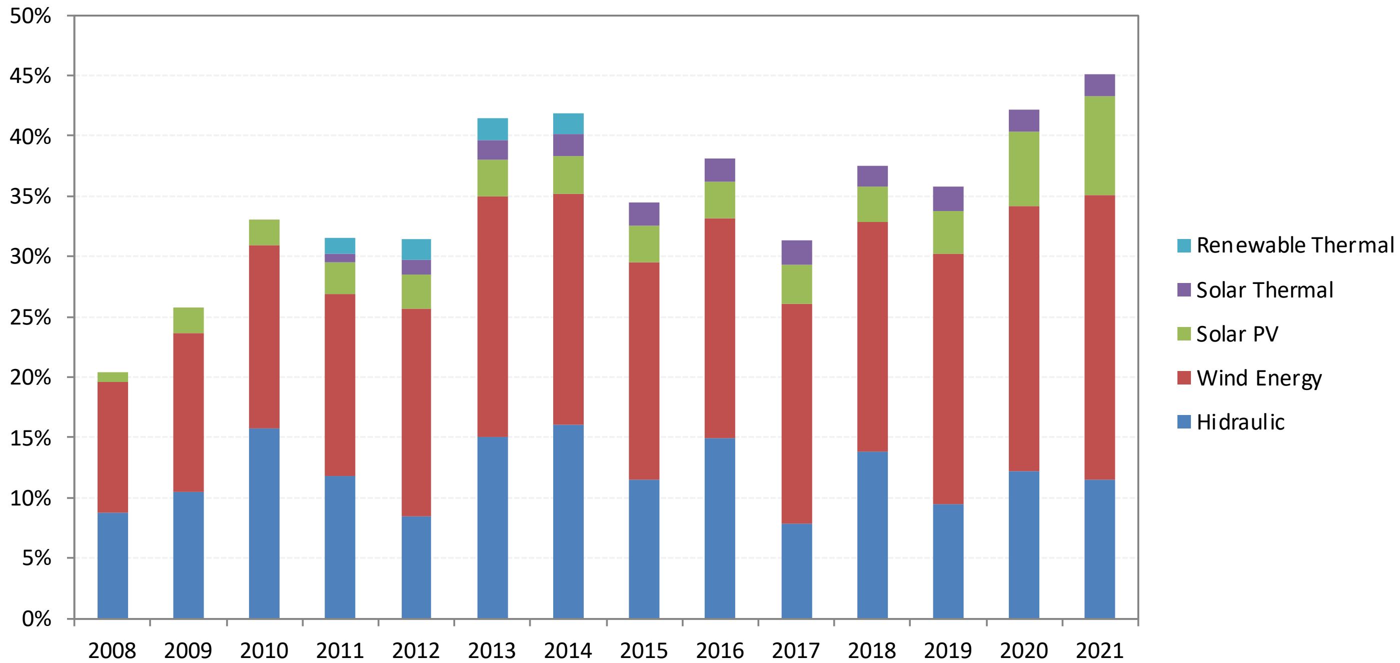

Fig.77 - Percentage of demand coverage from renewable energies.

REFERENCES

[1] Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030 (miteco.gob.es).

[2] Los Macroparques toman España frente al modelo más distribuido de Europa – Anpier.

[3] BOE Real Decreto 244/2019.

[4] BOE Real Decreto 477/2021.

[5] PERTE Energías Renovables.

[6] Spanish Strategy for Science, Technology and Innovation.

[7] State Plan for Scientific and Technical Research and Innovation.

SWEDEN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Tobias Walla (Swedish Energy Agency)

Fig.78 - The public was offered guided tours of the facility at the reopening of Sparbanken Skånes Solcellspark, a 18 MW PV project outside of Sjöbo. The facility ground is also used as grazing land for sheep. (Photo: © Svea Solar/ Sparbanken Skåne).

NATIONAL PV POLICY PROGRAMME

Sweden's goal for 2020 to have a renewable energy share of at least 50 % of the total energy use was achieved 8 years in advance, back in 2012! By the year 2020 the share was exceeding 60 %, which is the highest amount in the European Union.

In 2016, five parliamentary parties reached an agreement on Sweden's long-term energy policy. This agreement consists of a common roadmap, 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 relative to GDP.

While the common agreement still exists, the Moderate Party and Christian Democrats exited the agreement in 2019 due to disagreements about the first target above.

Sweden and Norway have a common technology-neutral market-based support system for renewable electricity production called "the electricity certificate system". The scheme has been an important driving force for the deployment of renewable energy during the last 10 years. The 2030 goal within the scheme of 46.4 TWh new renewable electricity production was reached already in 2021. Since the 31st December 2021 the scheme is closed for new applications.

A capital subsidy for PV installations was introduced in 2009. It was discontinued at the end of 2020. However, the government provided 260 MSEK in 2021 to cover existing applications that had not yet received support. Since 2021, the capital subsidy for PV installations for private individuals is replaced by a tax deduction for installation of green technology. Through this incentive a 15 % deduction for labor and material costs can be applied.

In 2015 a new tax credit scheme on small-scale renewable electricity production was introduced, which in practice works like a feed-in premium. The scheme entitles the owner of a PV system to a tax credit of 0.6 SEK 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.

The Swedish Energy Agency has developed a proposal for a national strategy to promote solar electricity. The strategy came out in 2016 and suggests that an annual production of 5-10 % PV production of total electricity usage (or 7-14 TWh) can be feasible in Sweden in 2040 (note that this figure is not an official national target).

RESEARCH, DEVELOPMENT & 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 an annual budget of 1400 MSEK and some 50 programmes and 1000 projects running, it is therefore the main funding source for research and innovation projects within PV.

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 (2016-2023) is about 280 MSEK. It includes both national and international research and innovation project. International projects are conducted in the EU collaboration SOLAR-ERA.NET.

In addition to the research funding distributed by the Swedish Energy Agency, three other bodies support PV related research: the Swedish Research Council, the Swedish Governmental Agency for Innovation Systems and the Swedish Foundation for Strategic Research. In total, about 142 MSEK was distributed from these four major actors to Swedish PV research in 2020.

There are strong academic groups performing research on a variety of PV technologies.

Comprehensive research in 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 start-up company Evolar, also located in Uppsala, is developing perovskite tandem solar cell technology to enable industrial-scale production.

An ongoing collaboration between Linkoping University, Chalmers University of Technology and Lund University, under the name Center of Organic Electronics, carries out research on organic and polymer solar cells.

Research on dye-sensitized solar cells is carried out at the Center of Molecular Devices. Two Swedish innovative companies, Exeger and Dyenamo, are developing and commercializing products based on this type of solar cells.

At Lund University, the division of Energy & Building Design studies energy-efficient buildings and how to integrate PV and solar thermal into those buildings. At the same university there is also extensive research on nanowire photovoltaics.

The Research Institute of Sweden AB (RISE) are conducting marked oriented research such as testing of PV components, systems and batteries along with BIPV and micro-grid research.

→ **Swedish Experts participate currently in 5 PVPS Tasks involving 11 separate entities as listed here**

INDUSTRY & MARKET DEVELOPMENT

The cumulative installed grid-connected PV power has grown from only 250 kW in 2005 to 1107 MW in 2020. The annual market for PV in Sweden grew by 42 % in 2020, as 400 MW was added. However, PV still accounts for only about 0.6 % of the total Swedish electricity production (159 TWh during 2020), 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 decentralized PV systems and by customers who buy and own their PV systems. However, utility-scale PV capacity grew by 250 % during 2020 compared to 2019. Large and centralized PV parks are now becoming more common and larger. The largest installation to date is an 18 MW PV park outside of Sjöbo.

The Swedish PV industry mainly consists of small to medium size installers and retailers of PV modules or systems. Over 300 companies sold and/or installed PV systems in 2020.

At the end of 2020, there were two active module manufacturing companies in Sweden (although the production volumes were small), 14 companies in manufacturing of production machines or balance of systems components, and at least 11 R&D companies.

In November 2021 it was announced that Exeger in partnership with ABB will build an industrial-scale factory in Kista outside of Stockholm with a capacity of 2.5 million m2 of solar cells per year. The product, called PowerFoyle, will be integrated into self-powered consumer product such as wireless earbuds and headphones. The first commercial headphones hit the market in October 2021.

By 2020

the share of renewable energy in Sweden exceeded 60 %

which is the highest fraction in the European Union

However, PV still accounts for only about 0.06 % of the total Swedish electricity production, which leaves a large potential for growth.

Fig.79 - Folded sheet metal roof with integrated CIGS solar cells, manufactured in Sweden by the company Midsummer. The roof has a PV capacity of 10,7 kW and is located in Österlen. (Photo: © Midsummer).

SWITZERLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Stefan Oberholzer (Swiss Federal Office of Energy SFOE); Stefan Nowak (NET Nowak Energie & Technologie AG)

Fig.80 - In 2021, a first larger agro-photovoltaic plant was put into operation in Switzerland. The technology was developed by the start-up Insoligt and is based on translucent solar modules, where the transparency can be varied using optical micro-tracking. The installation covers 165 m2 on a raspberry production farm. Other participants in this pilot project, supported by the SFOE, are Romande Energie as utility and Agroscope, the national centre of excellence for agricultural research (Image source: Insolight SA)

NATIONAL PV POLICY PROGRAMME

The "Energy Strategy 2050" forms the basis for Switzerland to transform its energy system in a sustainable and climate-friendly way. It is closely linked to national climate policy, where Switzerland has committed to halving its emissions by 2030 compared to 1990 as part of the Paris Climate Agreement, with the goal of climate neutrality by 2050. To define measures for the period 2021 to 2030, a complete revision of the CO_2 Act was envisaged with a series of measures for road and air transport and for the industrial and building sector. However, the Act failed to pass in a popular referendum in 2021 for several reasons. Climate measures already adopted in the existing CO_2 Act, which were limited in time, will be extended. The political discussion for a follow-up solution to achieve the goals of the Paris Climate Agreement continues. The government communicated that the already defined benchmarks of a halving target for emissions by 2030 and net zero by 2050 shall be adhered to and opened a consultation on a revised CO_2 Act in mid-December 2021. The new proposal addresses sectors that are central to climate protection, buildings and mobility with financing programmes for building renovation and the switch to climate-friendly heating systems, with funds for the development of charging infrastructure for electric vehicles, the conversion of bus fleets, risk coverage for the expansion of district heating networks and blending quotas for renewable aviation fuels (similar to regulations in the EU).

Mid-2021, the government passed a law on a secure electricity supply with renewables, which includes a revision of the Energy and Electricity Supply Act and is intended to strengthen the expansion of domestic renewable energies and Switzerland's security of supply, especially for the winter season. Measures proposed therein, like the introduction of a hydropower reserve for winter electricity supply, will be debated in parliament early in 2022. As in other countries, the political discussion about security of supply is in full swing, especially with regard to the electricity sector.

Photovoltaic power is the most important form of

renewable energy

in Switzerland after hydropower.

In parallel, nuclear power plants will be decommissioned in the coming decades and no new nuclear power plants are planned to be built. In winter, so far demand has been offset by imports from abroad, but future developments are uncertain, also due to the lack of an electricity agreement with the EU.

For an increasing number of stakeholders, targets for the development of photovoltaics in Switzerland are not ambitious enough. Apart from more ambitious expansion targets, points are brought into the discussion such as (1) an increase in the grid surcharge for promotion as well as a uniformly regulated purchase tariff in order to improve investment security for national plants, (2) the establishment of local energy communities or (3) a nationally uniform obligation to use suitable surfaces on new buildings. Also in 2021, a parliamentary initiative to extend the promotion of renewable energies (including photovoltaics) with investment contributions until 2030 was adopted by parliament to prevent a gap after the feed-in tariff system, limited to the end of 2022.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In Switzerland, approximately 35 million Euros of public funding is used for Research Technology & Development (RTD) in the field of photovoltaics (figures for 2020), 20 % thereof for pilot and demonstration. A large part of these funds is deployed competitively through various funding sources, with projects in the European context accounting for a large share. 92 projects are currently (31.1.2022) ongoing in various technology areas: 10 % in the area of Crystalline silicon, 19 % in the area of other cell technologies (perovskite, CIGS), 6 % on tandem approaches, 14 % on module technology and module testing, 10 % on BIPV, 7 % for grid integration, 7 % in new mounting technologies and the rest in different areas (LCA, forecasting etc.)

The Photovoltaics RTD Programme of the Swiss Federal Office of Energy (SFOE) involves a broad range of stakeholders and is part of long-standing coordinative activities by the SFOE to support research and development of energy technologies in Switzerland. SFOE funds are deployed in a subsidiary manner to fill gaps in Switzerland's funding landscape. Grants are given to private entities, the domain of the Swiss Federal Institutes of Technology (ETH), universities of applied sciences and universities.

As an R&D-highlight worth mentioning, the nationwide PV hosting capacity and energy storage needs for distribution grids were analysed in the context of a major research collaboration (Swiss Competence Center for Energy Research: Future Swiss Electrical Infrastructure, SCCER-FURIES) ∆. Since nationwide models of distribution grids are usually not available, the problem of estimating those from publicly available datasets was addressed and a method was developed to more accurately calculate the PV generation capacity and extend that capacity with energy storage systems. A detailed regional analysis shows that energy storage requirements are relatively low before rising sharply after 14 GW of installed PV capacity (cumulatively installed until 2020: 3 GW). Cost efficiency is higher for PV systems installed with larger capacity factors. In terms of increasing the PV uptake capacity of highly insulated distribution grids, investments in decentralised storage can be more efficient than installing PV systems with a low capacity factor.

At the Swiss Federal Institute of Technology Lausanne (EPFL) and at the PV Center of CSEM (Centre Suisse d'Electronique et de Microtechnique) in Neuchatel, major research projects are underway in the field of passivating contacts for crystalline silicon solar cells, which are key to a enable higher conversion efficiencies, in a way compatible with industrial production processes. As R&D-highlight in this field, a fabrication process for double-sided contacted c-Si solar cells with localised passivating contacts on the front side was presented◊. Although the approach is first intended for the front side only, it can also be applied to the back side of solar cells for bifacial applications. Promising efficiencies of up to 21.7 % with high open-circuit voltage (>710 mV) and high fill factor (80 %) were demonstrated.

→ Swiss Experts participate currently in 7 PVPS Tasks involving 12 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

Swiss power generation in 2020 comprised run-of-river power (25.2 %), hydro storage power (32.9 %), nuclear energy (32.9 %), renewables (5.0 %) and other sources. Renewable power generation increased by 17 % to 3.5 GWh in 2020 compared to 2019, with PV (2.6 GWh in 2020) the largest contribution and the most important renewable power source after hydropower (40.6 GWh). While annual PV capacity expansion between 2015 and 2019 was on average 290 MW, a record of 475 MW was added in 2020. Definitive figures for 2021 are not yet available, but the PV add-on could exceed 600 MW.

In recent years, the PV market in Switzerland has been largely driven by self-consumption. With the aforementioned adjustments to framework conditions and with further political initiatives, the incentives for the construction of larger systems are being improved. Depending on the specific energy scenario, however, further acceleration in PV expansion is necessary to achieve the targeted goals.

Industry players in Switzerland are grouped more or less along the entire photovoltaic value chain. A wide range of competitive technologies, products and services are offered for the growing photovoltaic market. An overview of the players can be found here.

The Swiss solar cell and module manufacturer Meyer Burger started operations at its production site in Germany in 2021 with a first expansion phase of 400 MW, applying the heterojunction/SmartWire technology developed to a large extent in Switzerland. According to Meyer Burger, financing has been secured for an accelerated expansion of further production capacities in order to reach 1.4 GW cell and module production capacity by the end of 2022, as well as to finance further growth. Meanwhile, Meyer Burger also announced plans to ramp up production capacities outside Europe.

Fig.81 - The installation on a raspberry production farm

∆ Countrywide PV hosting capacity and energy storage requirements for distribution networks: The case of Switzerland, Gupta, R., Sossan, F., Paolone, M.; Ap-plied Energy, 280 p116010 (2020)

◊ Localisation of front side passivating contacts for direct metallisation of high-efficiency c-Si solar cells, Meyer, F., Ingenito, A., Díaz León, J., Niquille, X., Allebé, C., Nicolay, S., Haug, F.-J., Ballif, C.; Solar Energy Materi-als and Solar Cells 235 p111455 (2022)

THAILAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Arkorn Soikaew (Department of Alternative Energy Development and Efficiency, Ministry of Energy of Thailand)

Fig.82 - The PEA+NSTDA portable "SolarMove" product designed to help unelectrified regions of Thailand.

NATIONAL PV POLICY PROGRAMME

Thailand has continually promoted PV system installation for quite a long time.

The Power Development Plan 2018 Rev.1 has set the target for Thailand's new PV installations at 9 290 MWp and floating PV at

2 725 MW by 2037

In 2021, the residential solar rooftop project continued to support the prosumers concepts of residential households with the emphasis on self-consumption and the FiT of 2.20 THB/kWh ($0.067 USD/kWh) for selling excess electricity back to the grid. The target of this year was set to be 50 MWp. However, higher public acceptance of this program is yet to be achieved as less than 5 MWp were installed. A public relations project is running for this purpose.

In 2021, the concept of a solar rooftop project for hospitals, academic institutions and agriculture was carried out to establish legal frameworks and support schemes in the near future. The FiT of this program was expected to be around 1 THB/kWh ($0.03 USD/kWh). The initial target of this program is 50 MWp in total – 20 MW for hospitals, 20 MW for schools and colleges, and 10 MW for agricultural water pumping.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Perovskite cells are under investigation from many leading research institutes in Thailand, including Chulalongkorn University, King Mongkut's University of Technology Thonburi (KMUTT), Mahidol University, Kasetsart University, Khon Kaen University, and National Science and Technology Development Agency (NSTDA). Research topics included designing new perovskite cell materials, surface photovoltage studies, cell structure characterization, development of novel methodologies, and stability improvement of perovskite cells.

There are also several research projects in PV power system improvements, such as those by KMUTT in PV module reliability of 18-year rooftop systems, PV power plant nowcasting with cloud tracking and deep learning. Moreover, KMUTT is developing approaches for re-using PV modules via a standard testing method to determine the service life and movable hybrid PV system (Wind turbine + PV) as well as micro-grid PV system on the island.

Furthermore, concentrated PV feasibility studies and demonstration projects are conducted by the state-enterprise Electricity Generating Authority of Thailand (EGAT).

In order to reach the last 0.03 % unelectrified portion of Thailand due to some legal complications, the Provincial Electricity Authority (PEA) and NSTDA are developing the SolarMove product, a portable integrated package of PV panels plus inverter and storage compartments to provide electricity access to those regions.

→ Thai Experts participate currently in 2 PVPS Tasks involving 2 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

In 2020, Thailand's total PV installed capacity stood at 3 939.8 MWp, a 143.6 MWp increase from 2019. In recent years, the PV market in Thailand has shifted towards further decentralization.

Thailand has been known to host both local and international PV manufacturers that produce a wide range of PV module products including crystalline silicon PV modules for large scale systems and high efficiency PV modules for rooftop PV systems. There are 15 PV manufacturers in Thailand, around half being international companies and the other half local manufacturers. The ongoing solar rooftop projects for households (and also for hospitals, schools and agricultures) will play an important role in penetrating new PV markets in Thailand.

PV panel manufacturing in Thailand is primarily aimed at exports with the total production capacity of

8 GW per year

while the domestic market is dependent on government projects (with certified standards)

Electricity generation from PV in Thailand can be implemented either for power purchasing (either in Adder or FiT scheme) or for self-consumption (to reduce electricity bills and to comply with carbon tax measures especially those in industrial estate areas). This would lead to more private sector growth in solar PV businesses in Thailand.

Apart from growth in PV cell and panel manufacturers, inverter and battery storage industries also show an upward trend of interest in response to the rising demand of PV rooftop and renewable energy installation and EVs expansion. These businesses are supported by both the public and private sectors with the aim of driving Thailand's energy sector to become more sustainable.

TURKEY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Prof. Dr. Abdullah CEYLAN, (TENMAK-Clean Energy Research Institute); Prof.Dr. Raşit Turan, Dr. Nilsun Hasançebi (ODTÜ-GÜNAM (Middle East Technical University Center for Solar Energy Research and Applications))

NATIONAL PV POLICY PROGRAMME

Turkey has been supporting the renewable energy sources through several programmes such as the Renewable Energy Support Mechanism (YEKDEM) and special auctions for large solar energy power plants with a purchase guarantee for a certain time interval. National policies aiming to increase the share of renewable energy in the electricity generation are formulated and implemented by the Ministry of Energy and Natural Resources (MENR). The YEKDEM mechanism is based on a Feed-in Tariff (FiT) system providing a purchase guarantee for PV electricity since 2011 with a flat price rate of 0.133 USD/kWh. There are also some additional supports for the use of equipment manufactured domestically. The system has been closed to new entries at this point due to policy changes and the necessity to revise the price in response to drastic reductions in the manufacturing cost of PV system components. The capacity increase from almost zero to 7.8 GW at the end of 2021 has been driven by the incentives provided by this system. The majority of the power plants installed under the YEKDEM system are operated according to the regulations on Unlicensed Electricity Generation in the Electricity Market.

The government introduced a new mechanism called Renewable Energy Resource Areas (YEKA) in 2016. The YEKA system introduced a new tender process to deploy renewable energy power plants (solar and wind) in pre-specified areas. The government plans to commission 10 GW PV solar capacity in the period 2017-2027, 1 GW each year. Each tender has its own technical and financial regulations and requirements. The first YEKA tender for a 1 GW installation in the Konya-Karapinar region was concluded in 2017 with a purchase price guaranteed rate of 6.99 c$/kWh. One of the requirements of this tender was to manufacture all components of the power plant domestically. As a result, a new manufacturing facility with an annual capacity of 500 MW for solar cells, Si ingot, wafer and modules started production in 2020. The Konya-Karapinar 1 GW power plant is expected to be completed in 2022. Another YEKA tender was concluded in 2021 for 74 distributed small power plants with a total capacity of 1 GW. Due to high competition, extremely low prices down to 2.8 c$/kWh were offered by the companies. This tender has shown PV electricity's solid and very competitive position in Turkey. Two new YEKA tenders are being prepared for 2022 by the MENR.

In May 2019, the government introduced a new regulation for residential, commercial and industrial applications. This system sets the power value in the connection agreement of the subscriber as an upper limit for the capacity of the application. It also allows the subscribers to sell the excess generation to the grid with the retail price for ten years. This upper limit for the private residential subscribers has been set to be 10 kW which is usually higher than many individual residential applications. The upper limit can be up to MW level for commercial, public, and industrial applications and contributed to the growth of the PV systems in Turkey in 2021.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Research, Development and Demonstration (RD&D) activities are primarily carried out at universities, public and private research centers in Turkey. Involvement and contribution of the private sector has been weak. Most of the RD&D projects are realized with the support from the main funding agency, The Scientific and Technological Research Council of Turkey (TUBITAK). TUBITAK offers research entities in Turkey a variety of over 50 grant-based support mechanisms, which are differentiated based on the distinct needs of researchers in the private and public sectors. Among these programs, Program #1007 and #1004 offer large project budgets to meet the needs of public institutions and to realize large projects carried out by a consortium rather than individual entities.

One of the #1007 projects, entitled "Development of National Solar Energy Power Plant (MILGES)", was carried out by TUBITAK Marmara Research Center (TUBITAK-MAM), Middle East Technical University-The Center for Solar Energy Research Center (ODTU-GUNAM) and Parla Solar, and completed in 2021. In this project, a 6 MW power plant in the city of Urfa in the southeast of Turkey was installed using components, solar cells, modules and power electronic components that were all developed and produced domestically. Program #1004 of TUBITAK aims to form high technology platforms in Turkey. It provides a generous budget to carry out some RD&D projects. The first #1004 call was concluded in 2020, and project grants have been awarded in 2021. Formation of the Turkish Photovoltaic Technology Platform (TFTP) led by ODTÜ-GÜNAM (Center for Solar Energy Research and Applications) is among the winning proposals. TFTP is currently executing several RD&D projects with three partners from the public domain and five from the private sector.

Turkey has been participating in the European Union Framework Programs supporting the RD&D project through many project calls coordinated by the EU offices in Brussels. The most recent program called Horizon Europe has started in 2021 and will continue until 2027. There have been several project calls in the field of PV technologies and their applications. Various RD&D entities have taken part in the EU programs.

Turkey supports the creation of RD&D infrastructures through different support mechanisms. The parliament approved a new law aiming to create and sustain independent public research centers in 2014. The government provides a special budget and a personnel regime to these centers. Among seven such centers chosen by the authorities, ODTÜ-GÜNAM has been focusing on developing PV system technologies (cells, modules, inverters, etc.) and their applications. Comprehensive technical infrastructure and human capital have been created at this center.

In 2021, MENR initiated a new research structure called TENMAK (Turkish Energy Nuclear and Mineral Research Agency), which is an umbrella organization hosting five research institutes including the Clean Energy Research Institute. TENMAK is currently developing roadmaps for RD&D activities for its research institutes.

INDUSTRY & MARKET DEVELOPMENT

Rising concerns about climate change, the health effects of air pollution, energy security and energy access, along with volatile oil prices in recent decades, have led to the need to produce and use alternative, low-carbon technology options such as renewables. Solar PV has been one of the pioneering renewable technologies both on a global scale as well as within Turkey.

In 2014, the solar energy sector in Turkey started to mobilize with the installation of about

40 MW **and by the end of 2021 it**

had reached an installed capacity of

about 7.7 GW

The increase in investment in solar energy has naturally led to the domestic production of PV panels. When the data for the year 2021 were analyzed, it was found that 22 companies in Turkey produce PV Panels and 1 of them also produces domestically solar cells with annual production capacity of 500 MW. Two other smaller solar cell production facilities with a capacity around 150 MW were built. In addition, with the establishment of a new factory with a production capacity of 500 MW, the domestic PV module production capacity has reached about 6.5 GW per year. It is expected that this figure will increase rapidly with new investments to be made.

When we evaluate the export performance of PV companies in Turkey, we do see that 25 % of the companies producing PV panels in Turkey export less than 10 % of their products, 70 % of the companies export 10 %-30 % and only one or two companies export 85 % of their products abroad (Stantec, 2020). The total annual export amount is approximately $31 million (Solarbaba, 2021). If we evaluate the export markets of companies producing PV panels in Turkey, the most important market is the Middle East with a 27 % share, followed by Europe (20 %) and Africa (16 %). We can say that the companies producing PV panels in Turkey are focused on the domestic markets in general, but the companies are increasing their exports and country/region portfolios.

Total PV imports in Turkey amount to $93 million annually (Solarbaba, 2021). However, the imports are increasing faster than exports. The most important problem in the sector is that access to finance is not easy and appropriate financing opportunities are limited. Finding suitable financing sources for increasing investments in solar energy and, accordingly, investments in PV panel production is one of the issues that should be on the policy agenda.

REFERENCES

Solarbaba, 2021., Sunny, 120 p., www.solarbaba.com

Stantec, 2020., Market Research on PV Panel Production in Turkey, 26 p. (in Turkish)

TEİAŞ, 2021., October 2021 Installed Capacity Report, 1 p. (in Turkish)

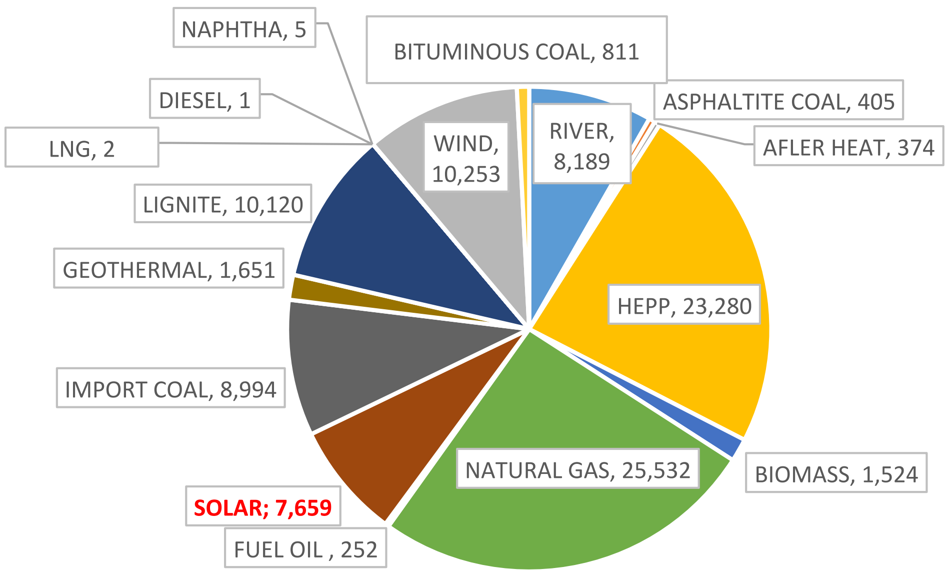

Fig.83 - Installed Capacity in Turkey according to sources (MW) in October 2021 Source: TEIAS, 2021

THE UNITED STATES OF AMERICA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Christopher Anderson (Solar Energy Technologies Office, U.S. DOE); David Feldman (National Renewable Energy Laboratory)

NATIONAL PV POLICY PROGRAMME

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 vary in form and magnitude. In 2021, there was not a national-level deployment mandate, but President Biden signed Executive Order 14057 which targets a carbon pollution free electricity sector by 2035 and net zero emissions economy wide by 2050. [1] Furthermore, individual state mandates have been successfully implemented, with 2021 bringing several new or modified mandates. Existing policy at the national and state level and rapid declines in technology costs have enabled PV to continue to grow rapidly in the U.S. As of the end of Q3 2021, the U.S. reached 112.4 GWDC of cumulative installed capacity, an increase from 95.1 GWDC in 2020, and 75.9 GWDC in 2019. [2] This deployment translated to an AC capacity of 88.5 GWAC in 2021, increasing from 73.9 GWAC in 2020, and 58.9 GWAC in 2019. [3]

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 had 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). Beginning in 2020, the credits stepped down from 30 % to 26 %. The credits drop again to 22 % for all projects starting construction in 2023 before expiring for residential markets and falling to 10 % for commercial and utility markets starting construction in 2024 or placed in service after 2025. Pending legislation (H.R. 5376, the Build Back Better Act) would extend the ITC by ten years. [4]

State incentives in the U.S. have been driven in large part by 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 vary considerably, RPS policies typically enforce compliance through penalties, and many include the trading of renewable energy certificates (RECs). Alternatively, a clean energy standard (CES) is similar to an RPS, but allows a broader range of electricity generation (e.g., nuclear) resources to qualify for the target. At the end of 2021, thirty-one states, four territories, and Washington D.C., had RPS policies or goals with specific solar or customer-sited provisions, while five states had CES policies. Four states – Delaware, Oregon, North Carolina, and Illinois – updated their RPS or CES in 2021.

In addition, Nebraska approved its first clean energy goal in December 2021, becoming the 20th U.S. state to commit to 100 % clean electricity by 2050. [5,6]

RESEARCH, DEVELOPMENT & DEMONSTRATION

The DOE is one of the primary bodies that supports research, development, and demonstration (RD&D) of solar energy technologies. In 2017, DOE announced that it had met its benchmark utility-scale 2020 goal of 6 USDcent/kWh and increased its focus on addressing the challenges of integrating increasing amounts of solar energy into the electricity grid by introducing a target of 3 USDcent/kWh by 2030. However, to meet the urgency of the climate crisis and President Biden's Executive Order 14057, it is estimated that solar deployment needs to increase by three to five times, and therefore, costs need to fall faster. Recognizing this need, SETO has accelerated its goal to 2 USDcent/kWh by 2030.

By funding a portfolio of complementary RD&D concepts, SETO promotes transformation in the way the U.S. generates, stores, and utilizes solar energy. These RD&D activities fall into five broad categories:

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 incorporate thermal energy storage to supply solar power on demand, as well as heat for direct use in industrial processes.
3. Systems Integration, which develops technologies to enable improved integration of solar power with the power grid including power electronics and systems-level research on renewables integration.
4. Balance of Systems Soft Cost Reduction, which works with a diverse set of stakeholders to cut red tape, streamline processes, and increase access to solar.
5. Innovations in Manufacturing Competitiveness, which supports U.S. businesses with innovative solar products to develop prototypes and validate their technologies.

The U.S. government also provides support for PV research through its work at the National Science Foundation, the Department of Defense, the National Aeronautics and Space Administration, and the Department of Energy's (DOE) Office of Science, Advanced Research Projects Agency - Energy (ARPA-E), and the Solar Energy Technologies Office (SETO). In addition to the U.S. government, states such as California, New York, Florida and Hawaii, as well as public and private companies also fund solar R&D.

→ US Experts participate currently in 5 PVPS Tasks involving 14 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

The first three quarters of 2021 saw significant PV installation growth in the U.S., increasing from 19.2 GWDC in 2020 to an estimated 27 GWDC by the end of 2021. [7] 2021 is likely to have seen the largest single-year increase in U.S. installed solar electric generation capacity, breaking the record set in 2020.

In January 2018, the previous presidential administration placed a tariff for a period of four years on imported cells and modules. The tariff was set at 30 % in the first year and fell to 20 % in 2020, from where it was scheduled to be further reduced by five percent in each of the next two years. The first 2.5 GW of cells imported each year were excluded, as well as certain other modules, such as ones with IBC cells (starting in September 2018) and bifacial cells (starting in June 2019). At the end of 2020, the President increased the tariff beginning in February 2021 to 18 % from the scheduled 15 % and, at around the same time, the U.S. Court of International Trade repealed the exclusion on bifacial cells. The U.S. Court of International Trade reinstated the Section 201 tariff bifacial exemption in November 2021 and reset the tariffs to 15 % (from 18 %). In Q1–Q3 2021, 11.6 GWDC of imported PV modules (62 % of all PV module imports) reported a tariff. [8] In February 2022, the President extended the tariffs at 15 %, with a bifacial exclusion and 2.5 GWDC cell exclusion.

In September, Illinois enacted expansive clean energy legislation (the Climate and Equitable Jobs Act) which increased its RPS to 40 % by 2030 and 50 % by 2050. It also set a date for a net metering transition. [9]

In December, California's Public Utility Commission proposed cutting compensation and levying a fee on distributed PV on the belief that it shifts costs and disproportionally harms lower income customers. This shift may serve to incentivize further growth of storage capacity. [10] California is the largest distributed market in the U.S., representing approximately 39 % of all U.S. distributed PV projects. [11]

The United States installed approximately

5.7 GWh / 1.9 GW_{AC}

of energy storage onto the electric grid in the first nine months of 2021, an increase of

419 % y/y

due to record levels of residential and front-of-the-meter deployment (mostly in California). [12]

Sector trends remained largely unchanged from 2020, with 2021 seeing growth in Residential and Utility scale installations, while the rate of Non-residential (or Commercial, including community solar) capacity growth has likely remained stable due to increases in demand offset by interconnection delays and price increases. [13]

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-Alone 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-Alone Photovoltaic Power Systems, T3-10:2002
8. Testing of Lead-Acid Batteries used in Stand-Alone PV Power Systems – Guidelines, T3-11:2002
9. Selecting Stand-Alone Photovoltaic Systems – Guidelines, T3-12:2002
10. Monitoring Stand-Alone Photovoltaic Systems: Methodology and Equipment - Recommended Practices, T3-13:2003
11. Protection against the Effects of Lightning on Stand-Alone Photovoltaic Systems - Common Practices, T3-14:2003
12. Managing the Quality of Stand-Alone Photovoltaic Systems-Recommended Practices, T3-15:2003
13. Demand Side Management for Stand-Alone Photovoltaic Systems, T3-16:2003
14. Selecting Lead-Acid Batteries Used in Stand-Alone Photovoltaic Power Systems – Guidelines, T3-17:2004
15. Alternative to Lead-Acid Batteries in Stand-Alone 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

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 9 – DEPLOYMENT PV SERVICES FOR REGIONAL DEVELOPMENT (1998-2018)

Task 9 Reports

1. Financing Mechanisms for SHS in Developing Countries, T9-01:2002
2. Summary of Models for the Implementation of Photovoltaic SHS in Developing Countries, T9-02:2003
3. PV for Rural Electrification in Developing Countries – A Guide to Capacity Building Requirements, T9-03:2003
4. The Role of Quality Management Hardware Certification and Accredited Training in PV Programmes in Developing Countries: Recommended Practices, T9-04:2003
5. PV for Rural Electrification in Developing Countries – Programme Design, Planning and Implementation, T9-05:2003
6. Institutional Framework and Financial Instruments for PV Deployment in Developing Countries, T9-06:2003
7. 16 Case Studies on the Deployment of Photovoltaic Technologies in Developing Countries, T9-07:2003
8. Sources of Financing for PV-Based Rural Electrification inDeveloping Countries, T9-08: 2004
9. Renewable Energy Services for Developing Countries, in support of the Millennium Development Goals: Recommended Practice and Key Lessons, T9-09:2008
10. Task 9 Flyer: PV Injection in Isolated Diesel Grids, T9-10:2008
11. Policy Recommendations to Improve the Sustainability of Rural Water Supply Systems, T9-11: 2011
12. Pico Solar PV Systems for Remote Homes, T9-12:2012
13. Rural Electrification with PV Hybrid Systems - 2013 (En), T9-13:2013
14. Mini-réseaux hybrides PV-diesel pour l'électrification rurale - 2013 (Fr), T9-13 :2013
15. Innovative Business Models and Financing Mechanisms for PV Deployment in Emerging Regions, T9-14:2014
16. PV Systems for Rural Health Facilities in Developing Areas, T9-15:2014
17. A User Guide to Simple Monitoring and Sustainable Operation of PV-diesel Hybrid Systems, T9-16:2015
18. Guideline to Introducing Quality Renewable Energy Technician Training Programs, T9-17:2017
19. PV Development via Prosumers. Challenges Associated with Producing and Self-consuming Electricity from Grid-tied, Small PV Plants in Developing Countries, T9-18:2018

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

CURRENT TASK DESCRIPTIONS

TASK 1

TASK OBJECTIVES

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. This activity will be transferred to the executive secretary in 2022.
- Task 1 contributes to the cooperation with other organizations and stakeholders.

TASK STRUCTURE

The 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.

Subtask 1.2: Think Tank activitie

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 and focused on several special topics since 2013 including: self-consumption policies; PPAs and merchant PV; PV for transport; solar fuels; PV as an enabler of the energy transition; policy recommendations and analysis. In 2022 Task 1 will focus on the question of social acceptance, which is increasingly at the core of discussions due to the growing visibility of PV development globally.

Subtask 1.3: Communication activities

Task 1 aims at communicating about the main findings of its experts through the most adequate communication channels.

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 and stakeholders outside the IEA network: IRENA, ISES, REN21, ISA and more.

PVPS TASK REPORTS

All Task 1's PVPS Publications, including 12 new Technical Reports from 2021, are available here

OTHER TASK PUBLICATIONS

We provide market data about PV development to the REN21 Global Status Report.

TASK 12

TASK OBJECTIVES

Within the framework of PVPS, the goal of Task 12 is to foster international collaboration and knowledge creation in PV environmental sustainability and safety, as crucial elements for the sustainable growth of PV as a major contributor to global energy supply and emission reductions of the member countries and the world. 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 policy maker 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 regarding all dimensions of sustainability.

The current objectives of Task 12 are to:

1. Quantify the environmental profile of PV in comparison to other energy technologies.
2. Investigate end of life management options for PV systems as deployment increases and older systems are decommissioned.
3. Define and address environmental health & safety and other sustainability issues that are important for market growth.

TASK STRUCTURE

Subtask 1: End of Life of PV Systems

The main objectives within this subtask are:

- Assist the development of collection infrastructure by examining and evaluating other recyclable industries (e.g., electronics, liquid crystal displays)
- Enhance the interaction among industry players so they share information and resources for collection and recycling
- Show the technical and cost feasibility of collection and recycling
- Identify common tasks where financial resources can be shared (e.g., separation of EVA from the module).

Subtask 2: Life Cycle Assessment (LCA)

The main objectives within this subtask are:

- Establish and demonstrate, with comprehensive and transparent LCA studies, that PV systems are environmentally friendly compared to other energy systems.
- Show the improvement trends of the PV environmental profile by certain indicators (e.g., EPBT, GHG emissions, waste reduction, recycling, etc.).
- Continue showing such progress in annual updates over the course of Task 12 (5 years).
- Valuate the environmental benefits of PV by showing avoided impacts or avoided "external" costs.

Subtask 3: Monitoring - Operation & Maintenance

The main objectives within this subtask are:

- Develop risk factors and compare PV with other energy technologies
- Identify accident prevention and control options for specific technologies
- Identify pollution control technologies for major types of PV manufacturing facilities
- Identify prevention and control strategies for green-house gases in PV manufacturing facilities

PVPS TASK REPORTS

All Task 12's PVPS Publications, including 4 new Technical Reports from 2021, are available here

TASK 13

TASK OBJECTIVES

The overall objective of Task 13 is to provide a common platform to summarize and report on technical aspects affecting the quality, performance, and reliability of PV systems in a wide variety of environments and applications. By working together across national boundaries we can all take advantage of research and experience from each member country and combine and integrate this knowledge into valuable summaries of best practices and methods for ensuring PV systems perform at their optimum. Specifically we aim to:

- Gather the most up-to-date information from each member country on a variety of technical issues related to PV performance and reliability. This will include summaries of different practices from each country, experiences with a variety of PV technologies and system designs.
- Gather measured data from PV systems from around the world. This data will be used to test and compare data analysis methods for PV degradation, operation & monitoring (O&M), performance and yield estimation, etc.
- Communicate to our stakeholders in a number of impactful ways including reports, workshops, webinars, and web content.

TASK STRUCTURE

Task 13 is subdivided into three topical Subtasks reflecting the 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.

Subtask 1: New Module Concepts and System Designs

PV technologies are changing rapidly as new materials and designs are entering the market. These changes affect the performance, reliability, and lifetime characteristics of modules and systems. Such information about new technology is of great importance for investors, manufacturers, plant owners, and EPCs. The objectives of Subtask 1 are to gather and share information about new PV module and system design concepts that enhance the value of PV by increasing either the efficiency/yield/lifetime or by increasing the flexibility or value of the electricity generated.

Subtask 2: Performance of Photovoltaic Systems

The objectives of Subtask 2 are to study the uncertainty related to the main parameters affecting yield assessment and long-term yield prediction. This will in turn have an impact on the LCOE and on the business model selected. As availability has an important impact on yield hence early fault detection and fault avoidance through predictive monitoring will be studied. Based on real case studies the effectiveness of predictive monitoring in avoiding failures were analyzed.

Subtask 3: Monitoring - Operation & Maintenance

Subtask 3 aims to increase the knowledge of methodologies to assess technical risks and mitigation measures in terms of economic impact and effectiveness during operation. Special attention was given to provide best practice on methods and devices to qualify PV power plants in the field. To compile guidelines for operation & maintenance (O&M) procedures of PV power plants in different climates and to evaluate how effective O&M concepts will affect the quality of PV power plants in the field.

PVPS TASK REPORTS

All Task 13's PVPS Publications, including 8 new Technical Reports from 2021, are available here

OTHER TASK PUBLICATIONS

Here is a list of selected journal articles and other outputs from Task 13:

D. Moser "Uncertainties in Yield Assessments and PV LCOE", Solar Outlook Report 2022, pp.44-46, MIDDLE EAST SOLAR INDUSTRY ASSOCIATION, January 2022. Home - MESIA

G. Oreski "Motivation, Benefits, and Challenges for New Photovoltaic Material and Module Developments", Solar Outlook Report 2022, pp.47-48, MIDDLE EAST SOLAR INDUSTRY ASSOCIATION, January 2022.

T. Tanahashi "Task 13: Performance, Operation and Reliability of Photovoltaic Systems", Journal of JSES, Vol.47, No.4, July 31, 2021, pp.20-26.

U. Jahn, G. Oreski, W. Herrmann, M. Herz "Quality, Durability and Integration of PV in Different Environments & Applications", 38th European EU PVSEC, Plenary CP.1.2, Online, 06 - 10 September 2021.

S. Lindig, A. Louwen, M. Herz, J. Ascencio-Vásquez, D. Moser, M. Topic "Performance Imputation Techniques for Assessing Costs of Technical Failures in PV Systems", 38th European EU PVSEC, Oral 5CO.9.4, Online, 06 - 10 September 2021.

U. Jahn, B. Herteleer "Climate-specific O&M for PV Power Plants", PV Tech Power, Volume 29, December 08, 2021. https://www.pv-tech.org/technical-papers/climate-specific-om-for-pv-power-plants/

TASK 14

TASK OBJECTIVES

As part of the IEA-PVPS programme, Task 14 aims at preparing the technical base for PV as major supply in a 100 % RES based power system. Task 14 focuses on working with utilities, industry, and other stakeholders to develop the technologies and methods enabling the widespread and efficient deployment of distributed as well as central PV technologies into the electricity grids.

Task 14 addresses high penetration PV throughout the full interconnected electricity system consisting of local distribution grids and wide-area transmission systems. Furthermore, also island and isolated grids in emerging regions are within the scope of Task 14.

From its beginning as 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. Through this, Task 14's work contributes to a common understanding and a broader consensus on methods to adequately evaluate the value of PV in a 100 % RES based power system. The objective is to show the full potential of grid integrated photovoltaics, mitigate concerns of PV to the benefit of a large number of countries and link technical expertise on Solar PV integration available within Task 14 with complementary initiatives (e.g. WIND Annex 25, ISGAN).

Through international collaboration and its global membership base, Task 14 provides an exchange platform for experts from countries, where Solar PV already contributes a significant share to the electricity supply and countries with emerging power systems and a growing share of variable renewables.

TASK STRUCTURE

Task 14's work programme addresses foremost technical issues related to the grid integration of PV in high penetration scenarios, particularly in configurations with a major share of the energy provided by variable renewables:

The main technical topics include Transmission – Distribution Grid Planning and Operation with high penetration RES, stability and transient response for wide-area as well as insular grids, grid codes and regulatory frameworks and the integration of Local Energy Management with PV and storage.

The integration of decentralized solar PV which is interlinked with the development of (future) smart grids complements the research in Task 14.

Accordingly, the work programme is organized in two technical subtasks and one cross-cutting subtask, which will be a hub between the technical subtasks ensuring efficient interaction, dissemination and outreach:

Subtask A: Dissemination and outreach

Subtask A focuses on dissemination & outreach activities and enhances Task 14 role as global forum for PV grid integration, extending Task 14's outreach to emerging economies and new PVPS members. Furthermore, it coordinates the collaboration with other initiatives and TCPs.

Subtask B: Operating and planning power systems with high penetration of Solar PV and other RES

Subtask B addresses questions on grid integration, grid operation, operational and long-term planning with large amount of PV and other RES in a comprehensive approach.

Subtask C: PV in the Smart Grid

Subtask C analyses control strategies and communication technologies to integrate a high number of distributed PV in smart electricity networks, aiming at formulating recommendations about PV communication and control concepts to optimize PV integration into smart grids within different kinds of infrastructures.

PVPS TASK REPORTS

All Task 14's PVPS Publications, including 2 new Technical Reports from 2021, are available here

TASK 15

TASK OBJECTIVES

Building Integrated PV (BIPV) can help reducing CO_2-emissions in the building sector, which is responsible for nearly 40 % of total direct and indirect CO_2 emissions. On the way towards zero-energy buildings, BIPV can help to cover the remaining energy demand in a way that respects architectural, aesthetical, environmental, economic, and technical requirements. BIPV elements as energy generating construction products can replace conventional construction products and activated building envelopes can provide a significant fraction of the area that is required by PV systems in renewable energy systems.

However, the BIPV market still occupies only a niche of both PV and building markets. Bringing the PV industry and the construction sector together requires several stakeholders and barriers still need to be overcome, especially regulatory, technical, economic, knowledge and communicational barriers.

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, BAPV products and regular building envelope components, respecting mandatory, aesthetic, reliability, environmental and financial issues.

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.

In its current workplan (2020-2023), Task 15 addresses barriers for the widespread implementation of BIPV by exchanging research, knowledge, and experience, and closes gaps between different BIPV stakeholders - from the building sector, energy sector, the public, government, and financial sector to overcome technical and non-technical barriers in the implementation of BIPV.

TASK STRUCTURE

Task 15 is divided into 5 main subtasks

Subtask A: Technical Innovation System (TIS) Analysis for BIPV

Subtask A identifies strengths and weaknesses of the BIPV innovation ecosystem and value chain by the Technological Innovation System framework. It specifically looks at the BIPV market development, and suggests policy and strategy measures for governments, individual firms and industry collectively.

Subtask B: Cross-sectional analysis: learning from existing BIPV installations

Subtask B works towards a well-defined multifunctional evaluation of BIPV. A multi-dimensional evaluation matrix considering energetic, economic, ecological, and aesthetic aspects is developed. This methodology is applied to selected BIPV plants to allow a structured assessment of the multifunctional performance of BIPV systems.

Subtask C: BIPV Guidebook

Subtask C supports the implementation of best BIPV practices by consolidating existing BIPV knowledge and compiling it into a technical guidebook for building professionals (architects, engineers and consultants).

Subtask D: Digitalization for BIPV

Subtask D facilitates the application of BIPV over the whole value chain by using the potential of digitalization. Digital methods and workflows are identified and requirements for digital product data models and information modeling/ management strategies collected aiming at an effective di-gital process to improve interoperability along the value chain.

Subtask E: Pre-normative international research on BIPV characterisation methods

Subtask E carries out pre-normative international research to develop new and optimised characterisation methods for BIPV modules and systems. Both experimental and model-based approaches are pursued. The goal is to cover a set of characteristics uniting all requirements on BIPV worldwide, to facilitate local/ national building component approval.

PVPS TASK REPORTS

All Task 15's PVPS Publications, including 2 new Technical Reports from 2021, are available here

OTHER TASK PUBLICATIONS

Here is a list of selected journal articles and other outputs from Task 15:

Building Integrated Photovoltaics: A practical handbook for solar buildings' stakeholders. Status report 2020, available here: https://solarchitecture.ch/wp-content/uploads/2020/11/201022_BIPV_web_V01.pdf

Saretta, E., Bonomo, P., Maeder, W., Nguyen, V.K., Frontini, F., 2022. Digitalization as a driver for supporting PV deployment and cost reduction. EPJ Photovoltaics 13, 1. https://doi.org/10.1051/epjpv/2021013

J. Polo, N. Martín-Chivelet, M. Alonso-Abella, C. Alonso-García, Photovoltaic generation on vertical façades in urban context from open satellite-derived solar resource data, Sol. Energy. 224 (2021) 1396–1405. https://doi.org/10.1016/j.solener.2021.07.011

T. Kuhn, C. Erban, M. Heinrich, J. Eisenlohr, F. Ensslen and D.H. Neuhaus, Review of Technological Design Options for Building Integrated Photovoltaics (BIPV), Energy and Buildings, 231 (2021). https://doi.org/10.1016/j.enbuild.2020.110381

TASK 16

TASK OBJECTIVES

The main goals of Task 16 are to lower barriers and costs of grid integration of PV and lowering planning and investment costs for PV by enhancing the quality of the forecasts and the resources assessments. Solar resources are introducing the highest share of uncertainty in yield assessments.

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

- Lowering uncertainty of satellite retrievals and Numerical Weather Prediction
- 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.
- Develop enhanced analysis for e.g. point to area forecasts, solar trends, albedo, solar cadastres and firm PV power.
- Contribute to or setup international benchmark for data sets and for forecast evaluation.

The scope of the work in Task 16 concentrates on meteorological and climatological topics needed to plan and run PV, solar thermal, concentrating solar power stations and buildings

The work programme of the Task 16 addresses on one side scientific meteorological and climatological issues to high penetration and large scale PV in electricity networks, but also includes a strong focus on user needs. Dissemination and user interaction is foreseen in many different ways from workshops and webinars to paper and reports and online code archives.

TASK STRUCTURE

The project involves key players in solar resource assessment and forecasting at the scientific (universities, met services and research institutions) and commercial level (companies). The work plan is focused on work that can only be done by international collaboration like definition and organization of benchmarks, definition of common uncertainty and variability measures.

The work programme is organized into three main technical subtasks (subtasks 1 – 3) and one dissemination subtask (subtask 4), including three to four activities:

Subtask 1: Evaluation of current and emerging resource assessment methodologies

- 1.1 Ground based methods
- 1.2 Modelling for NWP / satellite data
- 1.4 Benchmarking Framework

Subtask 2: Enhanced data & bankable products

- 2.1 Data quality and format
- 2.4 Long-term inter-annual variability
- 2.5 Products for the end-users
- 2.6 PV at urban scales
- 2.7: Data and models for bifacial modules

Subtask 3: Evaluation of current and emerging solar resource and forecasting techniques

- 3.2 Regional solar power forecasting
- 3.3 Probabilistic solar forecasting
- 3.4 Forecasts based on all sky imagers
- 3.5 Firm power generation

Subtask 4: Dissemination and Outreach

- 4.2 Produce a periodic Task Newsletter
- 4.3 Conduct periodic (annual) Subtask-level webinars and/or conference presentations
- 4.4 Update of solar resource handbook
- 4.5 Solar Resource Assessment in Python

PVPS TASK REPORTS

All Task 16's PVPS Publications, including 1 new Technical Reports from 2021, are available here

OTHER TASK PUBLICATIONS

Here is a list of selected journal articles and other outputs from Task 16:

Larrañeta, Miguel, López-García, Elisa, Jiménez-Valero Paola, Silva-Pérez, Manuel Antonio , Lillo-Bravo, Isidoro Use of Multiyear Tool: An Open Tool for the Synthetic Generation of Plausible Solar Years of Coupled GHI and DNI with 1-min Resolution. Solarpaces 2021 (online)

Polo, J., Martín-Chivelet, N., Alonso-Abella, M., Alonso-García, C., 2021. Photovoltaic generation on vertical façades in urban context from open satellite-derived solar resource data. Solar Energy 224, 1396–1405. doi:10.1016/j.solener.2021.07.011

Polo, J. et al., 2021. Modeling soiling losses for rooftop PV systems in suburban areas with nearby forest in Madrid. Renewable Energy 178, 420–428. doi:10.1016/j.renene.2021.06.085

Rodríguez-Benítez, F.J., et al, 2021: Assessment of new solar radiation nowcasting methods based on sky-camera and satellite imagery. Applied Energy, 292, 15, 116838.

Salamalikis. V., Ioannis Vamvakas, Philippe Blanc, Andreas Kazantzidis, 2021: Ground-based validation of aerosol optical depth from CAMS reanalysis project: An uncertainty input on direct normal irradiance under cloud-free conditions, Renewable Energy, Volume 170, 2021, Pages 847-857, ISSN 0960-1481.

Vignola, F. J. Peterson, R. Kessler, V. Sandhu, S. Snider, A. Habte, P. Gotseff, A. Andreas, M. Sengupta, and F. Mavromatakis, 2021: Improved Field Evaluation of Reference Cell Using Spectral Measurements, Solar Energy 215, 482-491, 2021

TASK 17

TASK OBJECTIVES

The main goal of Task 17 is to deploy PV usage in transport, which will contribute to reducing CO_2 emissions of the sector and enhancing PV market expansions.

To reach this goal, the Task 17 has the following objectives:

- Clarify expected/possible benefits and requirements for PV powered vehicles
- Propose directions for deployment of PV equipped charging stations as infrastructure
- Identify barriers and solutions to satisfy the requirements for both applications
- Estimate the potential contribution of PV in transport
- To realize above in the market to contribute to accelerating communication and activities within stakeholders in the PV and transport industry

The results of this task contribute to clarifying the potential for utilization of PV in transport and they indicate how the concepts could be realized.

The scope of the task includes PV-powered vehicles such as PLDVs (passenger light duty vehicles), LCVs (light commercial vehicles), HDVs (heavy duty vehicles) and other vehicles, and PV applications for electric systems and infrastructures such as charging infrastructures with PV, battery and other power management systems.

TASK STRUCTURE

Task 17 consists of four subtasks:

Subtask 1: Benefits and requirements for PV-powered vehicles

- Subtask 1 will clarify expected/possible benefits and requirements for utilizing PV-powered vehicles for driving and for auxiliary power.
- 1.1: Overview and recognition of current status of PV-powered vehicles
- 1.2: PV-powered passenger cars
- 1.3: PV-powered light commercial vehicles
- 1.4: PV-powered heavy duty vehicles

Subtask 2: PV-powered applications for electric systems and infrastructures

- Subtask 2 will discuss energy systems to design PV-powered infrastructures for EVs charge.
- 2.1: Overview and recognition of the current status of PV-powered for EV charging infrastructure
- 2.2: Requirements, barriers and solutions for PV-powered infrastructure for EV charging
- 2.3: Possible new services associated with the PV-powered infrastructure for EVs charging (V2G, V2H)
- 2.4: Societal impact and social acceptance for PV-powered infrastructure for EVs charging and new services

Subtask 3: Potential contribution of PV in transport

- Subtask 3 will develop a roadmap for deployment of PV-powered vehicles and applications, as well as the resilience and the business model.
- 3.1: Resilience provided for by PV and vehicles
- 3.2: Business models and market diffusion of VIPV/ VAPV
- 3.3: Possible contributions and deployment scenarios for 'PV and Transport'

Subtask 4: Dissemination

- Subtask 4 will communicate with stakeholders such as PV industry, transport industry such as automobile industry, battery industry, and energy service provider, in many different ways ranging from workshops to papers and reports.

PVPS TASK REPORTS

All Task 17's PVPS Publications, including 2 new Technical Reports from 2021, are available here

OTHER TASK PUBLICATIONS

Here is a list of selected journal articles and other outputs from Task 17:

Y. Krim, M. Sechilariu, F. Locment : "PV Benefits Assessment for PV-powered Charging Stations for Electric Vehicles", Applied Sciences, vol. 11, no.9, pp 4127, MDPI Ed., 2021, Impact Factor 2.679, https://doi.org/10.3390/app11094127

S. Cheikh-Mohamad, M. Sechilariu, F. Locment, Y. Krim : "PV-Powered Electric Vehicle Charging Stations: Preliminary Requirements and Feasibility Conditions", Applied Sciences, vol. 11, no.4, pp 1770, MDPI Ed., 2021, Impact Factor 2.679, https://doi.org/10.3390/app11041770

D. Wang, M. Sechilariu, F. Locment : "PV-powered charging station for electric vehicles: power management with integrated V2G", Applied Sciences, vol. 10, no.6, pp 6500, MDPI Ed., 2020, Impact Factor 2.679, https://doi.org/10.3390/app10186500

D. Wang, H. Wu, F. Locment, M. Sechilariu : "Management strategy of an electric vehicle charging station under power limitation", Lecture Notes in Electrical Engineering, vol. 697, pp. 191-202, Impact Factor 0.356. Springer Ed., 2020, DOI: https://doi.org/10.1007/978-3-030-56970-9_15

D. Wang, F. Locment, M. Sechilariu : "Modelling, simulation, and management strategy of an electric vehicle charging station based on a DC microgrid", Applied Sciences, vol. 10, no.6, pp 2053, MDPI Ed., 2020, Impact Factor 2.679, WoS, Scopus, https://doi.org/10.3390/app10062053

M. Sechilariu, N. Molines, G. Richard et al : "Electromobility Framework Study: Infrastructure and Urban Planning for EV Charging Station Empowered by PV-based Microgrid", IET Electrical Systems in Transportation, vol. 9, issue 4, pp 176–185, Impact Factor 2.88, Dec 2019. DOI: 10.1049/iet-est.2019.0032

TASK 18

TASK OBJECTIVES

The objective of Task 18 is to find technical issues and barriers which affect the planning, financing, design, construction and operations and maintenance of off-grid and edge-of-grid systems, especially those which are common across nations, markets and system scale, and offer solutions, tools, guidelines and technical reports for free dissemination for those who might find benefit from them.

Within the context of off-grid and edge-of-grid photovoltaic systems, the central discussion points will cover:

- Reliability: A system that can generate and distribute energy to meet the demands of those connected with a high degree of confidence
- Resiliency: A system that can withstand or recover quickly from natural disasters, deliberate attacks or accidents
- Security: A system that is sustainably affordable and provides an uninterrupted supply of energy which adequately meets the associated demand.

TASK STRUCTURE

Task 17 consists of four subtasks:

Subtask 1: Technical Innovations in Off-Grid and Edge-of-Grid PV systems:

- 1.1 – Lithium-Ion Batteries in Off-Grid and Edge-of-Grid Applications
- 1.2 – Compatibility of Off-Grid systems as they grow and consider interconnection
- 1.3 – Technology used in 100 % Renewable Energy fed Microgrids
- 1.4 – Digitisation in Off-Grid PV Systems
- 1.5 – Innovative Mobility in Off-Grid PV Systems

Subtask 2: Financial Optimisation in Hybrid Off-Grid Systems

Subtask 3: Operations and Maintenance of Remote Area Power Systems

PVPS TASK REPORTS

All Task 18's PVPS Publications are available here

ANNEX B

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