Technology Collaboration Programme
by iea

International Energy Agency
Photovoltaic Power Systems Programme

PVPS

ANNUAL REPORT 2022

PHOTOVOLTAIC POWER SYSTEMS TECHNOLOGY COLLABORATION PROGRAMME

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

ANNUAL REPORT 2022

Cover photo (source: LeGreenHouse and EF Solare)

This Agri-PV plan in Scalea, Italy, combines the cultivation of high-quality cedar lemons with the production of electricity in a dual land-use application.

COLOPHON

Task Status Reports
PVPS Task Managers
Member Status Reports
Executive Committee Delegates
Editor
Emily Jessica Mitchell
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MESSAGE FROM THE CHAIR

Solar PV technology is now deployed almost everywhere, from roofs of homes to factories, from car roofs to car parks, floating on lakes or standing in alpine environments, covering orchards and simply installed as ground mounted systems in desert areas.

In 2022, the sharp rise in electricity prices has put solar power at the heart of energy sovereignty and transition challenges. While self-consumption has held up well, a large number of ground-mounted power plant projects have suffered due to rising financing costs and the higher prices of photovoltaic equipment. While these conditions haven't gone away, all eyes are on 2023, which promises again to be exceptional in terms of added installed power capacity. Market data suggests an annual volume of 250 GW in additional capacity for this year 2023 and annual volumes 2 to 3 times higher by 2030.

There is an ever-growing understanding that photovoltaics has become one of the central renewable energies. The spectacular acceleration in the deployment of photovoltaics is increasingly recognized by analysts and decision makers and accepted as a reliable trend. The International Energy Agency (IEA) expects photovoltaics to surpass hydro in 2024, natural gas in 2026 and coal in 2027 for the production of electricity, with 2 350 GW of installed power worldwide by 2027.

April 2023 marks the 30 year anniversary of the creation of the IEA PVPS programme. I have the great honor to chair the program since early 2021. The stakes have never been higher, given the central role that photovoltaics will play globally in the coming decade, and this is a very exciting challenge. During my first 2 years as PVPS Chair, I have come to understand that the strength of our program 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.

The 8 currently ongoing PVPS Tasks provide scientific results on sustainability, reliability, grid and building integration, solar resources, integration with mobility and finally off grid challenges. As the PV sector rapidly develops, our current Tasks are already working on aspects of deployment trends such as AgriPV and Floating PV, as well as fundamentally important topics like social acceptance. This year, our Executive Committee is engaged in a strategic process that may lead to the launching of new Tasks. PVPS is continually contributing to enabling PV to obtain a central position in the world's energy systems.

PVPS will continue to provide the service of a knowledge broker and exchange forum for its member countries and beyond. Of course, the program will strive to uphold its scientific excellence and seeks to maintain the recognition of its work as an indisputable reference.

In this report you can find overviews of our current Tasks' recent achievements, including technical report highlights. You can also learn about the recent policy, market and industry trends in all of our participating countries via the Member Updates.

Enjoy your reading!

Daniel Mugnier

Chair April 2023

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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 2022, eighteen Tasks were established within the PVPS programme, of which eight are currently operational.

By end 2022, eighteen Tasks were established within the PVPS programme, of which eight are currently operational. The thirty-one PVPS members are: Australia, Austria, Canada, Chile, China, Denmark, Enercity SA, European Union, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Morocco, the Netherlands, Norway, Portugal, SEIA, SEPA, Solar Energy Research Institute of Singapore, SolarPower Europe, South Africa, Spain, Sweden, Switzerland, Thailand, Turkiye 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 Berlin in December 2022

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 future **energy system**;
- PV global supply chain development;
- Social acceptance of PV technologies and large scale deployment;
- PV interaction with other technologies (storage, grids, heat-pumps, fuel cells, bioenergy, etc.);
- PV applications such as AgriPV and Floating PV that address land use concerns;
- 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.

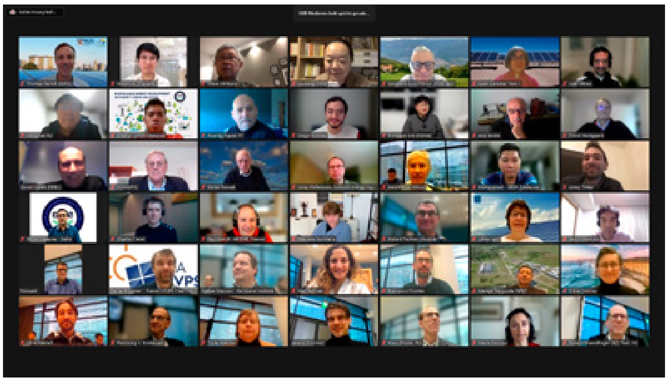
Supported by new ways of COMMUNICATION:

- A collaboration with PV Magazine including a monthly IEA PVPS column published on the PV Magazine website;
- 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 pave the way for photovoltaic solar energy as a key player in the transition to sustainable energy systems and a main contributor to meeting GHG targets.



Virtual participants of the last executive committee meeting

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 CO_2 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. Reliability, 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: Mr Gaëtan MASSON (Becquerel Institute, Belgium); Ms Izumi KAIZUKA (RTS Corporation, Japan)

Fig.1 - Photo from the Task 1 meeting held in Nagoya, Japan in November 2022, in combination with the PVSEC-33

INTRODUCTION

Task 1 continuously researches the drivers and status of PV development both in IEA PVPS countries and globally. It provides at least two reports or special events annually, highlighting the key developments in the PV sector.

Task 1 activities focus primarily on ensuring the development of quality information and effective communication on the most important and timely topics in support of the wider PVPS strategy. To ensure this, Task 1 analyses subjects from support policies, markets and industry to provide reliable, accurate and pertinent information to policy and decision makers and stakeholders.

→ **Read about the objectives and structure of Task 1 in the Annex**

2022 KEY ACCOMPLISHMENTS

NATIONAL SURVEY REPORTS

A key component of the collaborative work carried out within the PVPS Programme, the National Survey Reports (NSR) provide a detailed look into what has happened in the specific countries over the year. Written (and funded) by the country teams, the reports build on Task 1 discussions and effective data collection across the range of subjects addressed, from national market frameworks, public budgets, the industry value chain, prices, economic benefits, new initiatives including financing and electricity utility interests. These reports are available on the PVPS website here.

27TH EDITION OF THE TRENDS IN PHOTOVOLTAIC APPLICATIONS REPORT

Compiled from data collected for the annual National Survey Reports (NSR) and information supplied by a worldwide network of market and industry experts, the Trends in Photovoltaic Applications report presents a broad view of the current status and trends relating to the development of PV globally. It provides accurate information on the evolution of the PV market and the industry value chain, with a clear focus on support policies and the business environment, whilst also bringing an in-depth analysis of the drivers and factors behind PV market development and an analysis of the global PV market and industry.

Funded by the IEA PVPS Programme, it is prepared by a small editorial group within Task 1 and is distributed in both print and electronic formats. 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. Twenty-seven issues of the Trends have been published, all available on the PVPS website here.

SNAPSHOT OF GLOBAL PV REPORT

The Snapshot of Global PV report is compiled from the preliminary market development information provided annually by all countries participating in the IEA PVPS Programme. Published in April, the Snapshot report provides a first sound estimate of the prior year's PV market. Task 1 members collect and share data in the report, supplying an early look at the previous year's market developments and policy drivers. See the PVPS website here.

WCPEC-8 CONFERENCE

Task 1 was present at the 8th WCPEC in Italy in September, hosting a conference in the industry side events "PV Scenarios: Now and Then" in which task 1 members discussed PV development scenarios in member countries, Europe, China and across the world.

EXPLORING SOCIAL ACCEPTANCE

As a special focus topic in 2022, Task 1 members investigated social acceptance of PV in members countries, with preliminary data gathering and discussion in several meetings, including a workshop in April 2022 in Spain. The main barriers to social acceptance were discussed, with a comparative look at organized resistance, public policies and support to improve social acceptance, key drivers and the transferability of levers for improvement. This work influenced outreach and strategic reflections within Task 1, with a summary document in preparation and an article published in PV Magazine, the first of a series of monthly columns from the different PVPS tasks. Recognizing the importance of understanding the barriers and levers to social acceptance, Task 1 has maintained discussion with the Executive Committee and Task 12 with a view to prolonging investigations and collaborative work on the subject, paving the way for a future task on social acceptance, building on certain aspects of several other current PVPS Tasks.

COOPERATION WITH OTHER TASKS

Task 1 members sought open dialogue and collaboration on specific subjects with different tasks, linking market information, data collected for the NSR and Trends and the Task specific subjects. We can mention, in particular, Tasks 14, 15 and 17.

OUTLOOK FOR 2023

As communication activities become intrinsic to the Executive Secretariat's activities, Task 1 will focus more strongly on intelligence and data collection, with an eye to emerging trends and upcoming subjects.

This year the principal subject will revolve around grid connection and access costs, stakeholder contributions and how shifting contributions may impact the rate of PV deployment across the world - working in collaboration with Task 14. Cooperation with Task 15 (BIPV) and Task 17 (PV & transport) is planned, continuing on the exchanges on social acceptance in 2022. The PVPS All-Tasks meeting late in 2023 will also mobilise Task 1 as we look for efficient communication synergies.

All Task 1's PVPS Publications are available here

TRENDS IN PV APPLICATIONS 2022

TASK 1 HIGHLIGHT

Main Authors: Gaëtan Masson (Becquerel Institute), Izumi Kaizuka (RTS Corporation)

Analysis: Izumi Kaizuka (RTS Corporation); Elina Bosch, Gaëtan. Masson (Becquerel Institute); Caroline Plaza (Becquerel Institute France); Alessandra Scognamiglio (ENEA); Arnulf Jäger-Waldau (EU-JRC); Johan Lindahl (Becquerel Institute Sweden); Eddy Blokken (SERIS)

[TRENDS IN PHOTOVOLTAIC APPLICATIONS]

[Task 1 Webpage]

KEY MESSAGE

The market grew to 174 GW with strong growth in self consumption and systems developed outside of support frameworks due to the increased competitiveness of solar.

OBJECTIVE

The Trends report provides a comprehensive overview of the PV market across the world, highlighting the principal elements driving change and growth by looking at public policy, markets, technologies, and industry.

METHODOLOGY

Task 1 members provide detailed data from their individual countries, relaying both official data and expert evaluations. A comparative analysis is undertaken to determine trends and divergences across the different sectors studied, and a written synthesis highlights the main elements.

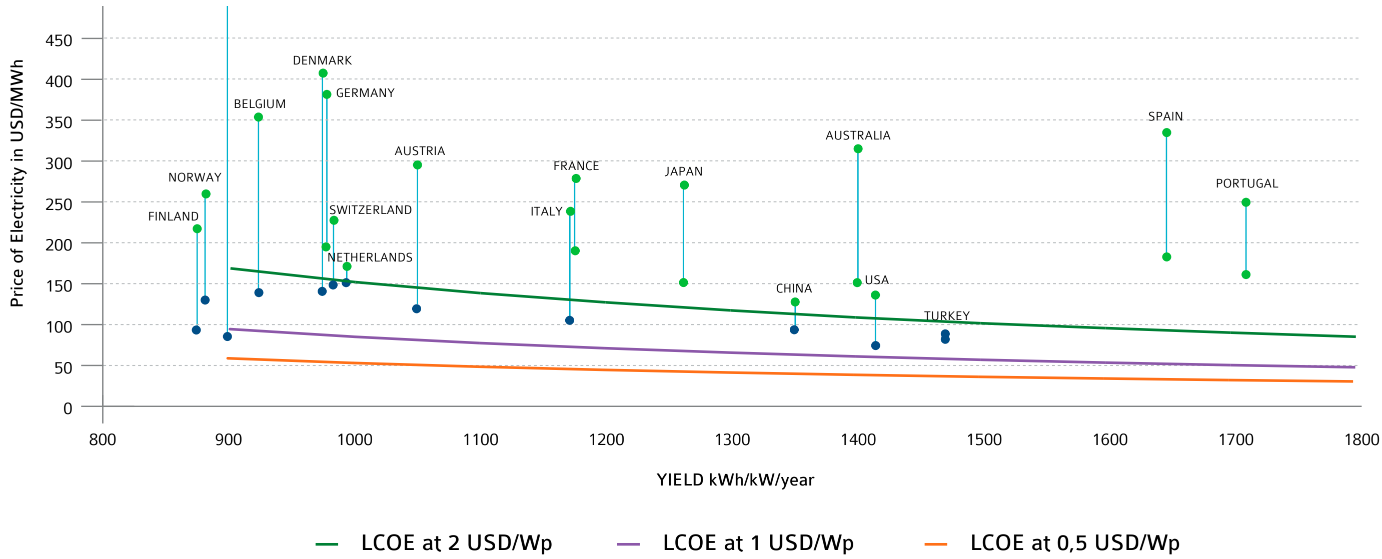


Fig.2 - LCOE of PV electricity as a function of solar irradiance & retail prices in key markets

Grid Parity refers to the moment when PV can produce electricity at a price below the price of electricity consumed from the grid. It is a reliable indicator of the increasing competitiveness of PV in member countries. Data collected for the Trends shows that this point has been reached across the principal PV markets of China, the US and western Europe.

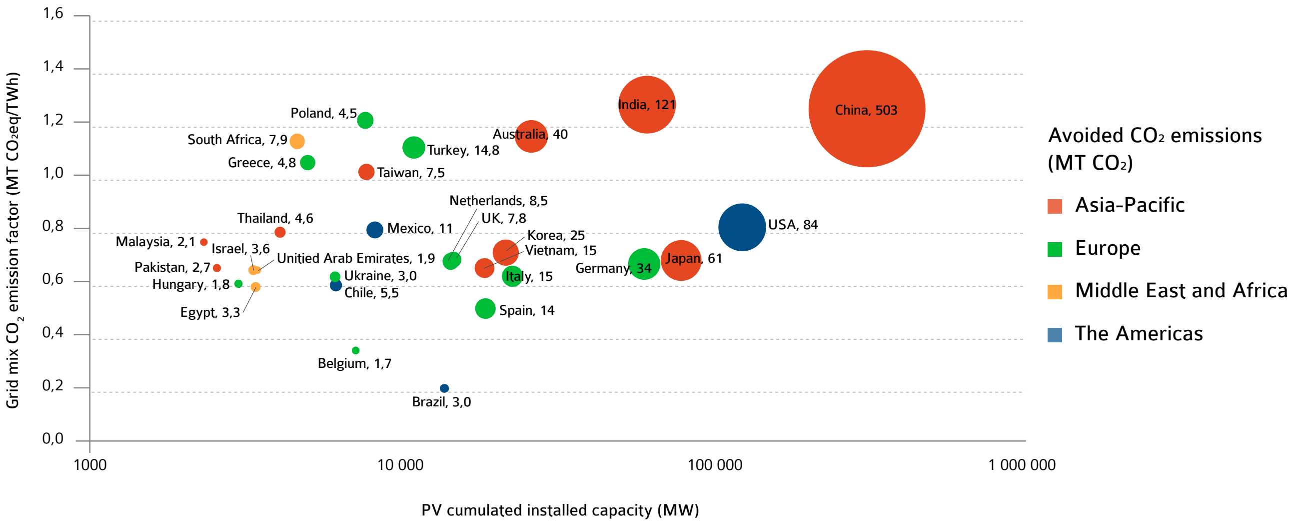


Fig.3 - CO2 emissions avoided by PV [MT CO2,EQ]

Increasing the PV share in the grid mix can significantly reduce emissions from power generation. The Trends reports shows that installed capacity avoided up to 1060 million tonnes of CO_2eq in 2021 - more than 3% of energy sector emissions. This is essentially due to the fact that PV is being massively installed in countries with carbon intensive grid mixes, such as China and India.

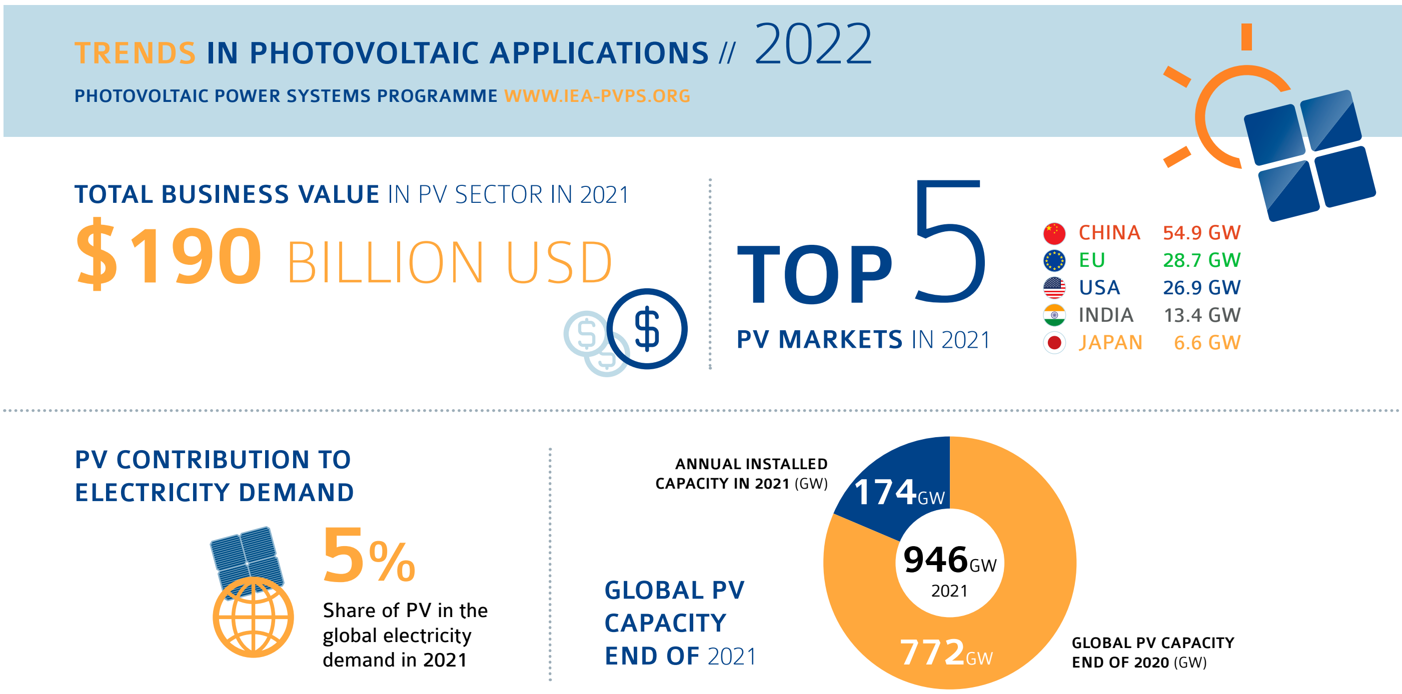


Fig.4 - Market recap infographic – Trends in applications 2022

Trends is published to provide guidance on solar energy policies and assist decision makers in business and public authorities, electricity utilities and other providers of energy services. Outreach is an important facet to this, so providing an overview – in this one page info graphic – of the entire Trends report is a necessary challenge.

The data for the Trends is collected for the National Survey Reports (for those countries that publish one), or directly for the Trends report. The National Survey reports are a comprehensive look at the local situation of PV in member countries.

TASK 12

PV SUSTAINABILITY ACTIVITIES

Task Managers: Mr Garvin HEATH (National Renewable Energy Laboratory, U.S.); Jose Bilbao (Univeristy of NSW, 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 projected 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 2023.

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

2022 KEY ACCOMPLISHMENTS

Task 12 published two reports and updated its PV LCA factsheet during 2022. During this period, Task 12 has increased its number of experts, with new or additional representatives from Spain, France, Switzerland, the Netherlands, USA, Australia, and Solar Power Europe.

A summary of the highlights of each publication can be found below, as well as more details in the following pages.

MINERAL RESOURCE USE FOOTPRINTS OF RESIDENTIAL PV SYSTEMS

For the first time, the resource use impacts of PV electricity are quantified using four impact category indicators as recommended or by the Life Cycle Initiative hosted at UN Environment. The indicators cover distinctly different aspects of resource use, namely resource depletion with the Abiotic Depletion Potential, ultimate reserves (ADPUR), economic resource scarcity with the Abiotic Depletion Potential, economic reserves (ADPER), resource quality with the Surplus Ore Potential, Ultimate Recoverable Resources (SOPURR) and re-source criticality with the ESSENZ method.

The resource use impacts caused from the generation of 1 kWh electricity with a residential scale photovoltaic (PV) system installed in Central Europe using mono- and multi-crystalline silicon panels and CdTe panels, respectively are quantified. The production of 1 kWh AC electricity by the system requires between 16 and 20 grams of primary mineral resources, with up to 90% used in required infrastructure such as factories and roads and in (solar) glass production, and a few percent being iron for supporting structure, aluminium for PV frames, and copper for cabling and inverters. Less than ten minerals and metals contribute to at least 95% of the overall score of all four resource use impact indicators. Gold, silver, and copper are always in the top ten minerals and metals (see Figure on next page). While Gold is mainly used in the inverter electronics and copper in the cabling and in the inverter, silver is mainly used in crystalline silicon panels and in the inverter electronics.

STATUS OF PV MODULE RECYCLING IN SELECTED IEA PVPS TASK 12 COUNTRIES

As Photovoltaic (PV) deployment accelerates, the expected PV end of life (EOL) waste streams also increases at a higher pace than anticipated. To meet this new waste volume and optimise PV EOL management, appropriate regulatory and technological approaches must be implemented in the near term. This report shows that the EU has adopted PV-specific EOL regulations, while in other countries it is typically handled under existing regulatory frameworks for general waste. However, policy approaches for accelerating PV EOL management, including supporting technology R&D, are under development across the world. In South Korea, EPR (extended producer responsibility) regulations will be enforced in 2023, whereas in Australia, PV modules are expected to be covered by the Product Stewardship Act 2011, in addition to state-level discussions. In the United States, regulations specific to EOL PV exist in some states. In Japan, although no PV-specific waste regulation exists, several recycling activities and R&D projects for supporting PV EOL management have been carried out, with commercial PV recycling technology now available. Similarly, while in China policies and regulations on PV module recycling and EOL management are still under development, ECOPV was officially established early 2020 with the goal of achieving a "PV green supply chain".

The report found that there is no reliable data on the volume of EOL PV (either processed or unprocessed), but a few thousand tons of EOL PV modules are annually processed in Germany, France, Italy, and Japan, with lower volumes in Spain and South Korea. The data available shows the EOL PV volume is increasing over the years. However, a survey carried out with PV recyclers showed a disparity between the available recycling capacity and the number of modules treated, resulting in high recycling costs per unit with current volumes.

UPDATE TO THE PV LCA FACTSHEET

This update to the LCA factsheet was done based on the latest available LCI data. This work quantifies the emissions of 1 kWh of electricity generated by a 3 kWp rooftop PV system in central Europe. The updated factsheet included the evolution of GHG emissions over time, for the modeled system, using mono-crystalline technology. Note that the improvements are not only due to the increase in yield, but also due to technological advancements in PV manufacturing.

TABLE 1

	UNIT	1996	2003	2007	2014	2016	2020	2021
GREENHOUSE GAS EMISSIONS	g CO_2 eq/ kWh	121	72	76	80	107	43	43
MODULE EFFICIENCY	%	13.6	14.8	14.0	14.0	15.1	19.5	20.0
YIELD	kWh/a	862	882	922	922	882	976	976
SOLAR MODULES	289 GW	58.8%						

Another key update is the non-renewable energy payback time, which is now below 1.3 years for a system in central Europe with any of the commercially available PV technologies.

TABLE 2

	UNIT	MONI-SI	MULTI-SI	CIS	CDTE
NREPBT	Years	1.2	1.2	1.3	0.9

OUTLOOK FOR 2022

In 2023 Task 12 members will deliver the remaining reports for the current workplan, which was extended for one additional year, and finalise the development of its new workplan for 2024-28.

Currently Task 12 has several reports in the making, with a combination of original research and reviews. A summary of the expected reports to be delivered in 2023 include:

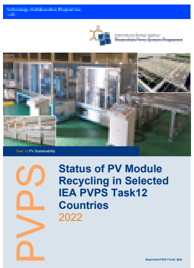
- Analysis of PV take-back and recycling in Germany.
- LCA of a module delamination process.
- LCA of PERC technology.
- Carbon footprint of floating PV.
- Review of PV sustainability standards.

All Task 12's PVPS Publications are available here

STATUS OF PV RECYCLING

TASK 12 HIGHLIGHT

Keiichi Komoto (Japan); Michael Held (Germany); Claire Agraffeil (France); Carmen Alonso-Garcia (Spain); Andrea Danelli (Italy); Jin-Seok Lee (South Korea); Lv Fang (China); Jose Bilbao (Australia); Rong Deng (Australia); Garvin Heath (USA); Dwarakanath Ravikumar (USA); Parikhit Sinha (USA)



Status of PV Module Recycling in Selected IEA PVPS Task12 Countries

Task 12 Webpage

KEY MESSAGE

Despite low volumes of EOL PV, they are properly treated and recycled in countries that have specific EOL regulations in place. Costs are still high and revenues low due to low volumes, limited PV recycling technologies, logistics challenges and undeveloped markets for recovered materials. However, the implementation of PV EOL regulations in more countries and R&D investment in PV recycling should accelerate improvements to meet future demand and lower costs of PV recycling.

OBJECTIVE

To contribute to the understanding of the status of PV recycling, so as to accelerate PV recycling as a promising option for the proper EOL management of PV modules in the coming decades around the world.

METHODOLOGY

Participating IEA PVPS Task 12 experts gathered information on regulatory schemes on PV module waste recycling and relevant companies to provide an outlook of each region or country. Furthermore, existing PV module recyclers in several countries were surveyed to understand current capabilities and barriers.

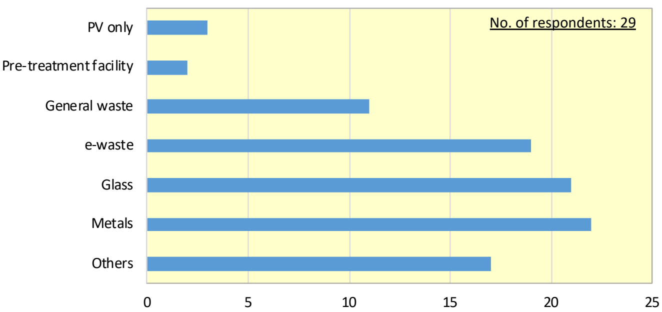


Fig.5 - Waste treated in the respondents' plants

Most survey respondents are treating different waste streams, with EOL PV modules being one of them. Only three respondents treat only PV module waste. In Japan, more than 10 respondents are using specific equipment for PV modules, even though most are treating other waste streams. Currently, it seems difficult to operate a recycling business focusing on PV modules because of the low waste volume and the associated revenue from the materials recovered.

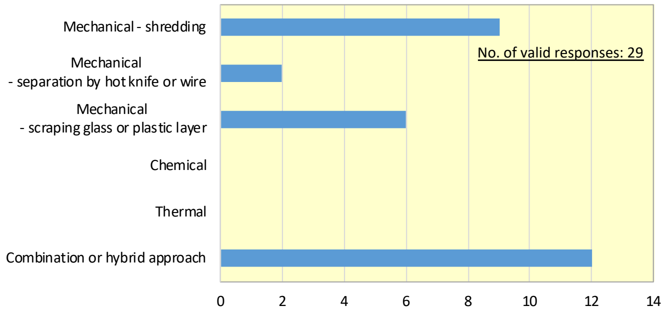


Fig.6 - Treatment technologies for PV modules

17 respondents answered they use only a mechanical treatment (e.g., shredding, hot knife or wire, scraping glass or a plastic layer, etc.). Another 12 respondents use a combination of a mechanical treatment with a thermal and/or a chemical treatment. No respondents use only thermal treatments or only chemical treatments.

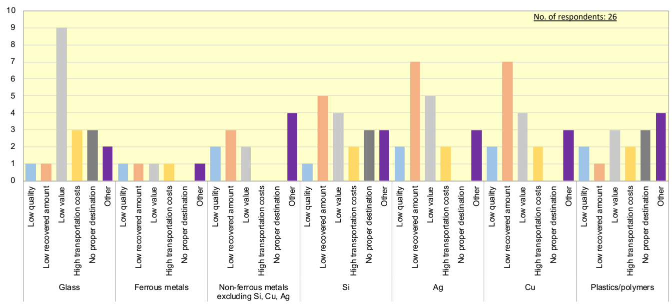


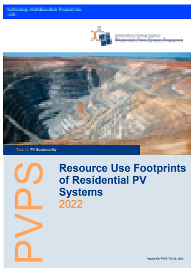
Fig.7 - Issues or barriers for recovering or recycling materials

Common barriers for PV recycling according to recycling companies are low recovered amount of silver, copper, and silicon, and low value of the recovered glass, followed by the low value of the recovered silver, copper, and silicon.

PV RESOURCE FOOTPRINTS

TASK 12 HIGHLIGHT

Rolf Frischknecht; Luana Krebs



[Resource Use Footprints of Residential PV Systems]

[Task 12 Webpage]

KEY MESSAGE

This is the first public report in which the mineral resource impacts of PV electricity are quantified simultaneously with four impact category indicators of resource use, namely resource depletion, economic resource scarcity, resource quality and re-source criticality. The production of 1 kWh AC electricity produced with residential scale PV systems requires between 16 and 20 grams of primary mineral resources, with up to 90% used in infrastructure (factories and roads) and solar glass production, and a few percent each being iron (supporting structure), aluminium (frame) and copper (cabling and inverter).

OBJECTIVE

To better understand the resource use impacts of different PV systems and their most important contributors to resource use impacts, which, once identified, can become targets for R&D to reduce them. The results reported in this study can be compared to those of other technologies assessed with the same indicators and on a life cycle basis using the same system boundary due to the international standard methodology followed.

METHODOLOGY

Data from Task 12 LCA for a 3 kWp PV system installed on a pitched roof of a residential building in central Europe, was used as a base for this study, comparing the mineral resource footprint for three PV technologies, mono-Si, multi-Si, and CdTe. Assumptions include an annual yield over lifetime of 975 kWh/kWp (incl. linear degradation of 0.7% per year), a panel lifetime of 30 years and inverter lifetime of 15 years.

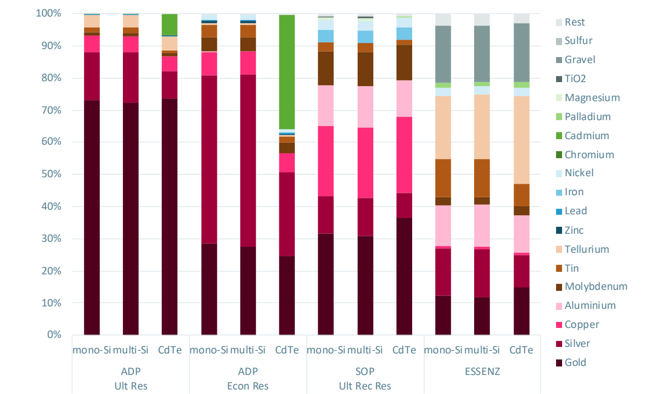


Fig.8 - Relative contribution of different metals and minerals to the resource use impacts (see full report for indicator details) per kWh AC electricity produced with residential scale PV systems operated in central Europe

The contribution of different materials changes with each use indicator. While ADPUR indicates that gold has a higher contribution for all systems (due to use in inverters), the indicator ADPER highlights the contributions of silver in crystalline Si modules. Copper shows a bigger contribution to the material use footprint with the SOP indicator.

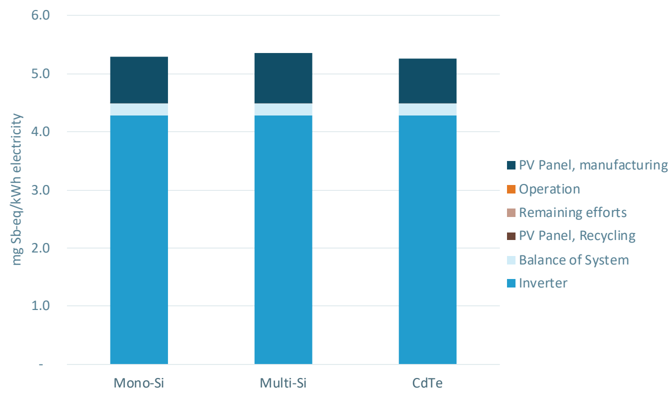


Fig.9 - Resource depletion impacts, quantified with the 'Abiotic Depletion Potential - ultimate reserves' (ADPUR), in mg Sb-eq per kWh AC electricity produced with residential scale PV systems operated in central Europe

The resource depletion impact quantified with ADPUR amounts to between 5.3 and 5.4 mg Sb-eq/kWh AC electricity. The resource use of the inverter contributes between 80% and 92% of the total score, followed by the panel (15%, 16% and 14.5% of mono-Si, multi-Si and CdTe PV systems, respectively). The balance of system contributes about 4% to the resource depletion impact. Remaining construction efforts, operation and end of life treatment are hardly visible.

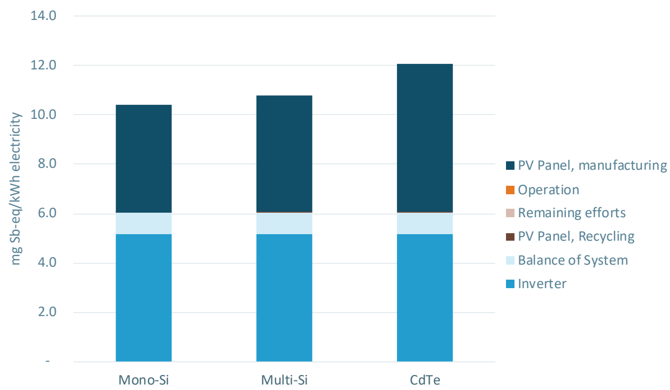


Fig.10 - Economic resource scarcity impacts, quantified with the 'Abiotic Depletion Potential - economic reserves' (ADPER), in mg Sb-eq per kWh AC electricity produced with residential scale PV systems operated in central Europe

The resource scarcity impact quantified with ADPER amounts to between 10 mg Sb-eq (crystalline silicon PV systems) and 12 mg Sb-eq (CdTe PV system) per kWh AC electricity, almost double compared with ADPUR indicator, mostly due to the increase in PV panel manufacturing. The resource use of the inverter contributes between 43% and 50% of the total score, and the panel between 45% and 42% for crystalline and CdTe PV systems, respectively. The balance of system contributes about 7% to 8% to the resource scarcity impact.

TASK 13

RELIABILITY AND PERFORMANCE OF PHOTOVOLTAIC SYSTEMS

Task Manager: Ms Ulrike JAHN (VDE Renewables GmbH, Germany)

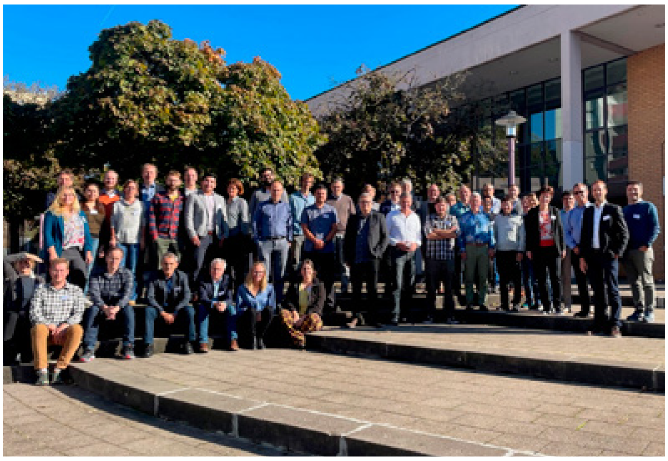


Fig.11 - Kickoff Meeting for the 4th term of IEA PVPS Task 13, with 50 in-person experts and 40 remote experts, in Frankfurt, Germany, October 2022

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 the estimated yield.

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, modules and components 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 size (global capacity doubles almost every three to four years) and in terms of the use of new technologies (e.g. changing cell thicknesses, introduction of Topcon technology and bifacial cells) and new deployment locations and applications, such as floating PV and agricultural PV.

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

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

2022 KEY ACCOMPLISHMENTS

DEGRADATION MODES IN NEW PV CELL AND MODULE TECHNOLOGY

Reliability over a lifetime is the most critical aspect of any PV module. In order to prove module reliability, degradation mechanisms must be studied and well understood. Experts collected information on degradation modes of new PV module technologies after the PERC cell generation starting with the PERC+ over TOPCON/HIT to tandem and perovskite PV modules and discussed the current developments during an international Task 13 workshop focusing on degradations modes, which show up with large wafer size technology, half cells, bifacial and other new module designs.

Most of the well-known degradation mechanisms also play a role in newer PV modules. However, their importance is shifting. The impact of cell cracks becomes less important because the module has more redundancy due to the use of multiple connections on one cell. However, the cells get cracks more easily, as half-cut cells are more susceptible to cracks at the cut edge of the cells. We see similar shifts in potential-induced degradation and light-induced degradation, to name a few examples. Therefore, we need to adapt our mitigation strategies for manufacturing and testing new PV module types.

Silicon heterojunction (SHJ) cells and Tunneling Oxide Passivated Contact (TOPCon) cells are two of the most promising emerging high-efficiency PV technologies. Current developments are reducing the impact of the drawbacks of these technologies, such as increased silver consumption and the need for expensive TCO layers. By comparing extracted cell segments from control and fielded modules and various cell characterisation investigations, we attempt to identify new degradation mechanisms in these new PV module types. With this approach, it can be confirmed that degradation in the field causes an increase in non-radiative recombination in SHJ cells.

Degradation modes for future Perovskite PV technologies can be classified in three groups: Extrinsic degradation due to water, oxygen, mechanical stress, and potential-induced degradation; intrinsic degradation due to phase instability, halide mixing and decomposition; device-specific degradation due to electrode diffusion, transport layer reactions and reverse bias. Degradation of Perovskite PV modules can be mitigated by the following measures: Extrinsic modes can be mitigated by effective encapsulation. Intrinsic modes can be mitigated by selecting the right composition, engineering measures to improve heat dissipation and surface design. Device-specific modes can be mitigated using non-metallic electrodes, diffusion barrier materials and bypass diodes. Mitigation solutions must be scalable in size and speed for production. In conclusion, further outdoor field testing is needed to identify relevant degradation modes for Perovskite modules and test their mitigation strategies.

Further results of the workshop on PV module degradation can be found here

MODELLING OF ENERGY YIELDS FOR FLOATING PV SYSTEMS

During a dedicated workshop on energy yield modelling of floating PV (FPV) systems, Task 13 experts presented and discussed different models needed for the energy yield assessment of FPV power plants. Many of the R&D teams share an understanding that the commercial tools do not provide accurate energy yield modelling of FPV today. Partly because they lack accurate models to calculate operating temperature and mismatch losses, but also because of uncertainty in other input parameters, such as soiling losses and performance loss rates. Hence it was discussed how improved models for FPV yield can be implemented in existing, bankable, commercial design tools for FPV power plants.

Ongoing work with thermal models to calculate operating temperature of various FPV technologies was described by several of the participants. The thermal models are often based on known heat transfer equations and can take into account several physical effects resulting in the cell temperature estimation:

- Forced convection with the wind, natural convection, infrared exchanges with the sky and the environment
- Air and water temperature
- Capacitive behaviour of the PV module.

Several models have been validated against experimental data collected at FPV sites. The experimental validation has shown that very accurate operating temperatures can be achieved with these models. Lessons learned from measured FPV systems also shows that for the most used commercial technologies, the same parameters as for ground-based systems are the most influential: air temperature, wind and mounting. For certain FPV technologies, the water temperature and water current are more influential. Although the air temperature above the water is generally cooler than the average air temperature, this is not always the case. In fact, a small warming effect can even be observed in winter (thermal inertia of the lake). Scientific challenges in current research projects are to assess the cooling effect of PV modules at the scale of a PV plant. Simulations must include micro-climatic effects and the distribution of convective airflows within an operating floating solar power plant.

Another paper presented the comparison of the cooling effect of FPV systems in the Netherlands and Singapore, based on field test data and reference system data. As a result, the best performing FPV systems showed 3.2°C (Netherlands) and 14.5°C (Singapore) lower irradiance-weighted temperatures compared to the land- or rooftop-based benchmarks. In conclusion, floating solar system design plays a very important role. The local weather conditions may play a larger role than the presence of water. Based on these calculations, the experts observed that the gain in energy yield from the cooling effect of FPV systems compared to the reference PV systems is up to 3% in the Netherlands and up to 6% in Singapore.

OUTLOOK FOR 2023

The development of new solar cell and PV module designs have never experienced such rapid change as in the past years. Therefore, Task 13 experts from the most important PV manufacturing countries (China, USA and Europe) will describe the challenges, compare sequential and combined test procedures and mitigation solutions to tackle the currently known degradation mechanisms in new PV module technologies. This will include degradation modes in recent PV technologies as well as Perovskite based future technologies' degradation. We will also analyse strategies to enable old or defective PV modules to possibly have a second life. As batteries become an important part in PV systems, we start to assess their reliability.

Task 13 experts will focus on novel PV applications. Emerging PV applications are Floating PV and Agrivoltaics. Experts will collaborate on energy yield modelling and specific loss mechanisms, field performance and reliability as well as operation & maintenance challenges and best practices. A general overview and definitions for these integrated PV applications will be given. PV systems with bifacial modules and trackers have a rising market share, as well as systems with module level power electronics. Task 13 will conduct a global survey of PV tracking technologies to gather information on their tracking algorithms and how they improve bifacial PV performance and system designs. Best practices on performance evaluation are compared and developed. Module level power electronics in the PV system and specifically the effect of shading conditions on the performance are also investigated. Finally, the role of digitalization in cost and performance optimization of PV systems and best practices are addressed by Task 13.

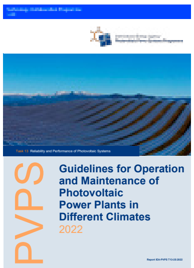
Task 13 will identify extreme weather events including hurricanes, typhoons, blizzards, dust storms, hailstorms and wildfires that impact PV systems, and assess the losses/damage associated with them. Experts will carry out a survey addressing asset owners and other stakeholders regarding the scope of and types of weather-related PV damage (equipment damage, replacement costs and production losses). The impact of decisions along the value chain of PV projects (i.e. during design, procurement, engineering, transport, installation, O&M, end of life) will be visualized to define best practice flowcharts for PV projects and contribute towards reducing the risk of PV investments. Data coming from various plant typology and configurations will be benchmarked in terms of techno-economic key performance indicators.

All Task 13's PVPS Publications are available here

PV OPERATIONS & MAINTENANCE

TASK 13 HIGHLIGHT

Ulrike Jahn (VDE Renewables, Germany); Bert Herteleer (Katholieke Universiteit Leuven, Belgium); Caroline Tjengdrawira (Tractebel, Belgium); Ioannis Tsanakas (CEA INES, France); Mauricio Richter (3E, Brussels, Belgium); George Dickeson (Ekistica, Alice Springs, Australia); Alexander Astigarraga (EURAC, Italy); Tadanori Tanahashi (AIST, Fukushima, Japan); Felipe Valencia (Atamostec, Chile); Mike Green (Green Power Engineering Ltd, Israel); Anne Anderson (RISE, Sweden); Bengt Stridh (Mälardalen University, Sweden); Ana Rosa Lagunas Alonso (CENER, Spain),Yaowanee Sangpongsanont (KMUTT, Thailand)



Guidelines for Operation and Maintenance of Photovoltaic Power Plants in Different Climates

Task 13 Webpage

KEY MESSAGE

Operations & Maintenance (O&M) operators need to customize O&M services to the climate zones where particular plants are located. This can be complemented by a comprehensive O&M agreement that considers future needs such as grid requirement changes.

OBJECTIVE

New guidelines for climate-specific operations & maintenance (O&M) programmes are published to address the lack of a standardised regime for climate-specific O&M, while also addressing topics such as O&M performance indicators, preventive maintenance, and fault diagnosis.

METHODOLOGY

To date, no comprehensive guidelines for climate-specific O&M programmes have been developed. Given this gap, this report aims to provide a comprehensive guide to tailor O&M services in seven different climatic zones. The first four refer to conditions that prevail in large parts of the world (temperate, hot and dry, hot and humid, high-altitude desert), while the last three represent extreme conditions (flood-prone regions, cyclone regions, snow regions).

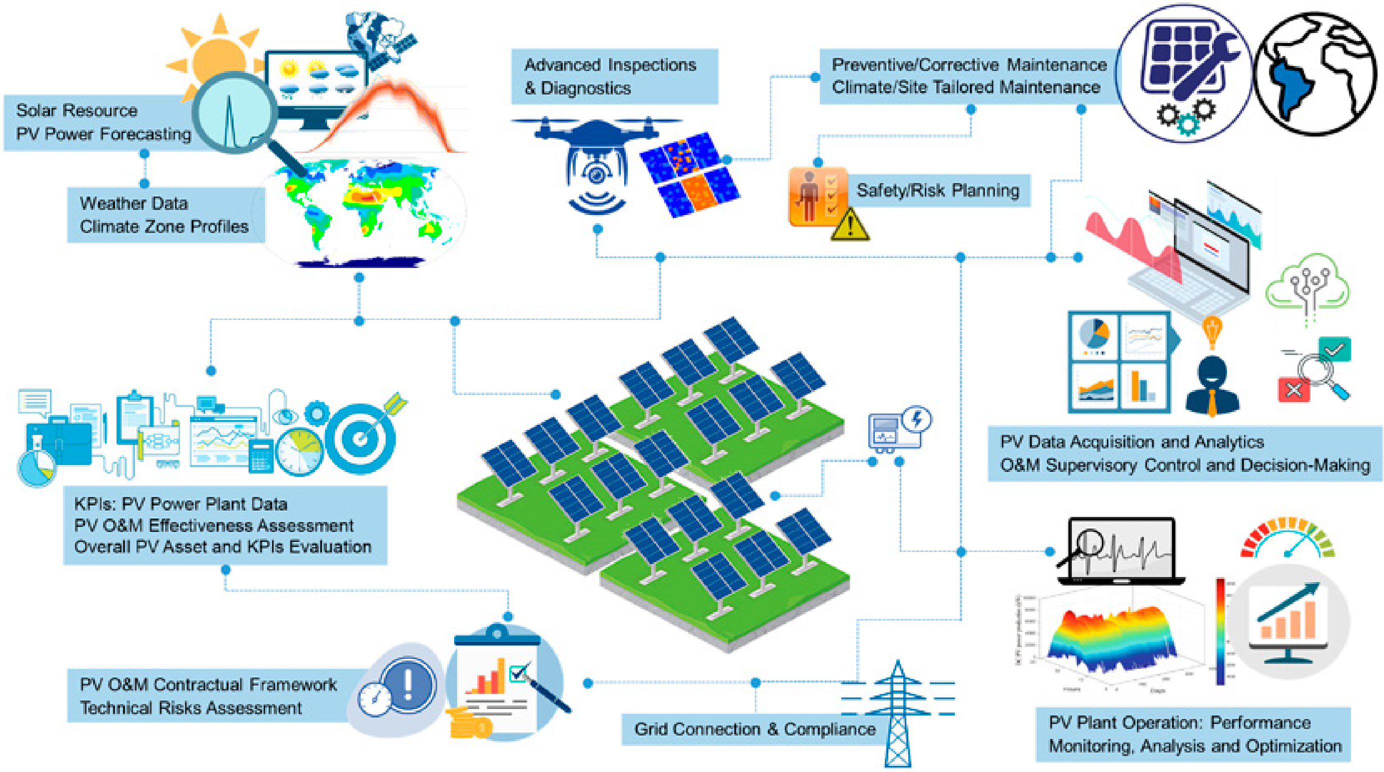


Fig.12 - Overview of O&M aspects and services for PV power Plants (source: CEA-INES)

The O&M services, which are all interconnected, include monitoring/inspection, data analysis, maintenance and optimisation of PV power plants. Figure 12 shows the entire O&M concept over the technical life cycle of PV plants.

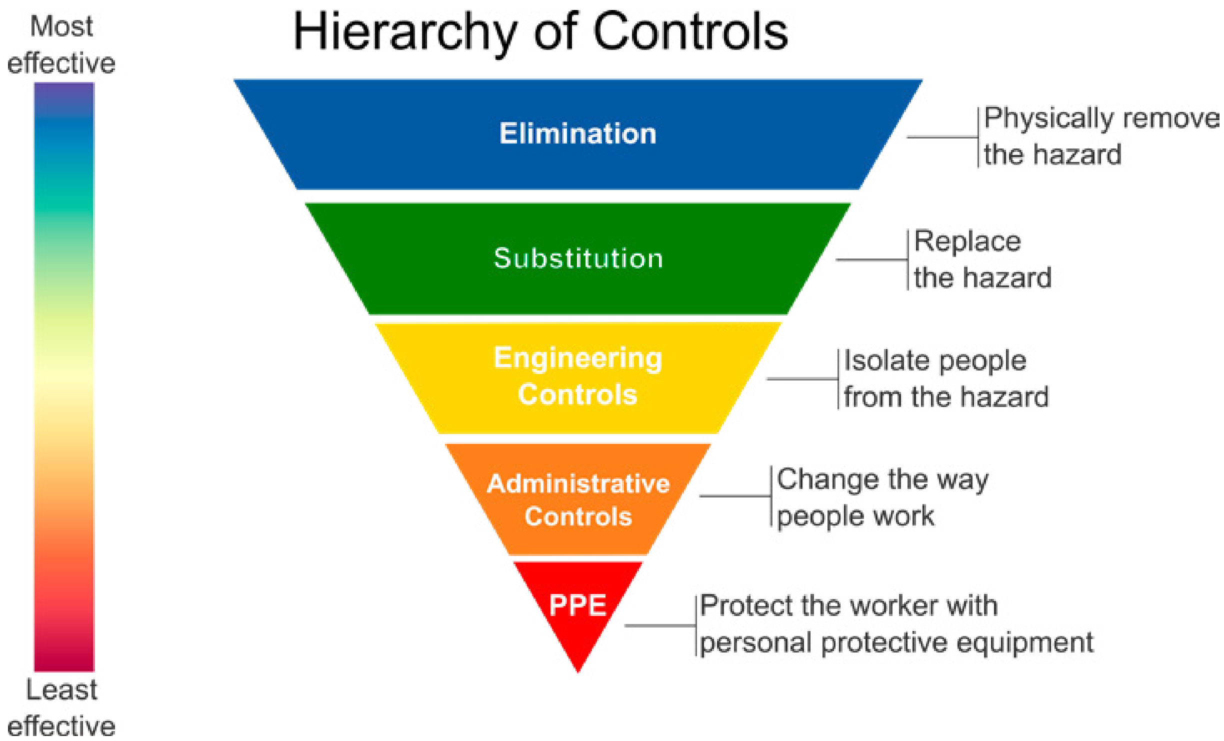


Fig.13 - Hierarchy of controls - A key tool to minimise or eliminate risks is the hierarchy of controls methodology

Reducing both safety and performance risks by ensuring that personnel are adequately trained and equipped to perform O&M operations and by applying PV forecasting. Both are essential to reducing plant downtime and maintaining plant performance to specifications.

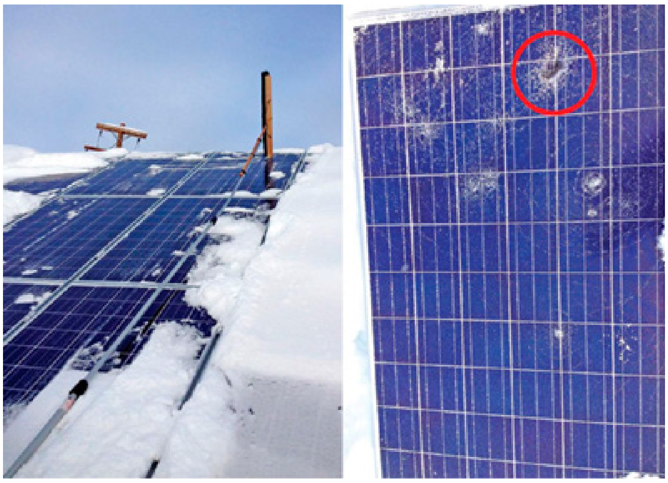


Fig.14 - PV module damage due to inappropriate snow cleaning techniques

Mechanical removal of snow by brushing or other types of active cleaning may sometimes be necessary if the weight threatens to damage the roof structures. However, snow removal also runs the risk of damaging the modules or scratching the glass, especially if ice has formed on the surface.

TASK 14

SOLAR PV IN THE 100% RES POWER SYSTEM

Task Managers: Mr Roland BRÜNDLINGER (Austrian Institute of Technology (AIT)); Mr Gerd HEILSCHER (Technische Hochschule Ulm, Germany)

Fig.15 - Experts from the Japanese electricity sector and research attending the NEDO/Task 14 workshop in November 2022 (source: NEDO)

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.

Following the massive increase of electricity prices for consumers as well as the industrial sector in 2022, investments into renewables and in particular Solar PV have become increasingly economical. This fast-paced deployment further intensifies the challenges related to the grid-connection and system integration.

In many markets, PV has now become a true game changer on the bulk power system level, strengthening the need for solutions to address the key issues, related to 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.

The work of Task 14 addresses these challenges and provides global experiences and best-practices 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**

2022 KEY ACCOMPLISHMENTS

In 2022, 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.

In the subtask C, a "PV in the smart grid" survey covering different aspects was published online and distributed through different channels, several expert "interviews" were organized to collect feedbacks from experts in various sectors. Despite the challenges posed by the COVID-19 restrictions, shift of personal workforce, the Task 14 experts have been making steady progress on multiple technical reports in parallel, to be published in 2023.

One of the main tasks in 2022 focused on the re-establishment of the international exchange in the post-COVID time, as the travel constraints have been relaxed in many participating member states. In 2022 multiple events and joint programs were held with the support of PVPS Task 14, or with a considerable number of contributions by the Task 14 experts, facilitating a direct dialogue with experts.

One of the highlights related to the dissemination of the Task 14 work was the IEA PVPS Task14 Workshop on DER integration, organized by the Japanese New Energy Development Organisation NEDO in November 2022. The event, held in person at NEDOs branch office in Tokyo, attracted more than 60 participants from industry, utilities, manufacturers, and research including members of IEA PVPS Task14. The main objective addressed by the workshop program was to share latest information of distributed energy resource integration, focusing on Solar PV and other resources. In conjunction with the workshop, an extended technical tour to NEDO project test facilities facilitated the exchange between Task 14 experts and Japanese research initiatives.

In Europe, Task 14 contributed to the World PV Conference (WCPEC9), organizing a dedicated parallel event titled "PV as an Ancillary Service Provider – Laboratory and Field Experiences from IEA PVPS Countries".

Further Task 14 dissemination activities, events and publications during 2022 are listed in ANNEX TASK DESCRIPTION – Publications.

Complementing the dissemination work and progress in the reports, the Task 14 management team has started the process to define the new Task related to Grid Integration of Solar PV, which is planned to continue the work after the conclusion of Task 14 at the end of 2023. During first internal sessions at Task 14 experts' meetings in 2022, significant progress was made, focusing on the basic concept and scope of the new task. During the next phase of the Task Definition Phase external experts and representatives of different stakeholders will be involved in order to develop a focused and targeted strategy and work-programme. In 2023, a number of dedicated events are planned to be held, including a workshop at the Intersolar in Munich. Finally, the full work-programme for the new Task is planned to be presented at the PVPS All Tasks Meeting at the end of 2023.

Fig.16 - The PV panels installed on the roof of the new THU campus building and the inverters in the smart grid laboratory of THU

OUTLOOK FOR 2023

Task 14 activities in 2023 will focus on finalizing the planned reports and promoting results and outcomes though global dissemination. In detail, the following topics will be addressed:

- Innovative smart functions of PV inverters
- Central reactive power management with VRE
- PV in Energy Communities
- Active power management of PV systems
- Capabilities of Smart Inverters
- Design recommendations for PV in Smart Grids

Results are planned to be disseminated through papers and presentations at major conferences. On the local level, targeted stakeholder workshops and events will be organized through the local expert networks in Task 14 member countries.

As the current phase of Task 14 will terminate at the end of 2023, experts will keep working together to finalize the new task definition, which aims at specifying major challenges of Solar PV in 100% RES power system and defining the objectives and scope of the new task. The new Task is planned to be presented at the PVPS All-Tasks Meeting at the end of 2023.

All Task 14's PVPS Publications are available here

TASK 15

ENABLING FRAMEWORK FOR THE DEVELOPMENT OF BIPV

Task Managers: Mr Francesco FRONTINI (Swiss BiPV Competence Center, Uni Applied Science & Arts Southern Switzerland (SUPSI)); Ms Helen Rose Wilson (Fraunhofer Institute for Solar Energy Systems, Germany)

Fig.17 - IEA-PVPS Task 15 experts' Meeting in San Sebastian, Spain, October 2022

INTRODUCTION

Building-Integrated PV (BIPV) represents a great opportunity to achieve zero-energy buildings and completely renewable energy systems. BIPV can facilitate using large areas of building envelopes for renewable electricity generation. For a large-scale deployment of BIPV, architectural, aesthetic, 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.

Today BIPV is receiving increasing attention in many countries, as it can provide renewable energy close to consumers, has very high social acceptance, saves space and provides new opportunities for architects and planners.

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

2022 KEY ACCOMPLISHMENTS

In 2022, more than 50 experts focused on preparing two new reports and organizing the last year of activities of Task 15, Phase 2. The following main activities were completed in 2022.

TECHNOLOGICAL INNOVATION SYSTEM (TIS) ANALYSIS FOR BIPV

Last year, a new report that analyses the Technological Innovation System (TIS) of the Building-Integrated Photovoltaic (BIPV) technology in Spain was published. The analysis aims to facilitate and support the implementation of BIPV, further innovation and development of industrial BIPV solutions. Knowledge diffusion and building social capital are two of the main challenges identified. Some key recommendations are to include BIPV in the building technical codes and to increase interaction and relations between BIPV and construction sectors.

Five more countries are working on their TIS analysis and new reports will be published in 2023, together with the TIS analysis guidebook that describes some common standards for analysis and offers the basis for a broader investigation of the topic involving other countries.

CROSS-SECTIONAL ANALYSIS: LEARNING FROM EXISTING BIPV INSTALLATIONS

To describe the electrical and building functions of BIPV systems, performance parameters/ indicators (PIs) were defined in four categories: 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 installations was developed. This can be used now for the evaluation of BIPV projects (cross-sectional analysis), with the aim of drawing 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.

Main results, the specific rating systems and visualization via spider diagrams were published and presented during the 8th World Conference on Photovoltaic Energy Conversion in Milan.

BIPV GUIDELINES: GUIDEBOOK AND TECHNICAL PRESENTATIONS THAT PROVIDE A COMPLETE PATHWAY FROM BIPV DESIGN TO INSTALLATION, MAINTENANCE AND SAFETY

The generic drawings for the technical integration of BIPV into roofs and façades have been completed by the Task 15 experts. Several chapters of the book have progressed, particularly the guidebook chapter on energy requirements for BIPV systems and products, and the chapter on case studies, which contains detailed technical descriptions for more than 20 BIPV projects around the globe, complete with photos and schematic drawings for each project.

DIGITALIZATION FOR BIPV: USING THE OPPORTUNITIES OF DIGITALIZATION TO MAKE BIPV MORE EASILY ACCESSIBLE, MORE RELIABLE AND CHEAPER.

A new report has been finalized: "BIPV Digitalization: Design Workflows and Methods". Currently, the BIPV design process involves various methods, approaches and workflows practised by professionals in both the Architecture, Engineering, and Construction (AEC) and BIPV industries. The aim of this study is to investigate the BIPV simulation and modelling methods, approaches and workflows used in BIPV design and analysis globally. The study used a questionnaire survey targeting 10 professional groups related to both building envelope design and BIPV design and management processes in Europe, Asia, Oceania, North America and South America. The professional categories included: architect, façade engineer, electrical engineer, mechanical/structural engineer, fire-safety engineer, environmentally sustainable design (ESD) consultant, academic, research and development scientist, PV consultant, BIPV system installer, developer and property manager. The study evaluated findings from eighty AEC and BIPV professionals in Europe, Asia, Oceania, North America and South America.

PRE-NORMATIVE INTERNATIONAL RESEARCH ON BIPV CHARACTERISATION METHODS

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. Comparison and critical analysis of different approaches to quantify the solar heat gain coefficient (SHGC) of transparent (or semi-transparent) BIPV element has been finalized and discussed among the experts of the IEC 63092.

An overview of fire-testing facilities in different countries has been prepared, with contributions from 15 different countries already submitted. A scientific paper has been submitted. Several task 15 experts are working on the revision of the EN 50583:2016.

OUTLOOK FOR 2023

2023 will be the last year of the current phase of Task 15 and 8 deliverables are expected to be published.

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

A detailed analysis of energy-related features of BIPV modules and systems and the technical guidebook for BIPV will be published.

Several national reports and one synthesis report on the technical innovation system for BIPV will be published.

Coordination with standardization bodies has been undertaken and it is planned to exploit this further in the coming year in the new normative groups on BIPV in IEC TC82 and the ISO/IEC JWG11, as well as the CENELEC group revising EN 50583.

With the ambition to further support the market implementation of BIPV as an important component in the energy transformation, continuation of Task 15 beyond 2023 is foreseen and a new workplan for 2024-2027 will be developed.

All Task 15's PVPS Publications are availablee here

BIPV DIGITALIZATION

TASK 15 HIGHLIGHT

Main Content: Rebecca Yang, W.M. Pabasara U. Wijeratne, Hongying Zhao (RMIT University, Australia); Nuria Martin Chivelet (CIEMAT, Spain); Erika Saretta, Pierluigi Bonomo (SUPSI, Switzerland); Johannes Eisenlohr (Fraunhofer Institute for Solar Energy Systems ISE, Germany)

Editors: Rebecca Yang, W.M. Pabasara U. Wijeratne, Hongying Zhao (RMIT University, Australia)

BIPV Digitalization: Design Workflows and Methods – A Global Survey

Task 15 Webpage

KEY MESSAGE

A global survey presents the BIPV design process involving various methods, approaches and workflows practised by professionals in both the Architecture, Engineering, and Construction (AEC) and BIPV industries.

OBJECTIVE

The aim of this study is to investigate the BIPV simulation and modelling methods, approaches and workflows under four key areas: 1. solar irradiation 2. BIPV power output 3. building performance and 4. financial and design outcome.

METHODOLOGY

The study used a questionnaire survey targeting 10 professional groups related to both building envelope design and BIPV design and management processes in Europe, Asia, Oceania, North America and South America. The professional categories included: architect, façade engineer, electrical engineer, mechanical/structural engineer, fire-safety engineer, environmentally sustainable design (ESD) consultant, academic, research and development scientist, PV consultant, BIPV system installer, developer and property manager.

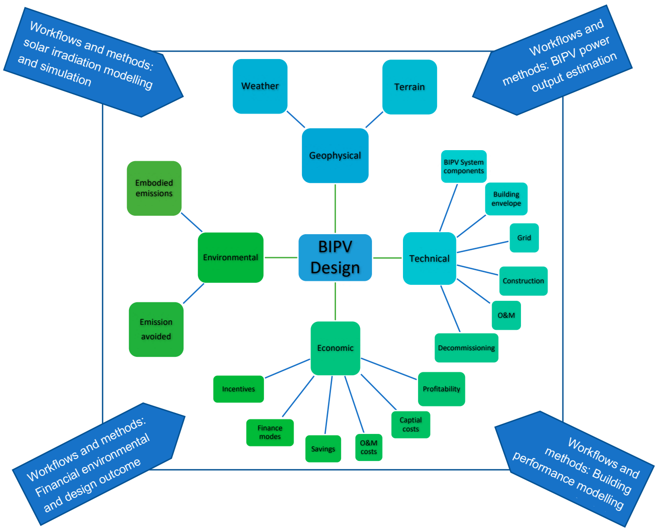


Fig.18 - Domains for BIPV design and simulation

In BIPV, the PV modules are integrated into the building elements. Therefore, both construction and electrotechnical elements need to be correctly designed, which makes the design process for a BIPV system more complex than for a conventional building element. BIPV systems consist of electrical, mechanical, and structural elements that have a direct impact on the performance of a building. Fig. 18 shows the operative approaches, methods, and workflows relevant to each domain of BIPV design and integration.

Solar irradiation **Stakeholders: Façade engineers, Architects, Electrical engineers, BIPV system installers, PV consultants, ESD consultants, Academics**
Power output analysis **Stakeholders: Electrical engineers, Architects, Façade engineers, PV consultants, and Property managers**
Building performance **Stakeholders: Architects, Electrical engineers, Mechanical/Structural Engineers, Fire engineers, Façade engineers, PV consultants, ESD consultants, Property managers and Academics**
Financial and design outcome **Stakeholders: Developers, ESD consultants, PV consultants, Academics and Property managers**

Fig.19 - Workflow of BIPV design and analysis

This figure shows four major steps and the relevant stakeholders in a comprehensive process for BIPV design and analysis. There is a need for a streamlined process or workflow for BIPV digital design and analysis. Furthermore, a simplified design process can improve the application of efficient and cost-effective BIPV in construction projects and thus contribute to reducing the carbon emissions associated with electricity generated from fossil fuels.

TIS ANALYSIS OF BIPV IN SPAIN

TASK 15 HIGHLIGHT

Authors: Nuria Martín-Chivelet (CIEMAT); Lucas García García (IES-UPM); Estefanía Caamaño Martín (IES-UPM); David Racero Patino (IES-UPM)
Editors: Michiel van Noord and Nuria Martín-Chivelet

[Analysis of the Technological Innovation System for BIPV in Spain]

[Task 15 Webpage]

KEY MESSAGE

To further develop BIPV towards a commercial market in Spain, it is recommended to include BIPV in the technical building codes and establish BIPV-specific incentives.

OBJECTIVE

The presented analysis aims to support and facilitate the implementation of BIPV projects, and to boost innovation and industrial BIPV solutions development.

METHODOLOGY

The Technological Innovation System (TIS) for BIPV starts by identifying the actors, networks, and institutions. Then, a review of the BIPV-related publications, projects, and patents, as well as interviews with relevant experts in the field and additional stakeholders' surveys, complete the experimental basis for analyzing the functioning of the innovation system.

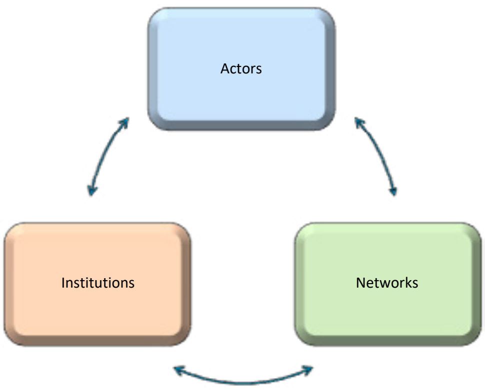


Fig.20 - The TIS structure

The main current TIS actors for BIPV in Spain are archi-tects, one globally leading BIPV manufacturer, research, and academia. National networks on PV exist but none fo¬cus on BIPV. BIPV is gaining strength because of the envi¬ron¬mental and energy emergency. However, neither har¬monized standards nor specific regulations exist for BIPV.

Fig.21 - Fulfilment assessment of the TIS functions

Although the BIPV knowledge level is acceptable, its dissemination is weak, especially between the PV and construction sectors. Entrepreneurial experimentation is increasing slowly and the competence of more companies is needed. There are funds for PV but not specifically for BIPV and there is a lack of BIPV-qualified technicians. Smooth communication and trust are limited to the known agents. There is good acceptance of BIPV from architects and general society; however, costs and lack of regulations increase the customers' resistance to BIPV.

Fig.22 - BIPV façade in a commercial building in Spain. Architect: Natalia Santafé. ©N. Martín-Chivelet

Most BIPV in Spain has been installed in tertiary buildings and most products are developed for BIPV glazing. This report presents recommendations for policy makers, industry & market players, and the education sector to improve the development of BIPV in Spain.

TASK 16

SOLAR RESOURCE FOR HIGH PENETRATION AND LARGE SCALE APPLICATIONS

Task Managers: Mr Jan REMUND (Meteotest AG, Switzerland); Mr Manajit SENGUPTA (National Renewable Energy Laboratory, U.S.)

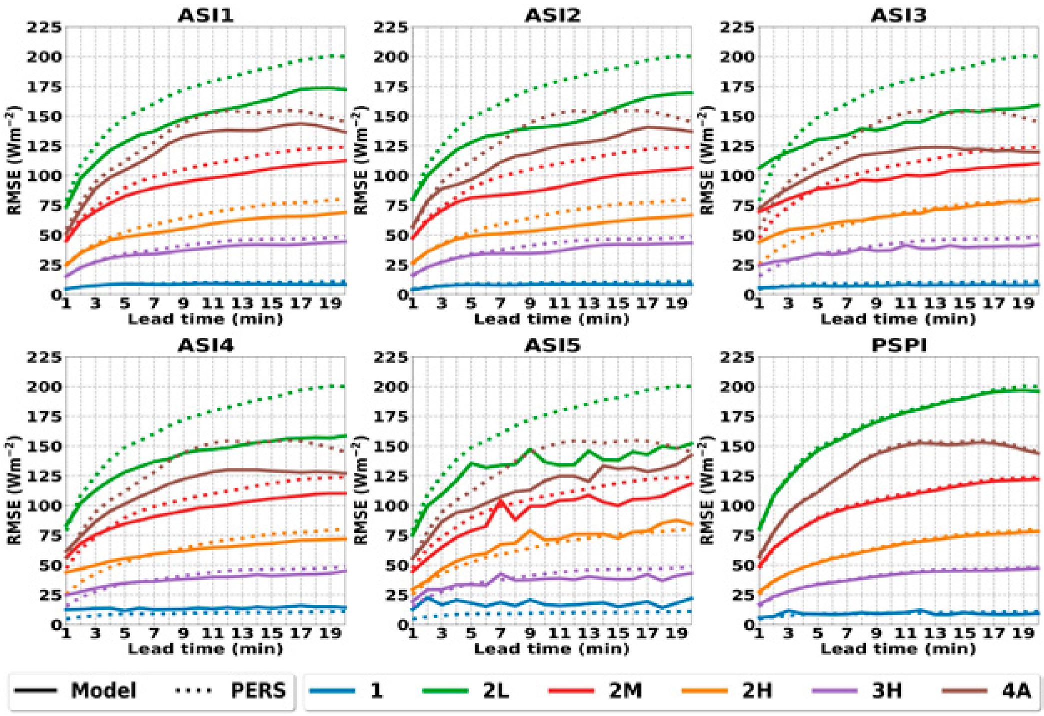


Fig.23 - Root mean square error (RMSE) variability, under the 6 different cloud clusters and forecast minutes. The time horizon ranges from 1 to 20 min with a latency of 1 min. The color represent different cloud classes: 1 = cloud free, 2L = broken. low clouds, 2H = broken, high / middle clouds, 2M = 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**

2022 KEY ACCOMPLISHMENTS

BENCHMARK OF LONG-TERM RADIATION DATA

The work on the benchmark for solar radiation data led by CSP Services (Anne Forstinger) is ongoing. First results are obtained and all stations have been evaluated. The results have been presented at a webinar on 28th of June and at four conferences in September 2023 (PVPMC, EMS, WCPEC-8 and SolarPACES). The ongoing work on benchmarking showed that a report separate to the solar resource handbook would be useful. It will include the current benchmark of the different solar resource data. The report is foreseen for summer 2023.

BENCHMARK OF GHI GAP-FILLING METHODS

The report on GHI GAP-Filling methods, written by Mines Paristech (Philippe Blanc, FRA) is in the final stages of editing, with publication foreseen in Spring 2023. Here the key takeaways:

1. Gaps in irradiation time series data are inevitable.
2. Different methods exist to fill irradiation gaps such as linear interpolation, machine learning, kernel regression and other methods based on satellite data.
3. In general, linear interpolation works best on short irradiation data gaps and satellite data works best on longer gaps.

BENCHMARK OF FORECASTS BASED ON ALL-SKY IMAGERS

The work on all-sky imagers (ASI) benchmarking lead by Univ. Patras, GRE is finished. There were 5 ASI's in the study. The results show that ASI 1-2 and 3-5 can predict 55%-65% and nearly 100% of the ramps respectively. The ASI benchmarking results have been presented in a webinar in December 2023 and published in two papers Logothetis et al., 2022a and 2022b).

BENCHMARK OF INTRA-HOUR/INTRA-DAY PROBABILISTIC FORECASTING

The work for the benchmark has started in 2021. Forecasts have been sent to the evaluation team (the deadline was November 2022). By spring 2023 the draft report is planned. The work is led by Philippe Lauret of Univ. La Reunion. FRA.

FIRM PV POWER

In January 2023 the report about different firm power generation studies was published as a PVPS report (see highlights on the next page of this annual report). In August 2022 a webinar about this topic was organized. Here the key takeaways of the report:

1. 100% VRE power grids with full renewable resource adequacy guaranteeing 24x365 firm availability are not only possible but would also be economically sound, insofar as supply and demand are concerned.
2. VRE overbuilding and operational curtailment (i.e., implicit storage) are key to achieving economically acceptable firm power solutions.
3. It is essential that optimal implicit storage configurations be enabled by appropriate market rules and remuneration vehicles favoring firm power.

The report demonstrates that proactive curtailment will be an important part of the solution. In Switzerland 10-20% of energy curtailment of PV is optimal. In a pan-European evaluation approximately 20-30% curtailment is optimal. Curtailment has been historically considered as something that must be avoided/minimized operationally. On the contrary, the article demonstrates that curtailment is a prerequisite and an enabler of the energy transition.

OUTLOOK FOR 2023

Task 16 will continue its work in 2023. The current phase will end mid-2023. The new work plan for mid 2023 – 2026 has been confirmed by the Exco in December 2022.

Based on the existing phase 5 reports are due in 2023. The main product of the Task the Solar Resource Handbook will be updated. This will take the whole year. The 4th edition of this handbook will include an updated chapter structure and new chapters.

Additionally, a report on Firm Power Generation will be published in January 2023. In spring a report about a benchmark of GHI gap filling method is foreseen. Two further benchmarking reports are prepared for summer 2023. One about probabilistic solar forecast and one about solar resource data.

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

All Task 16's PVPS Publications are available here

FIRM POWER GENERATION

TASK 16 HIGHLIGHT

R. Perez; M. Perez; J. Remund; K. Rabago; Morgan Putnam; Marco Pierro; MG. Prina; D. Moser; C. Cornaro; J. Schlemmer; J. Dise; T.E. Hoff; A. Swierc; P. Kellin; J. Boland; E. Tapaches; M. David; P. Lauret; R. van Eldik; W. van Sark; J. Lopez-Lorente; G. Makrides; G.E. Georghiou

Firm Power generation

Task 16 Webpage

KEY MESSAGE

Overbuilding and dynamic curtailment (aka implicit storage) lowers significantly the overall costs of energy transition.

OBJECTIVE

The concept of Firm power generation is to analyze the optimal way to achieve high shares of variable renewable resources (VREs) based on the in-depth knowledge of their spatio-temporal variability. The objective is to determine the lowest overall costs, the optimal shares of renewables, storage and energy curtailed.

METHODOLOGY

The report describes the general concept of firm power generation and includes summaries of 14 distinct studies. The most comprehensive studies include least cost analysis of electrical or all energy systems per country or transmission system.

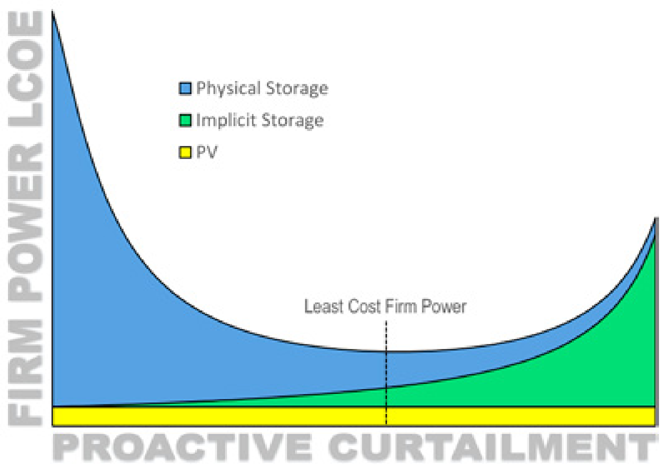


Fig.24 - Contributions of PV, storage, and implicit storage (aka PV overbuild) to the cost of firm power

The storage-alone option (zero curtailment) is significantly more expensive than an optimized real/implicit storage configuration.

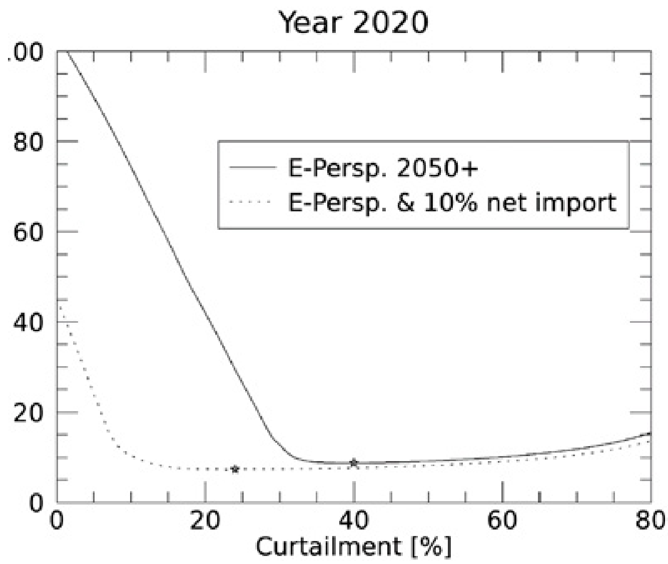


Fig.25 - Least costs of electricity in relation to curtailment for two specific scenarios in Switzerland

Least costs are reached with 25-40% of energy curtailed. Scenario E-Persp. 2050+ include no import of electricity from abroad. The 2nd scenario include 10% net annual imports. The LCOE are in the same range for both – in case of isolation of Switzerland higher curtailment would be needed.

TASK 17

PV AND TRANSPORT

Task Managers: Mr Keiichi KOMOTO (Mizuho Research & Technologies, Japan); Ms Manuela SECHILARIU (Université de technologie de Compiègne, France)

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: VIPV).

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 (PV-powered charging station: PVSC), battery and other power management systems.

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

2022 KEY ACCOMPLISHMENTS

TECHNICAL REQUIREMENTS FOR PV-POWERED PASSENGER VEHICLES: EXPERT SURVEY RESULTS

A survey of world experts to gain insights into what the community consider important in the transition of VIPV from niche to a mainstream and accepted technological application was conducted by TNO.

Covered topics are 'PV technology', 'VIPV system', 'Safety and reliability', 'Benefits', and 'Technical and market bottlenecks'.

The survey was conducted in November 2021, and sent out to 110 experts in VIPV including individuals from industry, academia, research institutes, consultancy and representing people from 5 continents (Europe, Asia, Australia, North America, and South America). Overall 70 people responded to the survey. All responses were completely anonymous. Survey responders were given the option to choose N/A for any questions that they felt they did not have sufficient expertise to answer. The completed questions in the incomplete responses are also included in the results. This leads to an average of 40 countable responses for most questions.

The results and findings were analysed in 2022 and presented at the PVSEC-33 in Japan in November 2022[†].

Key takeaways from the survey:

- c-Si (IBC) dominant technology now with tandem expected to grow in the future
- Efficiency, km/year and range extension were the most important system properties
- Willingness to sacrifice efficiency for more colour choice
- Preference for glass on the roof and polymer everywhere else – glossy or matte on roof everywhere else matte
- System costs: now 2-5 USD/Wp should drop to < 1 USD/Wp
- Minimum lifetime: 10-15 years
- Biggest technical bottleneck: complexity of manufacture

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

The main results and findings analysed in 2022 were published in international journals and/or presented at several conferences.

Key takeaways from the main results:

- The algorithms implemented to control small and large PVCS are able to maintain a high rate of PV contribution for EV charging and to satisfy the EV user demands.

  Experimental results obtained for:

  - Local PVCS (5 charging spots) for real-time power management including optimization problem and solar irradiation prediction
  - PV-powered charging infrastructure (+200 charging spots) for energy management including solar irradiation prediction

  Simulation results obtained for:

  - Local PVCS (5 charging spots) for energy management with V2G operation and EV users interactions via a human-machine interface

- The proposed set of methodologies, assessment tools, sizing and regulation of PVCS and associated services will provide support to stakeholders to promote the emergence PVCS.
  - Global cost assessment methodology
  - Carbon impact assessment methodology
  - Decision-making tool considering life cycle costing and carbon footprint assessment
- The social acceptability survey, with 864 respondents, revealed very good prospects for PVCS. Regarding the social acceptance the study shows that the majority of those polled are eager to use PVCS and the new associated services V2G and V2H; however, this acceptance is conditional on a number of users' needs and constraints.
- The carbon impact comparison between the power grid charging stations and PVCS shown that the PVCS has 32.1% lower impact compared with a low-carbon grid (e.g. French public grid) and 91.2% lower impact compared with a high-carbon grid (e.g. Germany public grid).

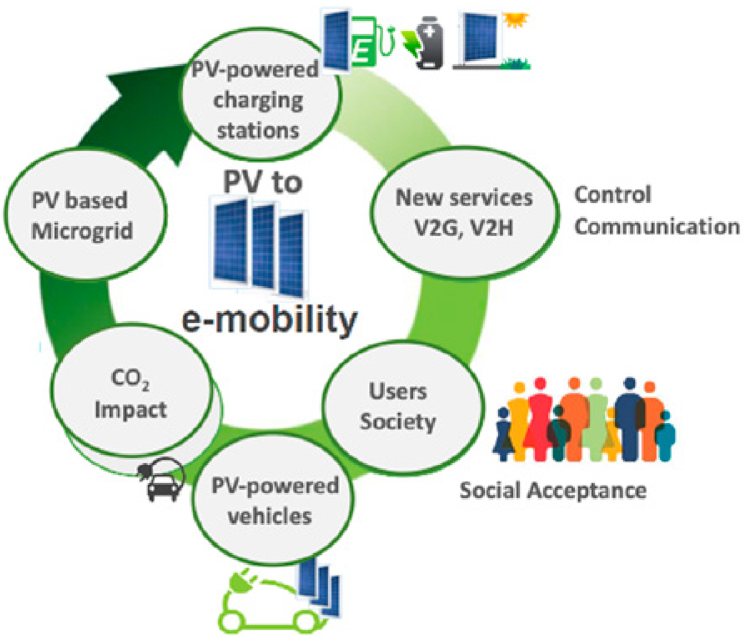


Fig.26 - PV & transport: PV-powered vehicles and charging stations

OUTLOOK FOR 2023

One of the challenging technical requirements for VIPV is the weight of VIPV technologies. A required methodology to study the impact of VIPV weight on the energy balance of passenger electric vehicles is proposed and a comprehensive analysis will be performed. Focusing on PV-powered heavy duty vehicles, energy flow analysis of truck/trailers and busses will be implemented, and benefits of PV installation on board will be discussed. As well, a cross sectional analysis of VIPV is proposed.

Technical requirements for PVCS related mostly to passenger cars have been discussed and analysed. Several studies related to the PVCS for e-buses will be conducted, aiming at the characterization of the current recharge and the impact analysis, designing the PVCS, and clarifying the possible PV contribution. Regarding the PVCS optimal sizing, a technical-economic-environmental co-optimization will be considered.

As expected benefits and approaches covering both PV-powered vehicles and infrastructures for transport, resilience of PV-powered vehicles and charging stations, and business models for 'PV and Transport' are discussed.

All Task 17's PVPS Publications are available here

† Anna J. Carr and Bonna K. Newman, 'VIPV – Technical requirements – Survey results', 33rd International Photovoltaic Science and Engineering Conference, Nagoya, Japan, 13-17 November 2022.

TASK 18

OFF-GRID AND EDGE-OF-GRID PHOTOVOLTAIC SYSTEMS

Task Managers: Mr Christopher MARTELL (Global Sustainable Energy Solutions, Australia)

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**

2021 KEY ACCOMPLISHMENTS

Task 18 accomplishments this year:

1. Task 18 was able to present virtually at the COP 27 in Egypt in November 2022. The event was hosted by Dr David Rene, ex-president of the International Solar Energy Society (ISES) and was joined by Sean White of IREC training organization, HeatSpring as well as Saba Kalam from the International Solar Alliance (ISA) and other members from solar development companies. Task 18 was presented during the session by Task Manager, Chris Martell. The two most recent publications were discussed as well as the Task 18 mission and a call for participants was made.

2. Task 18 was able to present at the India Smart Utility week in New Delhi, India at the end of February 2023. The event was hosted by Reji Kumar Pillai, President of India Smart Grid Forum and was attended by members from NREL, IRENA, ISGAN, Tata Power, etc. Remarks were provided by a Brazillian representative from the energy regulator ANEEL and by Chris Martell, the Task Manager of Task 18. Task 18 presented its current reports and provided context about how off-grid and edge-of-grid systems can be used to reduce the operational cost of servicing the electricity network and can be used to support power quality on the grid.

3. Task 18 was also able to present at WCPEC-8 in Milan, Italy. Key publication authors Michael Muller and Lachlan McCleod were able to present their respective Task 18 reports. Additionally, Task 18 was able to conduct its first face to face meeting since March 2020 (due to the beginning of the pandemic).

4. Task 18 Activity 1.4 is also nearly complete. A report will be produced prior to the Executive Committee Meeting in Neuchatel, Switzerland. The report will be submitted as a final draft for ExCo review and voting.

5. Task 18 will also be meeting at the S-access off-grid conference in Palma de Mallorca, Spain. In this meeting, Task 18 will be finalising and presenting the activity 1.4 outputs as well as finalising the workplan for presentation to the ExcO.

OUTLOOK FOR 2022

Task 18 has consolidated its efforts onto activity 1.4 led by Dr. Pavol Bauer, TU Delft, Netherlands.

Activity 1.4 considers off-grid system modelling using the two modelling software packages with the greatest market use (Homer Pro and iHOGA). These modelling packages will be used to analyse several case studies and the modelling inputs and subsequent outputs will be evaluated.

The evaluation will not seek to rank the software against each other, instead, the evaluation will attempt to draw conclusions about how differences in the case study parameters affect the outcomes of the modelling. The hope is that this analysis will help to inform users of the software to be aware of these differences and commonalties

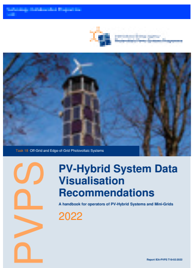
All Task 18's PVPS Publications are available here

DATA VISUALISATION

TASK 18 HIGHLIGHT

Author: Michael Müller (Germany, mm@ofres.org, available to process PV-Hybrid system battery data free of costs)

Editors: Georg Bopp, Johannes Wüllner, Lluis Billet Miosca



https://iea-pvps.org/key-topics/pv-hybrid-system-data-visualisation-recommendations/

Task 18 Webpage

KEY MESSAGE

Template on how to display Monitoring data of battery based PV-Hybrid off-grid systems.

OBJECTIVE

To provide a standardised one page graphical visualisation output of monitoring data of battery based PV-Hybrid off-grid systems. It allows to compare the performance of different systems and to identify problems. Sample visualisations are presented.

METHODOLOGY

Based on earlier research activities a set of several data visualisation graphs was developed. The focus is battery data. Important data analyses where grouped to fit into a standardised one page graphical output. A proprietary linux based tool chain was developed. With the help of existing PV-Hybrid System data the graph output was validated.

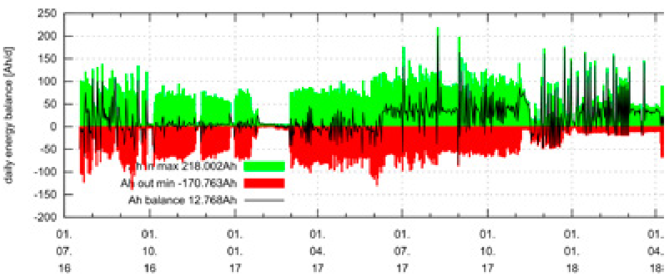


Fig.27 - The systems daily energy profile

This graph displays the daily energy balance of the system. The black line provides a fast overview whether it is positive or negative.

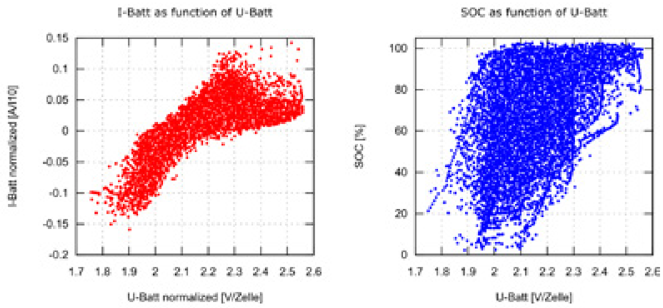


Fig.28 - Overview on State of Charge functions

This figure show the real life relation between the State of Charge, the battery current and the battery voltage. It indicates the charging and discharging hysteresis of all cycles within the data set.

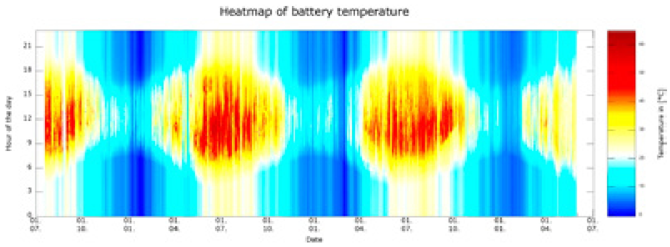


Fig.29 - Heatmap of the battery temperature

This figure provides an overview on the battery temperature over 3 years while the x-axis shows the date, the y-axis the time within one day and the color indicates the actual battery temperature.

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 (GSES)								TM
	IT Power Australia								
	Murdoch University								
	Royal Melbourne Institute of Technology (RMIT)								
	Solcast								
	University of New South Wales (UNSW)		TM						
	University of South Australia (UniSA)								
	Ekistica								
AUSTRIA	Austrian Institute for Technology GmbH (AIT)				TM				
	Austrian PV Technology Platform (TPPV)								
	Austrian Research Institute for Chemistry and Technology (OFI)								
	ertex Solartechnik GmbH								
	Polymer Competence Center Leoben GmbH (PCCL)								
	Salzburg University of Applied Sciences (FH Salzburg)								
	University of Applied Sciences Technikum Vienna								
	University of Applied Sciences Upper Austria (FH-OO)								
BELGIUM	3E N.V.								
	Becquerel Institute	TM							
	Energyville								
	Interuniversity Microelectronics Centre (IMEC)								
	KU Leuven (Catholic University of Leuven)								
	LuciSun								
	PV Cycle Association								
	Université Libre de Bruxelles (ULB)								

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
CANADA	Canada Centre for Mineral and Energy Technology (CAMET)								
	Concordia University								
	Natural Resources Canada								
	University of Waterloo								
	Yukon Research Centre								
CHINA	Chinese AcaDEMY of Science (CAS)								
	Zhejiang Jinko Solar Co. Ltd								
	Energy Internet Research Institute, Tshinghua University								
	Hunan University								
	Longi Solar								
	Public Meteorological Service Center (CMA)								
DENMARK	Danish Meteorological Institute (DMI)								
	European Energy A/S								
	Kenergy								
	Solar City Denmark								
	Technical University of Denmark (DTU)								
EU	EU Joint Research Centre (JRC)								
FINLAND	Aalto University								
	Lappeenranta University of Technology								
	Turku University of Applied Sciences								

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
	Energy Network & Renewable Energies Department (ADEME)								
	CSTB								
	Ecole Polytechnique à Palaiseau								
	Electricité de France (EDF R&D)								
	Enedis								
	Institut National de l'Energie Solaire (CEA-INES)								
	PIMENT laboratory, University of Reunion Island								
	MINES ParisTech								
FRANCE	SAP Labs France								
	POLYMAGE								
	PLANAIR FRANCE SAS								
	Promes-CNRS								
	Réseau de Transport d'Électricité (RTE)								
	TotalEnergies								
	University of the Antilles and Guyana						TM		
	Université de Technologie de Compiégne								
	SOREN (PV Cycle France)								
	German Aerospace Center (DLR)								
	Forschungszentrum Jülich GmbH								
	Fraunhofer IBP								
	Fraunhofer Institute for Solar Energy Systeme (ISE)					TM			
	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH								
	Institute for Solar Energy Research Hamelin (ISFH)								
GERMANY	LBP Stuttgart University								
	OFRES								
	Technische Hochschule Ulm (THU)				TM				
	TÜV Rheinland Solar GmbH								
	VDE Renewables (VDE)			TM					
	Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)								
	Arava EC&T								
ISRAEL	Electricity Authority (PUA)								
	Ministry of Energy								

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
ITALY	Electricita Futura								
	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)								
	European Academy Bozen/Bolzano (EURAC)								
	Gestore dei Servizi Energetici - GSE S.p.A								
	i-em								
	Ricerca sul Sistema Energetico - RSE S.p.A.								
	University of Rome II - Tor Vergata								
	Sapienza University of Rome								
	University of Catania (UNICT)								
	University of Naples Federico II								
JAPAN	Photovoltaic Power Generation Technology Research Association (PVTEC)								
	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								
KOREA	Kongju University								
	Korean Institute of Energy Technology (KENTECH)								
MALAYSIA	Sarawak Energy Berhad								
	Sustainable Energy Development Authority (SEDA)								
MOROCCO	Institut de Recherche en Énergie Solaire et Énergies Nouvelles (IRESEN)								

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
NETHERLANDS	Bureau for Eco-planning, Architecture + Renovation (BEAR-ID)					■			
	Rijksdienst voor Ondernemend Nederland (RVO)	■							■
	SmartGreenScans		■						
	Netherlands Organisation for Applied Scientific Research (TNO)		■			■		■	
	University of Delft		■						■
	University of Twente							■	
	University Utrecht			■			■		
NORWAY	Institute for Energy Technology (IFE)			■		■	■		
	Norvegian Water Ressources and Energy Directorate (NVE)	■							
	Norwegian Meteorological Institute						■		
	RISE Fire Research AS					■			
PORTUGAL	Energias de Portugal S.A. (EDP)	■							
	University of Lisbon (FCUL)							■	
SOUTH AFRICA	Council for Scientific and Industrial Research (CSIR)	■							
SPAIN	Centro de Investigaciones Energéticas (CIEMAT)		■			■	■		
	Escola Superior de Comerc Internacional (ESCi) / Oxford Brookes University		■						
	National Renewable Energy Centre (CENER)			■			■		
	Mactech						■		
	Onyx					■			
	Public University of Navarra						■		
	Tecnalia					■		■	
	Trama Techno Ambiental (TTA)								■
	Union Española Fotovoltaica (UNEF)	■							
	University of Almería						■		
	University of Las Palmas de Gran Canaria						■		
	University of La Laguna				■				
	University of Alcala								■
	University of Jaén						■		
	University of Malaga						■		
	University of Murcia		■						
	University of Seville						■		
	Universidad Politécnica de Madrid (ETSAM, UPM)					■			

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
SWEDEN	Becquerel Sweden								
	CheckWatt AB								
	Mälardalen University								
	Research Institutes of Sweden AB (RISE)								
	Swedish Meteorological and Hydrological Institute (SMHI)								
	Soltech Energy								
	University Uppsala								
	White Architects								
SWITZERLAND	Berner Fachhochschule (BFH)								
	Institut für Solartechnik (SPF)								
	Meteotest						TM		
	Planair SA, Switzerland								
	Scuola Universitaria Professionale della Svizerra Italiana (SUPSI)					TM			
	Bern University of Applied Sciences								
	treeze Ltd., fair life cycle thinking								
	Viridén + Partner AG								
	Zurich University of Applied Sciences (ZHAW)								
	Kromatix								
TAIWAN	PV Guider Consultancy								
THAILAND	King Mongkut University of Technology Thonburi (KMUTT)								
	Ministry of Energy (DEDE)								
TURKIYE	Türkish Clean Energy Research Institute (TENER, TENMAK)								
	Middle East Technical University								

TM = Task Manager

		T1	T12	T13	T14	T15	T16	T17	T18
USA	Case Western Reserve University (SDLE Research Center)								
	Clean Power Research (CPR)								
	Department of Energy (DoE)								
	Envision Digital LLC								
	Electric Power Research Institute (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 University of New York at Albany (SUNY)								
	University of California San Diego (UCSD)								
	University of Oregon								
PVPS SPONSORS	Enercity SA, Ecuador								
	Solar Energy Research Institute of Singapore (SERIS)								
	SolarPower Europe								

TM = Task Manager

AUSTRALIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Renate Egan (APVI and UNSW)

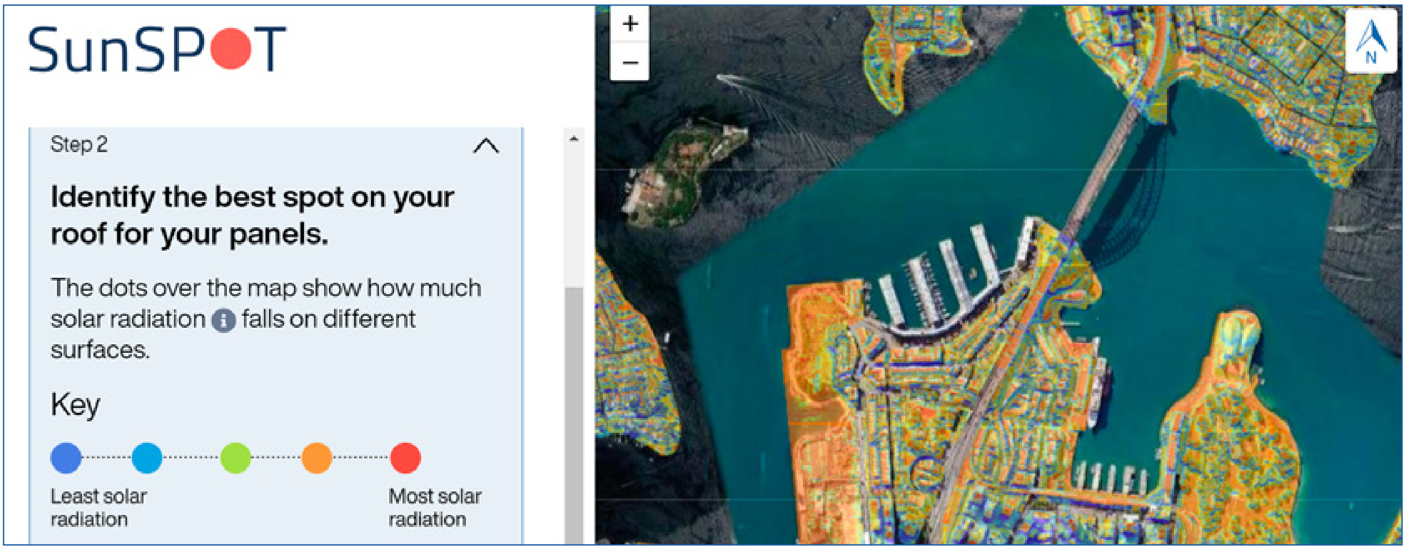


Fig.30 - The APVI SunSPOT solar and battery calculator estimates your system size, the cost, and how much a household can save

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 $AUD 654 million 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 2022, research was funded by the Australian Renewable Energy Agency (ARENA), the Australian Research Council and Co-operative Research Centre.

ARENA is the largest funder of photovoltaics research in Australia. In 2022, ARENA committed over AUD 85 m for accelerating solar PV innovation and in lowering the cost of systems and integration, with the aim of achieving AUD15/MWhr.

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 9 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

End 2022 saw a cumulative 29.7 GW and a total of at least over 3.36 million PV installations in Australia. We saw a pull back in the Australian PV market with early estimates indicating close to 4 GW of solar was installed, after 5 GW in 2021. Average residential solar PV system prices saw an increase, to more than AUD 1.10 per Watt after subsidies, or around AUD 1.55 per Watt on average without STC support, due to supply chain challenges and growing international demand [1].

The average system size in the sub-100 kW market grew further to over 9 kW/system, reflecting both the growth in commercial installations, and the growth in the typical size of residential systems, as householders prepare their homes for future addition of batteries and electric vehicles [2].

The Australian storage market remained strong in 2022, with the Clean Energy Regulator now tracking and reporting battery installations. Over 19 000 new batteries were installed with small scale solar systems in 2022, increasing the total number of batteries installed to upwards of 60 000 by the end of 2022.

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 the large uptake of residential PV.

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

2023 is expected to see stability in rooftop solar – with some 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. Commercial PV deployment continues to grow and corporate interest in solar PPAs is building.

Sustained interest in rooftop solar has led to a number of innovations including the SunSPOT solar and battery calculator that estimates your system size, the cost, and how much a householder will save (see Figure 30).

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 or replacement.

AUSTRIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Hubert Fechner, Chairperson (Austrian Photovoltaic Technology Platform); Arno Gattinger (Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology)

Fig.31 - 24.5 MW Floating PV System in Grafenwörth, Austria Credit: ECOWind

NATIONAL PV POLICY PROGRAMME

Austria's gas supply and its great dependence on Russia was the focus of discussions about Austria's energy supply in 2022. The country experienced an offensive by private and commercial companies to use renewable energy sources instead of gas. The goal of 100% renewable electricity supply set in the Renewable Energy Expansion Act in 2021 thus became the focus of further discussions. Photovoltaics experienced an unprecedented boom, which was slowed down by barriers in the supply chain as well as by restrictions on connections to the electricity grid. To a certain extent the lack of installers and planners was also a limiting factor. Nevertheless, in 2022 Austria will have exceeded the 1 GW limit for new installations for the first time.

Since 2022, either a market premium, paid monthly over a period of 20 years, or an 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). In the course of the application, the applicant must report the level of the economically necessary electricity price of the PV system. The subsidy applications are ranked according to the registered electricity price. 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, in 2022 and 2023 this price is set with 9.33 EUR Cent/kWh. Registered bids with a higher electricity price are invalid.

There is also nationwide investment support for the construction or expansion of PV systems (maximum size 1 MW) and the associated new electricity storage systems (maximum size 50 kWh). In order that the subsidies support small and large systems equally, 4 categories were set up (0 to 10, 10 to 20, 20 to 100 and 100 to 1000 kWp) with different subsidy rates. From the second smallest category onwards, the maximum funding requirement must be specified, after which a ranking is made in the event of oversubscription.

Innovative PV systems receive a surcharge of 30%; they include building-integrated systems, floating PV, PV panels as parking lot roofing, systems on noise protection walls as well as agri PV systems.

In addition, there is a large number of subsidies from the federal states, some of which are aimed at specific target groups (e.g. municipalities) or at special types of application (e.g. car park roofs).

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Austrian PV-Technology platform, which was initially supported by the Ministry of Transport, Innovation and Technology (now the Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology) acts as a legal body since 2012. It brings together more than 30 Austrian based industries and commercial entities, active in the production of PV relevant components and sub-components, as well as the relevant research community, in order to create more innovation in the Austrian PV sector.

The transfer of latest scientific results to the industry by innovation workshops, trainee programs and conferences, joint national and international research projects, and other similar activities are part of the work program. Additionally, necessary actions are taken for raising awareness, as well as aiming to further improve the frame conditions for manufacturing, research and innovation in Austria at the relevant decision making levels.

The "Austrian Innovation Award for Integrated PV" is organized by the PV platform on a biannual basis. The target of "PV Integration" covers all kinds of integration of PV into the building-, mobility- and agricultural sectors. Three projects from the building and mobility sector were awarded in early 2022.

In general, the public sector invested 44% more in energy research in the year 2021 than in the previous year. Public spending on Research, Development and Demonstration projects in the energy sector amounted to 224.1 million euros in 2021, of which around 2.9 million went to the photovoltaic sector.

The topics of energy efficiency, transmission, storage as well as hydrogen and fuel cells were clearly in the foreground of the research, development and demo projects. In the frame of mission innovation, Austria is leading the programs towards a net zero industry together with Australia.

In the European research environment, Austria is coordinating the Clean Energy Transition Partnership (CETP), a co-funded Partnership in Horizon Europe. Furthermore, Austria is still active in the ERA-Net Cofunds as well as in other research activities of the European Union programme.

Austria supports the European initiative IPCEI (important projects of common European interest) for the joint development of a strong European photovoltaic industry.

Most Austrian producers in the field of photovoltaics are currently expanding their production capacities based on innovative technologies in order to be able to position themselves on the growing world market. Research and innovation will increasingly play an important role.

→ Austrian Experts participate currently in 4 PVPS Tasks involving 8 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

All of the Austrian PV module producers have started to increase their production capacity focusing on specific modules for building integration as well as standard modules. 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.

On the home market, 2022 was the start of the first larger ground mounted photovoltaic projects; Systems up to around 150 MW are currently in preparation. Since the nationwide prerequisites have been set by the increased subsidies within the Renewable Energy Expansion Act and the political goals, it is now primarily up to the federal states to make the projects possible. Large-scale projects are constantly the subject of critical discussion, above all due to nature and landscape protection as well as local spatial planning. The local designation of suitable zones is progressing, but the question of integration into the power grid is often the limiting factor.

The first agricultural PV systems and a larger floating PV system were installed in 2022. Energy communities continue to thrive, with PV systems at the heart of nearly every community. After the market doubled in 2021‡), the market figures for 2022 will certainly be able to report a gigawatt market for the first time.

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 2022, the association counted 364 companies and persons involved in the PV and storage industries as its members.

Photovoltaics experienced an unprecedented boom, slowed down by barriers in the supply chain as well as by restrictions on connections to the electricity grid. Nevertheless, in 2022 Austria will have exceeded the

1 GW limit for new installations for the first time.

‡ Biermayr, Dißauer, Eberl, Enigl, Fechner et al. Innovative Energietechnologien in Österreich - Marktentwicklung 2021, Berichte aus Energie- und Umweltforschung 21b/2022, Federal ministry for climate action environment energy mobility innovation and technology, 2022

CANADA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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N. Gall, P. Mckay (Canadian Renewable Energy Association)

Fig.32 - Vulcan County, Alberta, 465 MW-AC Travers PV array consisting of bifacial modules with single-axis tracking. Photo credit: Greengate

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 achieve a net-zero electricity supply by 2035. While there are no specific capacity targets for PV set by the federal, provincial, or territorial governments, according to the Canada Energy Regulator, Canada's PV capacity is expected to reach 27 GW by 2050.

At the national level, PV is eligible for several federal support programs including the $1.564 billion§ Smart Renewables and Electrification Pathways Program, the $500 million Low Carbon Economy Fund, the $520 million Clean Energy for Rural and Remote Communities program, and the $100 million Smart Grid program. At the household level, the Canada Greener Homes Grant provides rebates of $1 000 per kW for a maximum system size of 5 kW.

The provinces and territories also implement their own local support policies such as feed-in tariffs, capital subsidies, self-consumption, and net metering. Several provinces offer Property Assessed Clean Energy programs whereby PV system costs are repaid through property taxes.

As of December 31, 2021, Canada's PV sector reached approximately 4.55 GW of installed capacity representing a 26% increase over the previous year [1]. Much of the growth in 2021 was from a 465 MW transmission-connected array newly commissioned in Alberta (see Figure 32).

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 increasing grid flexibility and energy storage options.

In terms of the burgeoning fields of agrivoltaics and floating PV, there is growing interest in agrivoltaics among the Canadian PV community and farmers. More work is necessary to promote research and development, case studies for a range of crops and PV configurations, and policy mechanisms to support farmers in their transition. Projects to prove the effectiveness of these systems in temperate climates are underway. For example, the province of Quebec, through the Ministry for Economic and Energy Innovation, has recently offered financial support for agrivoltaic demonstration systems.

§ All dollar amounts in this section 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.

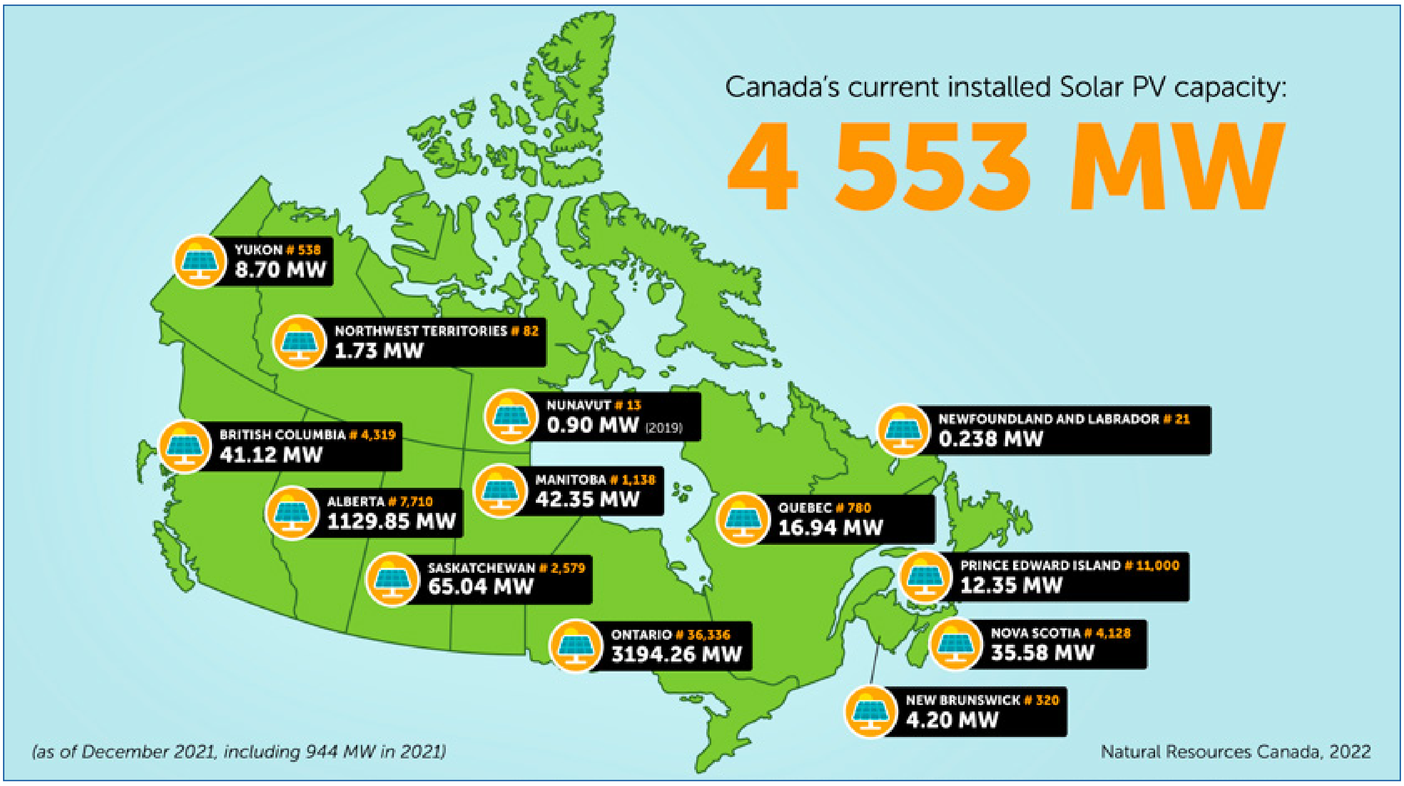

Fig.33 - Map showing PV power capacity (MW) as of December 31, 2021. This map is for illustrative purposes only and sizes or distance scales are approximate. Note: PV data for Nunavut were not available in 2021, and so the capacity from 2019 was reported. Estimated accuracy of nationwide capacity is ±3%

Canada's largest PV system was inaugurated this year.

The 465 MWAC

Travers PV system installed in Vulcan County, Alberta, consists of

bifacial modules

with single-axis tracking.

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

INDUSTRY & MARKET DEVELOPMENT

Approximately 66% of Canada's cumulative 4.55 GW PV capacity is connected to the low/medium voltage distribution grid and the remaining 34% connected to the high voltage transmission grid. A map of cumulative capacity nationwide is given in Figure 33.

The economic value of the Canadian PV industry in 2021 was approximately $2.18 billion. The combined number of full-time manufacturing, installation, distribution, and research employment in this sector was conservatively estimated to be approximately 15 000 jobs. Examples of several large PV manufacturers in the Canadian market include Canadian Solar, Heliene, Stace and Silfab. Producers in the field of concentrating solar and sun-tracking systems include Morgan Solar.

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 1.89 $/W to 2.36 $/W. Commercial roof-mounted PV from 100 kW to 250 kW in size varied between 1.68 $/W to 2.10 $/W. Small ground-mounted centralized arrays 1 MW to 20 MW in size varied from 1.65 $/W to 1.90 $/W. Lower prices of around 1.31 $/W were achieved for utility scale PV larger than 20 MW [1].

CHINA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Lv Fang (Electrical Engineering Institute, Chinese Academy of Sciences/ China ECOPV Allianc); Xv Honghua (Researcher, Chinese Academy of Sciences);
Dai Jinhong (China ECOPV Alliance)

NATIONAL PV POLICY PROGRAMME

In 2022, China's intelligent manufacturing and modernization of the PV industry accelerated via a steady and positive development throughout the whole year. This strongly supported approaching the goal of "carbon emissions peak and carbon neutrality", via five key channels of progress: industry scale, innovation, intelligent manufacturing, market growth and subsidy phase-out.

Firstly, the industry scale continued to increase and the output of the PV industry chain set new records in 2022. The production of polysilicon, wafers, cells and modules reached 827 000 tons, 357 GW, 318 GW and 288.7 GW, respectively. This marks a 58.8% year-on-year increase, with the industry's total output value exceeding 1.4 trillion RMB.

Secondly, the innovation of technology improved quickly. The P-type PERC cell average conversion efficiency of the mainstream enterprises in 2022 reached 23.2%. The N-type TOPCon cell technology impacted the scale of mass production, and the average conversion efficiency increased to 24.5%. The output of HJT cells accelerated and the conversion efficiency created a new world record of 26.81%. The research and production lines of perovskite and c-Si tandem solar cells have made new breakthroughs.

Thirdly, the demonstration of intelligent PV has achieved initial success. This refers to the blending and innovation of the PV industry and new information technology, which has been accelerated, including the timely expansion of the third batch of intelligent PV pilot demonstrations. The total systematic solutions of industry, buildings, transportation, agriculture and energy were frequently in focus, and the levels of PV industry intelligent manufacturing, intelligent operation and maintenance, intelligent scheduling and PV/storage hybrid implementation were significantly improved.

Fourthly, the domestic market applications grew continuously. The utility PV base as well as the distributed PV market steadily improved throughout 2022. The new installed capacity of 2022 domestic PV was more than 87 GW, which can effectively support the growth of both domestic and foreign PV markets.

Fifthly, the green certificate trade & market gradually improved while the PV market became fully independent of subsidies in 2022. The government has encouraged power users to sign green certification trading contracts with new energy enterprises for more than one year, locking in longer-term and stable price levels for new energy enterprises. By the end of 2022, 20.6 million green certificates had been issued, corresponding to 20.6 billion kWh of power, which was an increase of 135% compared to 2021. (Each green power certificate generated and traded corresponds to 1000 kWh of renewable power consumed, and renewable generators enterprises obtain the environmental value of green power by trading green certificates.)

RESEARCH, DEVELOPMENT & DEMONSTRATION

Chinese PV enterprises and research institutions refreshed PV cell efficiency records 14 times in 2022, including 10 times for n-type cell technology. A highlight was the highest world record of 26.81% for silicon-based solar cells created by LONGI in December 2022.

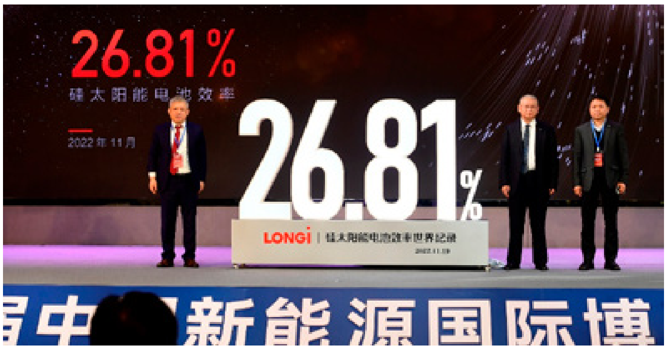

Fig.34 - LONGI made the new record of 26.81% for silicon-based solar cells [Source: LONGI]

The wafer thickness continued to decrease, with p-type monocrystalline wafers dropping to 155 μm, n-type TOPCon monocrystalline wafers dropping to 140 μm, and n-type HJT monocrystalline wafers dropping to 130 μm. Large size wafers were becoming a trend, with combined market share of 182 mm and 210 mm size increasing to 82.8% up from 45% in 2021. It is expected to exceed 93% in 2023.

The n-type cell technology is rapidly increasing, with the market share of TOPCon and HJT cells increasing from 3% to 8.9% in 2022, and an expectation to exceed 20% in 2023. The market share for bifacial modules has now increased to 40% up from 10% in 2018.

To support the construction of a new power system, China synchronized the application of new energy storage technology innovation and high-quality development of the industry. By the end of 2022, the installed scale of new energy storage projects in operation nationwide reached 8.7 million kW, with an average energy storage time of about 2.1 hours. Among them, lithium-ion cell energy storage accounted for 94.5%.

On the aspect of PV applications, in addition to the utility PV base and other distributed "PV+" model, SPI (State Power Investment Corporation) completed the first floating deep-sea 500 kW PV power station in November 2022 in China. The location is 30 kilometers offshore, on 30 meter deep water, and can withstand extreme wave heights of 10 meters. It consists of two circular floating units, demonstrating wind, wave and marine environment resistance, and has been grid-connected via the surrounding 20 MW offshore wind power stations, realizing the technical exploration of wind / PV hybrid power on the deep sea.

Fig.35 - The first floating deep-sea 500kW PV power station in the world [Source: SPI]

China built the 800 MW Kharsaah PV station, which was Qatar's first PV power plant and strongly supported Qatar's commitment to hosting a carbon-neutral World Cup. The power plant uses LONGI's Hi-MO4 bifacial modules, and is currently the third largest single PV plant in the world and the largest PV project in the world utilizing tracking systems and bifacial modules.

Fig.36 - Kharsaah PV station [Source: LONGI]

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

INDUSTRY & MARKET DEVELOPMENT

In 2022, the production volumes of polysilicon, silicon wafers, solar cells and modules in China increased significantly compared to 2021 (see table 3). The fractions of large-size silicon wafers and n-type cell technology are expected to grow rapidly beyond the 2022 market.

On the aspect of PV applications, in addition to the utility PV base and other distributed "PV+" model, SPI (State Power Investment Corporation) completed the first floating deep-sea

500 kW PV

power station in November 2022 in China.

TABLE 3

	CHINESE PV INDUSTRY PRODUCTION VOLUME IN 2022	YEAR ON YEAR INCREASE FROM 2021
POLYSILICON	827 000 tons	63.4%
SILICON WAFERS	357 GW	57.5%
SOLAR CELLS	318 GW	60.7%
SOLAR MODULES	289 GW	58.8%

Source: China Photovoltaic Industry Association (CPIA) "2022 Photovoltaic Development Review and Outlook in 2023 Conference" in Beijing on 16 February 2023

The new installed PV capacity in China made a large leap in 2022 up to 87.4 GW AC (see table 4). The fraction of distributed capacity saw particularly strong growth, including growth in the residential home rooftop systems (see figure 37).

TABLE 4

	CHINESE PV CAPACITY INSTALLED IN 2022	YEAR ON YEAR INCREASE FROM 2021
TOTAL PV CAPACITY	87.4 GW	59%
DISTRIBUTED CAPACITY	51.1 GW	74%
RESIDENTIAL FRACTION OF DISTRIBUTED	25.2 GW	17%
CENTRALIZED CAPACITY	36.3 GW	42%

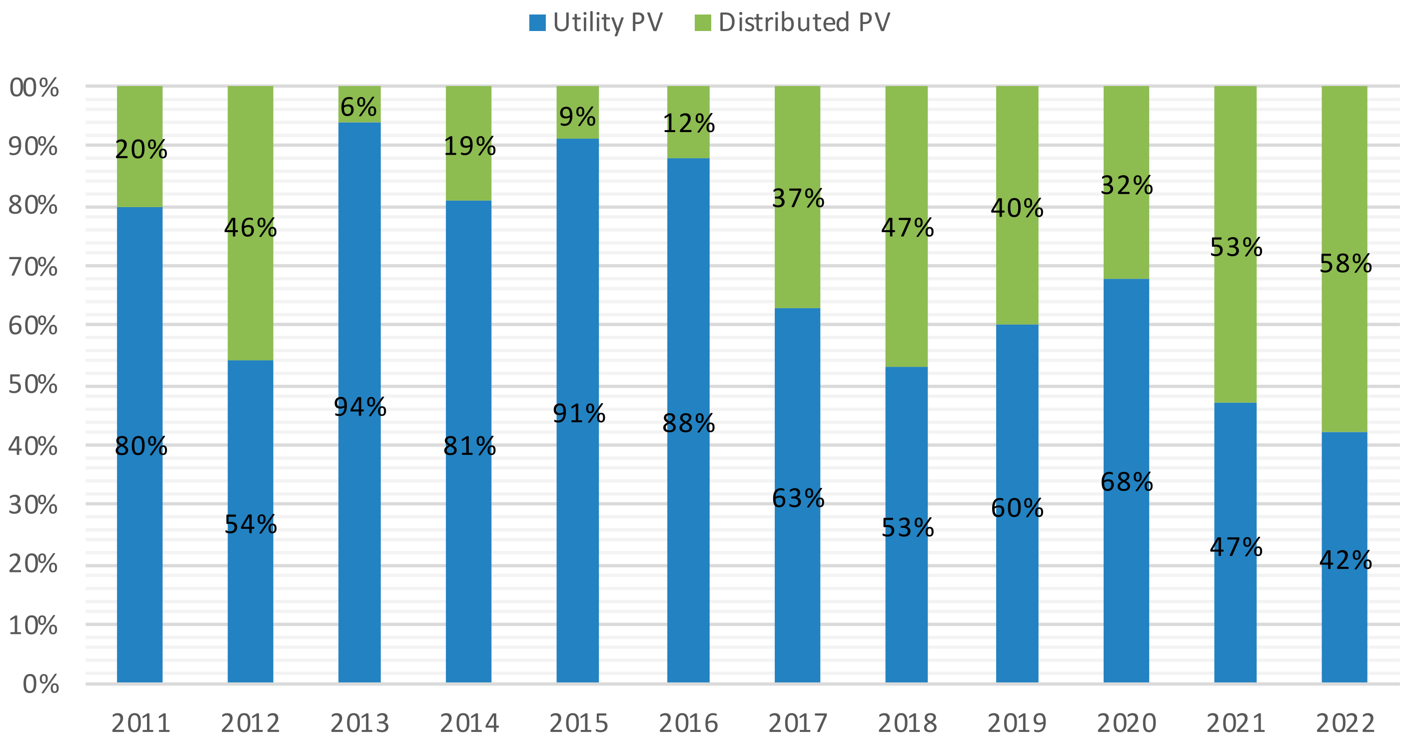

Fig.37 - The composition chart of the new installed PV in the past [Source: ECOPV]

China's combined wind and PV new installations accounted for 78% of the Country's new electricity installations In 2022, which was an increase of 207.2 billion kWh from 2021, and an increase of 21% year-on-year. Wind power and PV power generation reached 1.19 trillion kWh, which was 13.8% of the total power consumption of China. It was an increase of 2% year-on-year, getting close to the national urban and rural residential power consumption. Among them, the national grid-integration of PV was significantly enhanced with lower curtailment and an annual utilization rate of 98.3%.

China's renewable energy generation capacity had reached 2.7 trillion kWh by 2022, accounting for 31.6% of the society's power consumption, which was equivalent to reducing domestic CO_2 emissions by about 2.26 billion tons. The exported wind power and PV products additionally reduced CO_2 emissions in other countries by about 573 million tons, giving a total emissions reduction of 2.83 billion tons. China has become an active participant and an important contributor to the fight against global climate change.∆

China has a strong market reserve for PV power generation. The future development of distributed PV will be combined with the "Rural Revitalization Plan" and the "Clean Heating" national project. Additionally, in the distributed PV building market, the roof area of new buildings in public institutions will be installed to achieve PV coverage rate of 50% by 2025. At the same time, the construction of large PV bases in the Gobi desert region is developing fast. The first batch of wind and PV power bases (97 GW) had been all started by 2022, and by now the second batch of bases have also been started one after another.

It is estimated that China's new installed PV capacity will be 95 GW-120 GW by 2023.

∆ Source: China National Energy Administration (NEA) "2022 CHINA Renewable Energy Press Conference " in Beijing on 13 February 2023

DENMARK

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Flemming V. Kristensen (FKSOL ApS); Kenn H. B. Frederiksen (Kenergy ApS)

Fig.38 - Grenaa Varmeværk is a community owned district heating company with 5 600 consumers. In 2022 their generation was 137 151 MWh from biomass, 17 837 MWh from solar heating, 4 811 MWh from heat pumps and 200 MWh from a newly installed PV plant at 6.92 MW

NATIONAL PV POLICY PROGRAMME

Denmark has no unified national PV programme, but a continuous 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 transition have also been initiated.

Net-metering for privately owned and institutional PV systems 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 fraction of PV installations not applying for the additional support but operating in the economically attractive "self-consumption mode" or based on selling electricity on the commercial market or via PPAs is growing both in number and volume, and several commercial PV developers have activities in deploying PV across the EU, as well as internationally.

The main potential for deployment of PV in Denmark has traditionally been identified as building applied or integrated systems. However, the number of ground-based centralised PV systems in the range of 50 to >200 MW has been growing dramatically. Mostly, the projects are based on commercial PPAs or providing 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.

The Danish PSO system (Public Service obligations) has phased out financing for grid investments needed for connecting new renewable energy capacity, which ran until end of 2022. Now new RE systems connected to the grid must pay for the full grid connection costs.

As the connection costs for new RE installations vary across the different parts of the Danish grid, the TSOs and the DSOs have developed a map with green, yellow, and red areas. In the green areas, the grid is influenced by significant consumption of electricity e.g. industry and high population density. In the red areas it is the opposite situation because the grid is influenced by huge production from wind and PV but the population and industry is quite limited. In the yellow areas there is a composition of both production and consumption.

The intention of the map is to incentivize RE developers to focus on installations in the green areas to lower their project costs. Developers of both wind and PV projects claim that it will dramatically reduce the implementation of new capacity and put the targets of the green transition under pressure. The capacity map can be seen in figure 39. The DSO´s have also now introduced self-consumption tariffs and production tariffs for PV plants used for self-consumption.

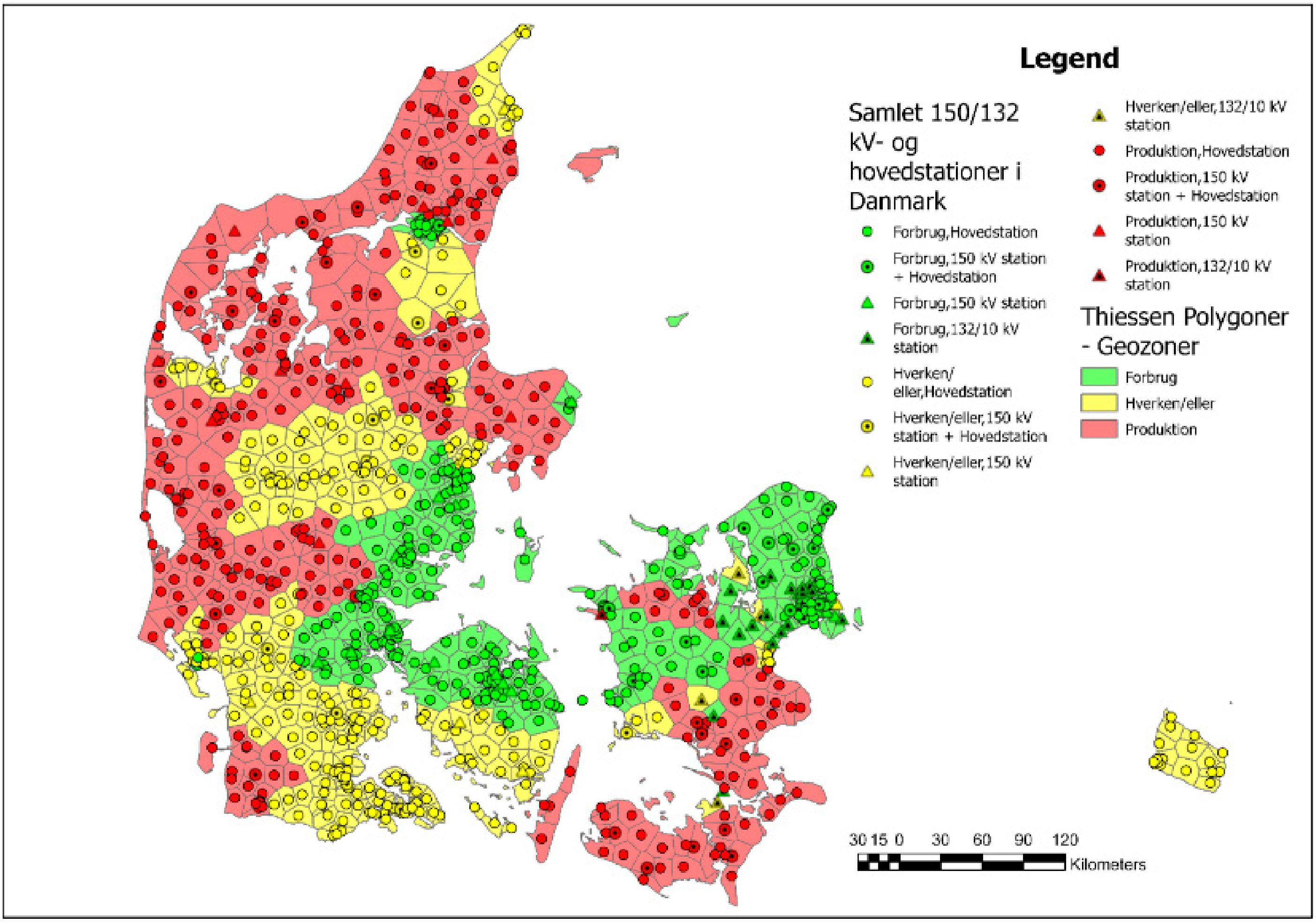

Fig.39 - Capacity map Denmark (Green Power Denmark)

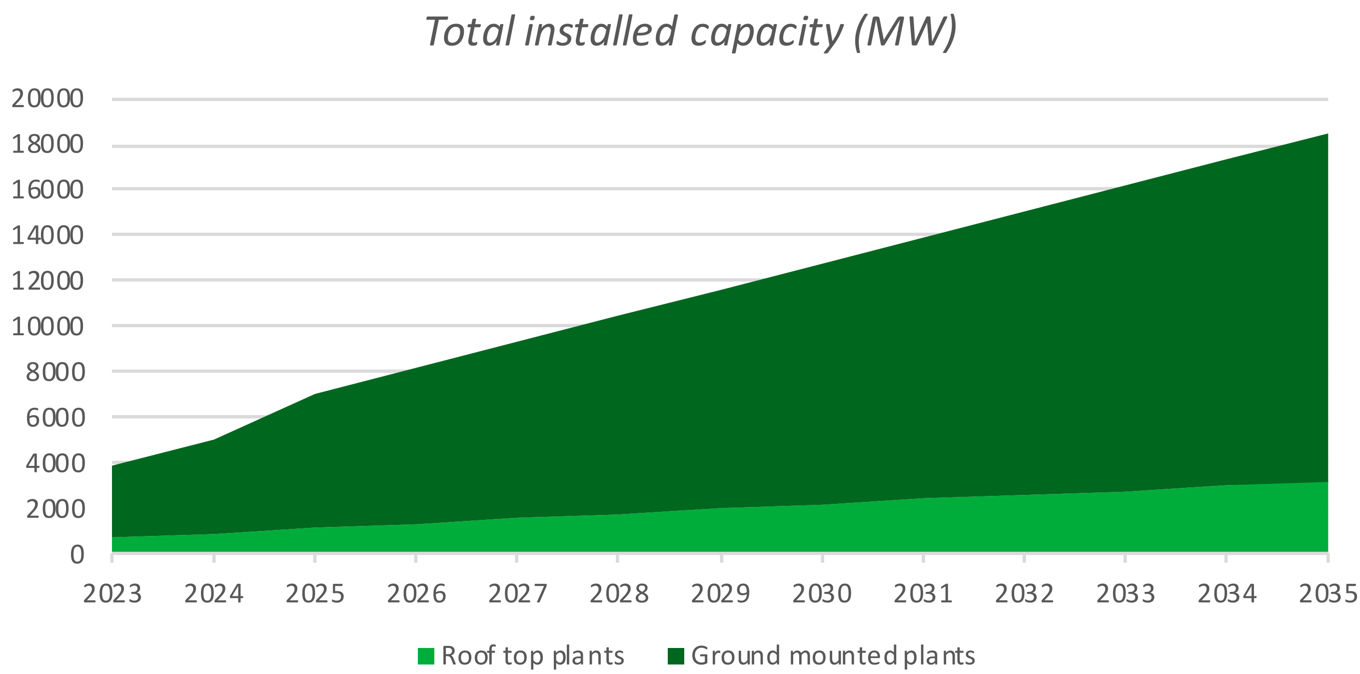

Fig.40 - 2022 Prognoses (Danish Energy Agency)

RESEARCH, DEVELOPMENT & DEMONSTRATION

The website of the national Energy Research and Development Program provides general information about three programs as well as links to specific R,D&D support schemes. It is possible to see information about ongoing and completed R&D projects.

The Energy Technology Development and Demonstration Program (EUDP) under The Danish Energy Agency funds work by enterprises and universities on demonstration of new green energy technologies. The program supports PV via different related projects each year. The linked website details the R&D program as well as both ongoing and completed PV related projects.

The strategic innovation topics in the EUDP program are:

1. More green electricity and for more purposes
2. Increase 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 consumption

ELFORSK (Green Power Denmark) supports projects that ensure a more efficient use of electricity at the end-users. The projects are 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

The political target of

70% reduction

of the carbon dioxide emissions by 2030 has been raised by the newly elected national government to

100% by 2045.

INDUSTRY & MARKET DEVELOPMENT

The Danish PV Association, established late 2008 with approximately 40 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 higher than in 2019.

A few PV companies exist producing tailor-made modules such as windows-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. Some the members have activities inside and outside Denmark.

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

The political target of 70% reduction of the carbon dioxide emissions by 2030 has been raised by the newly elected national government to 100% by 2045. This has pushed the PV market forward. The dramatic increase in the electricity prices during 2021 and especially in 2022 have heated up the market significantly. The speed of the growing market has resulted in a lack of availability of various PV system components in Denmark, as in the rest of Europe.

The national green transition and the ambitious governmental target for CO_2 reductions have the consequence that the forecast for the electricity consumption in Denmark will be doubled in 2030. This puts the grid operators under pressure because the connection of several GW capacity of wind and solar parks and establishing thousands of electric vehicle charging stations consumes a lot of resources, both financially and personnel.

The accumulated capacity in 2022, according to the Danish Energy Agency, is 3.018 GWac. With a DC/AC capacity factor of 1.3 the estimated installed module capacity is 3.923 GW.

The latest forecast from the Danish Energy Agency expects PV to reach 7.5 GW by 2025, over 12 GW by 2030 and 18 GW by 2035. These figures are periodically revised. See figure 40 for the prognoses for future growth in the PV capacity.

EUROPEAN COMMISSION

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Maria GETSIOU; Charles CLERET DE LANGAVANT

Fig.41 - Barlaymont building in Brussels shows the PV trend

NATIONAL PV POLICY PROGRAMME

As part of the REPowerEU plan, the Commission adopted an EU solar energy strategy in May 2022, which identifies remaining barriers and challenges in the solar energy sector and outlines initiatives to overcome them and accelerate the deployment of solar technologies. Alongside the plan, the Commission also presented a Recommendation on fast permitting for renewable energy projects and a legislative proposal on permitting that will contribute to accelerating solar energy deployment in the EU.

The EU solar energy strategy proposes 3 initiatives:

European Solar Rooftops Initiative

The initiative aims to accelerate the vast and under-utilised potential of rooftops to produce clean energy. It includes a proposal to gradually introduce an obligation to install solar energy in different types of buildings over the next years, starting with new public and commercial buildings, but also residential buildings.

EU large-scale skills partnership

This partnership will address the skills gap in the EU and promote the development of a skilled workforce in the solar energy sector. Current bottlenecks in the workforce will become an opportunity for new green jobs in the clean energy transition.

EU Solar PV Industry Alliance

This alliance aims to become a forum for stakeholders in the sector and help diversify the supply chains, retain more value in Europe and deliver efficient and sustainable PV products to reduce supply risks for the necessary massive deployment of solar energy in the EU. The Commission formally endorsed the "kick-off" of the Alliance on 11 October 2022.

The recent European solar energy strategy communication calls for about 450 GWac of new photovoltaic system capacity between 2021 and 2030. Given the current trend of installing a DC capacity 1.25 to 1.3 times the AC capacity to optimise the use of the grid connection, this would bring the total nominal PV capacity in the EU to approximately 720 GW by 2030.

The competitiveness of PV continued to improve by comparison with non-renewable electricity sources. The number of countries where photovoltaic electricity generation is the cheapest source is therefore growing. Increases in fossil fuel prices due to natural disasters, accidents or international conflicts, can only reinforce this trend.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Horizon Europe announced already in 2022 its second Work Programme (2023-2024) on "Climate, Energy and Mobility". Under the section 'Destination - Sustainable, secure and competitive energy supply' it includes activities in support of photovoltaic research and innovation, with a total EC contribution of 134 MEURO on the following priority areas:

PV integration in buildings and in infrastructure - to demonstrate economic and sustainable integration of PV products in the built environment and establish enhanced collaborative innovation between PV companies and the (building) construction sector.

Floating PV Systems - to demonstrate an economic opportunity for solar energy production in inland and offshore waters and overcome the challenges stemming from various environmental conditions that could adversely affect the electrical output and lifetime of the FPV plant.

Solar Systems for Industrial Process Heat and Power - to demonstrate energy efficient solar resource integration in the industrial sector for achieving low-carbon, emission-free production systems.

Advanced concepts for crystalline Silicon technology - to research and develop novel architectures approaching the theoretical efficiency limit of c-Si cells and provide the direction for even higher mass-production industrial cell performance.

Large Area Perovskite solar cells and modules - to demonstrate scaling up of the device area to fabricate efficient perovskite solar modules, tackling complex stability issues at the device and module level and overcoming the efficiency gap between the small and large size.

Operation, Performance and Maintenance of PV Systems - to increase PV system performance, reliability, security and flexibility under various topology and operating conditions with enhanced digitalization tools. To facilitate utility-friendly integration of PV generation into the European energy system at high-penetration levels.

Alternative equipment and processes for advanced manufacturing of PV technologies - to demonstrate alternative processes and equipment for PV manufacturing with reduced CAPEX, OPEX, energy and material consumption and implement Industry 4.0 concepts. To increase the productivity and sustainability of large-scale PV manufacturing equipment and processing.

Low-power PV - to develop the potential of PV for low power, low irradiation applications (harvesting energy in low light intensity and/or artificial light conditions).

PV-integrated electric mobility applications - to demonstrate effective Vehicle Integrated PV (VIPV) concepts and PV Charging Stations able to provide a significant part of the charging demand.

Innovative, Community-Integrated PV systems - to demonstrate a community-aggregated concept with a portfolio of producers and users to facilitate the energy transition to a low carbon economy.

Resource Efficiency of PV in Production, Use and Disposal - to define guidelines for design and processing to optimally address circularity of PV systems.

→ EC Experts participate currently in 3 PVPS Tasks involving 1 entity as listed here

INDUSTRY & MARKET DEVELOPMENT

Higher material costs experienced in many industrial sectors in 2021 and 2022 led to an exceptional and unprecedented increase in production costs for cells and modules, reversing a decade-long cost reduction trend. As a result, 2021 (latest data available) saw a deterioration of the EU's trade balance in solar technologies compared to previous years, because its imports increased while its exports remained stable, representing 13% of global exports. The EU nonetheless retains a considerable share in the production equipment (50%) and inverter (15%) manufacturing segments of the PV value chain.

Furthermore, the competitiveness of PV continued to improve by comparison with non-renewable electricity sources. The number of countries where photovoltaic electricity generation is the cheapest source is therefore growing. Increases in fossil fuel prices due to natural disasters, accidents or international conflicts, can only reinforce this trend.

Over the course of the year 2022, in a context of high energy and electricity prices triggered by the unprovoked Russian invasion of Ukraine, the EU has confirmed its position as one of the largest markets for PV and as a strong innovator especially in emerging PV technologies and applications (such as agri-PV, building-integrated PV and floating PV). However, the EU is heavily dependent on imports from Asia for several crucial components (wafers, ingots, cells and modules), and retains significant presence only in the production equipment and inverter manufacturing segments (which are currently facing a bottleneck due to the shortage of chips). Additional bottlenecks due to affordability limitations (especially for low-income households and SMEs), excessively long waiting times (e.g. linked with insufficient skilled PV installers) are already impacting the large deployment of PV.

The measures and flagship actions announced in the EU's solar energy strategy provide the main opportunities to invest in PV assets and develop PV manufacturing capacities in the EU, as well as the diversification of imports. In parallel, continuous technological advances towards more efficient and sustainable cell designs and manufacturing processes have made it possible to further improve the competitiveness of PV technologies by comparison with non-renewable energy sources – even though raw material costs have risen. These elements strengthen the business case for boosting both production and deployment in the EU, including innovative applications.

ENERCITY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Diego Amores (Innovation and Technology Executive)

Fig.42 - Industrial photovoltaic plant of 1 MW capacity designed and installed by Enercity, located in the Ecuadorian highlands at 2860 meters above sea level. It helps the industrial production of broccoli for International export

ECUADORIAN PHOTOVOLTAIC INDUSTRY CONTEXT

Photovoltaic energy represents one of the smallest contributors to the Ecuadorian energy generation sources. From January to November 2022, the major contributor of energy generation was hydro power with a contribution of 87.05% of the total energy generated in the country. In the same period, photovoltaic energy generation represented 0.12% of the total energy generation which translates to approximately 316.5 GWh according to the Ecuadorian National Electricity Operator (CENACE) November 2022 statistics.

Additionally, the mean cost of energy in the internal commercial market was registered at 0.34 USD per kWh for the same time interval.

Current photovoltaic energy generation policies came into force on May 2021. They allow photovoltaic plants to be installed behind the meter for self-energy consumption purposes, can be connected to the national electric grid and are limited to a maximum nominal power capacity of 1 MW. There is no remuneration paid for excess generation that is fed into the grid, but kWh's injected are credited to the customer for use in subsequent billing periods for up to 2 years.

COMMERCIAL AND INDUSTRY DEVELOPMENT

Enercity is a private company that aligns its efforts to lead the clean energy transition in Ecuador and Peru towards a more sustainable future. Enercity focusses on the design and commissioning of renewable energy systems, mainly photovoltaic plants, that diminish the reliance on fossil fuels as energy generation source.

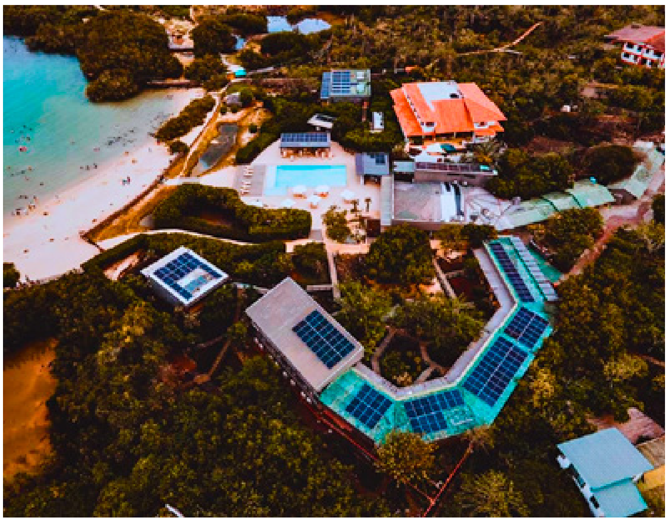

Fig.43 - 223 kW photovoltaic plant designed and installed by Enercity. It contributes to the conservation of the Galapagos islands which is considered a world natural heritage region by UNESCO

By the end of 2022, Enercity has designed and installed a total power generation capacity of 4.28 MWDC ranging from industrial, commercial and residential applications. This power capacity equates to 15% of the installed national photovoltaic capacity as registered in the latest Electric Ecuadorian Atlas published by CENACE in 2021 which estimated the national photovoltaic installed capacity at 27.65 MWDC.

Enercity's photovoltaic energy contribution in 2022 helped to reduce approximately 1 243 tons of CO_2 emissions that would have been produced if fossil fuels were used to produce the same amount of energy under the Ecuadorian energy reality.

→ Enercity Experts Experts participate currently in 1 PVPS Tasks involving 1 separate entities as listed here

Enercity is running feasibility studies for large scale

green hydrogen generation

RESEARCH AND DEVELOPMENT

In 2022, Enercity became sponsor member of the IEA PVPS programme actively contributing in Task 1 and 18, with the purpose of innovating and accelerating the energy transition to renewable sources in Ecuador and the region.

Furthermore, Enercity understands the fundamental role that renewable energy plays in the existing global energy challenges. This became the driver factor to place green hydrogen generation in the short and medium goals of the company. Enercity is currently running feasibility studies for large scale green hydrogen generation projects that aim to support the sustainable fulfillment of the global energy demands.

Enercity is a company that embraces continuous innovation and expands its technology expertise day to day. One of Enercity's objectives is to create a bridge between research and development of the photovoltaic industry in Ecuador. Connecting national research institutions with international programs such as IEA PVPS is fundamental to accelerate the technology deployment.

Enercity has brought the attention of the IEA PVPS programme to the Ecuadorian National Research Institute of Geology and Energy (IIGE) with the purpose of exposing Ecuador to the international efforts of building a more sustainable future.

Fig.44 - Industrial photovoltaic plant of 580 kW capacity designed and installed by Enercity. It is located in the Ecuadorian Andes and contributes to the sustainable fabrication of construction materials

FINLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Karin Wikman (Innovation Funding Agency Business Finland); Tuula Mäkinen (VTT Technical Research Centre of Finland)

Fig.45 - PV is increasing its popularity in Finland. A rooftop-installation at an office building in Helsinki (Photo: Tapani Saarenpää)

NATIONAL PV POLICY PROGRAMME

Finland has an objective to become a carbon-neutral society by 2035. The latest National Climate and Energy Strategy was presented by Prime Minister Sanna Marin's Government to the Parliament of Finland on June 30, 2022. It outlines measures by which Finland will meet the EU's climate commitments for 2030 and achieve the targets set in the Climate Change Act for reducing greenhouse gas emissions by 60 per cent by 2030 and being carbon neutral by 2035. Finland has stated that its target is to increase the share of renewable energy to at least 51% of the total final energy consumption.

Approximately 80% of all greenhouse gas emissions in Finland come from energy production and consumption, including transport. One of the main solutions to achieve carbon-neutrality is direct and indirect electrification of energy use with emission-free electricity. In addition, forest-based carbon sinks have an important role in achieving the target. A growth in decentralized small-scale energy production has been a visible trend. The increase of wind power and PV production highlights the importance of introducing various flexible solutions such as energy storage and system integration.

There is no specific national strategy nor objectives for photovoltaic power generation in Finland. Instead, solar PV has mainly been considered an energy technology that can be used to enhance the energy efficiency of buildings by producing electricity for self-consumption. However, interest in grid-connected PV systems has gradually increased during the last few years.

To support PV installations, the Ministry of Employment and the Economy and Business Finland grant investment subsidies to renewable energy production. In 2022, a total of 82.3 MEUR investment subsidies for 632 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 15% of the total project costs for conventional technology, and 19-20% for new technologies. Agricultural companies are eligible to apply an investment subsidy of up to 35% for PV installations from Centres for Economic Development, Transport, and the Environment. Individuals are eligible for a tax credit for the labour component of the PV system installation. The sum is up to 40% of the total labour cost, including taxes, resulting up to about 10-15% of the total PV system cost.

By the end of 2021, the installed grid-connected PV capacity was estimated to be approximately

395 MW,

almost doubled during the last two years.

RESEARCH, DEVELOPMENT & DEMONSTRATION

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

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, and on high-efficiency multi-junction solar cells based on III-V semiconductors at Tampere University.

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.

VTT Technical Research Centre of Finland is active in the field of solar energy integration into buildings and energy systems. VTT is piloting new uses for perovskite solar cells and organic photovoltaics and working on roll-to-roll printing and coating processes for photovoltaics.

The research and development work at universities and research institutes is mainly funded by the Academy of Finland and Business Finland, which also finance company-driven development and demonstration projects, and the European Union funding programs. 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. By the end of 2021, the installed off-grid PV capacity was estimated to be approximately 22 MW, installed in over 55 000 houses.

Presently, the market of grid-connected systems heavily outnumbers the market of off-grid systems. Since 2010, the number of grid-connected PV systems has gradually increased, and in 2020-2021, the installed grid-connected PV capacity almost doubled. By the end of 2021, the installed grid-connected PV capacity was estimated to be approximately 395 MW, about 2.2% of the total installed grid-connected power production capacity in 2021 in Finland.

The grid-connected PV systems are still mainly roof-mounted installations on public and commercial premises and in private dwellings. The first multi-megawatt ground-mounted PV plant in Finland, with a total power of 6 MW, started its operation in 2018 in Nurmo. In recent years several companies have announced their plans for multi-megawatt scale PV plants, even up to a scale of hundreds of MW.

Business interest is currently particularly focused on plants being implemented in areas where it is difficult to find other uses for the land, e.g., decommissioned peatlands. Integrating power storage in PV plants is often considered beneficial for balancing variable PV production. In addition, there is an increasing interest to combine PV production with wind power production, thus balancing the variation of power production, using a common infrastructure, and improving the cost effectiveness of the projects.

FRANCE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Melodie de l'Epine (Becquerel Institute France); Emilien LASSARA (Association HESPUL)

Fig.46 - The image credits are BORALEX and the site is a 14.7 MW floating PV at Peyrolles-en-Provence

NATIONAL PV POLICY PROGRAMME

The current 10-year Energy Programme Decree PPE, published in 2020, targets 3 GW to 5 GW a year new capacity, to reach 20 GW in 2023 and 35 GW to 44 GW in 2028, whilst consultations for the next revision began mid-year amidst a clear shift in the government's desire for solar as ballooning electricity costs hit industry, enterprise, communities, and private citizens.

The soaring electricity costs resulting both from the conflict in Ukraine and the delayed safety checks and maintenance work on a number of nuclear power stations, (resulting in a record nearly 50% unavailability of France's nuclear power capacity), highlighted the opportunities of "cheap" solar.

The combination of high market prices for electricity and cost blowouts due to rising module and steel prices also resulted in policy shifts on support mechanisms, allowing soon to be commissioned systems to sell electricity on the market for a limited time before entering the terms of their Contract for Difference (CfD) at the generally much lower tendered rate, whilst structural reductions in feed in tariffs were frozen to compensate for these higher material costs.

The CfDs guarantee a target tariff for generators with the state bearing the financial risk - if electricity prices are high then profits for the state can be large. In 2022, existing systems passed back an estimated 700 MEUR to the state and an estimated 2 960 MEUR are expected in 2023 from both the CfD and obligated buyer FiT mechanisms.

Total installed capacity tops

20 GW DC

The need for renewables to meet the challenges of security-of-supply and cost constraints in the context of the 2050 low carbon strategy led to a law being tabled to accelerate renewables. In a strong industry effort, thousands of amendments to the original text were proposed to increase effectiveness, but ultimately it was judged poorly by industry and not published until early 2023. Main focal points are facilitated and accelerated permitting, mandatory solar for car parks and new buildings, and a definition of agriPV.

Finally published in March 2023, the law builds on simplifications published in 2022 in permitting for ground-based systems, lifting the lower limit for permitting and mandatory environmental impact studies to 1 MW. It also covers AgriPV as government and agricultural stakeholders met through the year to work on a common definition of agriPV and ease emerging tensions created by competition for land surfaces. Regarding grid connection, propositions from a series of working groups in simplifying grid access early in the year resulted in an a series of consensual propositions that may include flat rate grid connection costs for small systems and future-proofing new network connections for buildings requiring mandatory solar.

TABLE 5: COMPETITIVE TENDERS 2021 TO 2026

SYSTEM TYPE AND SIZE	BUILDING MOUNTED SYSTEMS INCLUDING GREENHOUSES AND PARKING CANOPIES	GROUND BASED SYSTEMS	SELF CONSUMPTION*	BUILDING MOUNTED INNOVATIVE SOLAR SYSTEMS	GROUND BASED INNOVATIVE 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	Same size limits as building mounted systems and grounted based systems
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 **	2022: 90.91 EUR/MWh	2022: 68.51 EUR/ MWh	2022: 10.8 EUR/MWh	2022: 84.46 EUR/ MWh (no detailed data)		2022: 74.87 EUR/ MWh

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

** All most recent tender prices are higher than 2021 last tendered prices

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 17 different research or tertiary education organizations and competitive clusters, with the goal of coordinating national energy research efforts and ensuring alignment with the National Energy Research Strategy.

France's public financing of Research and Development for photovoltaics was 76 million euros in 2021 (latest data), whilst private funding is present in collaborative work through the main laboratories and in-house for a few specialized applications.

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, including a solar-to-fuel program, work on perovskite, on silicon tandem modules and III-V materials, with a clear goal of industrial transfer. Work on the 2023/24 program re-affirmed the goal of industry ready processes, materials, and devices to demonstrate 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 research on low-carbon modules, low-silver cells and flexible perovskite modules with some record efficiencies for tandem perovskite/silicon cells and heterojunction silicon cells. They have also been building expertise on environmental life cycle analysis, accelerated aging and the eco-design of modules.

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. It is the French relay for the IEA PVPS and SOLAR-ERA.net pan-European network.

→ French Experts participate currently in 6 PVPS Tasks involving 17 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

The main market segments in France are residential systems (under 9 kWp), roof mounted systems on commercial, public and agricultural buildings (up to about 300 kWp), solar parking canopies (up to several MW) and ground mounted systems from 3 MW up. AgriPV and floating systems are becoming more common but remain mostly experimental.

Between 2006 and 2017 small generators in France generally opted to sell 100% of their production because rates were favourable. Since then, the shift to self-consumption (only exporting excessgeneration) in residential systems is nearly complete, and has accelerated for systems on commercial and agricultural buildings. The number of collective self-consumption projects has increased dramatically, +93% in the 12 months to December 2022, due to a combination of factors including the rise in domestic and wholesale electricity costs, temporary fiscal measures, and a formal interdiction to combine feed in tariffs with other support measures, leaving local authorities and citizen groups looking for alternative business plans for systems with upfront subsidies. The upheaval on the electricity market has helped the attractivity of power purchase agreements, although leveraging debt financing has remained a real barrier to a development – a guarantee fund is in the process of being set up by the government and should facilitate this.

Overall grid-connected volumes grew in 2022 by an estimated 2.9 GW DC (3.4 GW in 2021). A direct consequence of the raised ceiling for feed in tariffs, the fastest growing segment was for systems between 100 kWp and 250 kWp with 11% of new capacity, although systems connected to the medium voltage grid (over 250 kW) still make up over 50% of the newly installed capacity. Total installed capacity at the end of 2022 has reached 19.6 GW DC (16.3 GW AC). This is slightly below last year's +3.3 GW DC, and still below the capacity that needs to be installed to reach the 2023 PPE AC target of 20 GW (roughly 24 GW DC).

New grid connection requests remained high with over 8 GW of new projects in 2022 (compared to approx. 4 GW in 2021, 3 GW in 2020). The stock of projects with ongoing grid requests remains high, over 19 GW, of which about half is utility scale. Only about half this volume can be traced back to systems designated in the competitive tenders or accessing feed-in tariffs; the remainder has either not yet tendered or is planned outside of the government support mechanism – i.e. with remuneration through PPAs. Estimates for 2023 range from a steady 3.5 GW to 4.5 GW, ahead of a more significant increase in 2024.

TABLE 6: FEED IN TARIFFS FOR 4RD QUARTER 2022

<table>
<tr><th>POWER OF PV INSTALLATION (KW)</th><th>FEED IN TARIFF NO SELF-CONSUMPTION (TA,B,C)</th><th>FEED IN TARIFF FOR PARTIAL SELF-CONSUMPTION AND BONUS (PA,B)</th><th>BONUS FOR CERTIFIED BUILDING INTEGRATION PRODUCTS (PINT)</th></tr>
<tr><td>≤3 kW</td><td>224.2 EUR/MWh</td><td>125.3 EUR/MWh (+0,48 EUR/W installed)</td><td rowspan="4">0.238 EUR/W installed</td></tr>
<tr><td>3 kW to 9 kW</td><td>190.6 EUR/MWh</td><td>125.3 EUR/MWh (+0,36 EUR/W installed)</td></tr>
<tr><td>9 kW to 36 kW</td><td>136.5 EUR/MWh</td><td>75.2 EUR/MWh (+0,20 EUR/W installed)</td></tr>
<tr><td>36 kW to 100 kW</td><td>118.7 EUR/MWh</td><td>75.2 EUR/MWh (+0,10 EUR/W installed)</td></tr>
<tr><td>100 KW to 500 KW</td><td>122.8 x inflation coefficient EUR/MWh</td><td>122.8 x inflation coefficient EUR/MWh</td><td>< 250 kW : 0.235 EUR/W installed
< 500 kW : 0.233 EUR/W installed</td></tr>
</table>

GERMANY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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

Fig.47 - Ground-mounted solar and wind power plants are the sign of the energy turnaround in Germany (© elxeneize – stock.adobe.com)

NATIONAL PV POLICY PROGRAMME

The energy transition is central to a secure, environmentally compatible and economically successful future. This process will overhaul Germany's energy supply, moving away from nuclear and fossil fuels towards renewable and efficient energy supply. To meet the climate targets, the German government adopted an immediate action climate protection programme. Electricity generated from renewable energy technologies such as wind and solar power plants will become the central building block for an energy system without fossil fuels. Simultaneously, the target triangle of (1) security of supply, (2) environmental compatibility and (3) affordability remains the guiding principle of energy policy.

The so-called Easter package, which was passed by the German Bundestag at the beginning of July 2022, comprises a total of five legislative amendments and is intended to accelerate the expansion of renewable energies. In order to connect more wind turbines and solar panels to the grid, the German Bundestag has decided that the use of renewable energies is "in the overriding public interest" and serves public safety.

In the future, the promotion of renewable energies will be disbursed from the federal budget. The Renewable Energy Sources Act (EEG) levy on the energy prices will be abolished. This will relieve the burden on electricity customers and favor the use of electricity over other energies, in particular natural gas.

At the same time, the tender volume will be significantly increased compared to the previous EEG 2021 specifications and the eligibility conditions, especially for solar installations, will be made much more attractive. PV systems that are connected to the grid after July 2022, and feed their electricity into the grid in full will receive higher remuneration. The range of free land areas on which PV systems can be operated will be significantly expanded. For example, the dual use of agricultural land and photovoltaic power generation will also be eligible for subsidies.

New and simplified standards for connecting small PV systems (up to 30 kW) will ensure that the mass market of rooftop PV systems develops strongly.

Furthermore, renewables are already financially competitive to other energy sources and hence the number of large ground-mounted systems proceeding without support of an EEG subsidy is continuously increasing. The electricity generated by these systems is marketed directly via PPAs (Power Purchase Agreements). PPA-marketed systems with a capacity of approximately 873 MW were newly commissioned in 2022.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Energy research has been governed by the 7th Energy Research Programme since September 2018. It continues to set the guidelines for energy research funding. Under the programme, the German government has allocated around 6.4 BEUR for a five year period aimed to support research, development, demonstration and testing of sustainable energy technologies and concepts.

Based on the Energy Research Programme, the BMWK (Federal Ministry for Economic Affairs and Climate Action) issued a call for proposals in June 2021 that is still active and reflects the goals of the programme. For Photovoltaics, the five main topics addressed have a clear orientation with regard to applied industry-oriented research:

- Efficient production and process technologies to increase performance 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), combination of agriculture and PV (Agri-PV) or avoidance of hazardous materials and recycling of PV systems,
- Innovative system technologies for both grid-connected and island PV plants.

Within this broad approach, the 2022 focus areas were again on silicon-perovskite tandem solar cells, technological advancements of industrialization processes, e.g. through the utilization of larger wafer formats, and operation and maintenance of PV plants. The development of funding activities in recent years shows a fairly constant financing volume of well over 60 MEUR for new projects (Figure 48). In 2022, the BMWK support for R&D projects on PV amounted to about 69 MEUR shared by 486 projects in total. That year, 110 new grants were contracted. The funding for these projects amounts to 63 MEUR in total. Highlights of research projects can be found on the programme webpage for sustainable power generation technologies.

Recent project presentations include, for example, a new record efficiency of 35.9% for monolithic triple-junction solar cells and new printing technologies for efficient silicon solar cells with triangular shaped front contact structures.

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

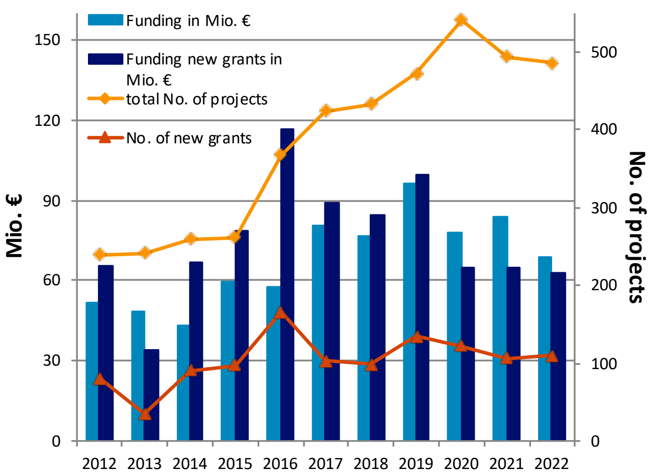

Fig.48 - R&D support and quantity of PV projects funded by BMWK in the 6th and 7th EFP

The German Bundestag has decided that the use of renewable energies is "in the overriding public interest" and serves

public safety

INDUSTRY & MARKET DEVELOPMENT

In 2022 the share of electricity consumption covered by renewable energy increased again to 48%, of which 11.4% was covered by photovoltaics.

This coincides with a photovoltaic market that has been growing steadily over the past eight years. In 2022, a total of 7.2 GW of photovoltaic capacity was newly installed, which corresponds to a total capacity of 66.5 GW of PV power plants in operation (preliminary assessment in January 2023).

The levelized cost of electricity (LCOE) of photovoltaic systems in Germany ranges from ~3 to 11 EUR cent/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. This is reflected in the feed-in tariff surcharges paid for free-field power plants (5.0 EURcent/kWh) and large rooftop plants (6.9 EURcent/kWh).

The low LCOE and the sharp rise in electricity prices due to the overall energy crisis have led to a sharp increase in a wide variety of photovoltaic power generation options. This ranges from private households with mini balcony power plants to utilities building PV systems without subsidies or opting out of subsidies.

The renewable energy generated is increasingly marketed via PPAs directly to industrial consumers or to utilities. The utilities can thus offer their customers renewable electricity tariffs at a good price. In addition, the first Federal States have made photovoltaics mandatory on all new buildings and covered parking lots as of this year.

The German solar industry has shown double-digit growth for the sixth year in a row and PV business climate index is at an all-time high. This positive market development is also reflected in the further expansion of Meyer Burger's production capacity to 1.4 GW for both cells and modules. A further expansion of annual production capacity to 3 GW is planned by 2024.

In the coming years, a significant increase in employment figures can be expected from the planned further expansion of PV. The annual installation of 10 GW of PV alone will require about 46 500 full-time employees.

ISRAEL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Yael Harman (Chief scientist office at the Ministry of Energy)

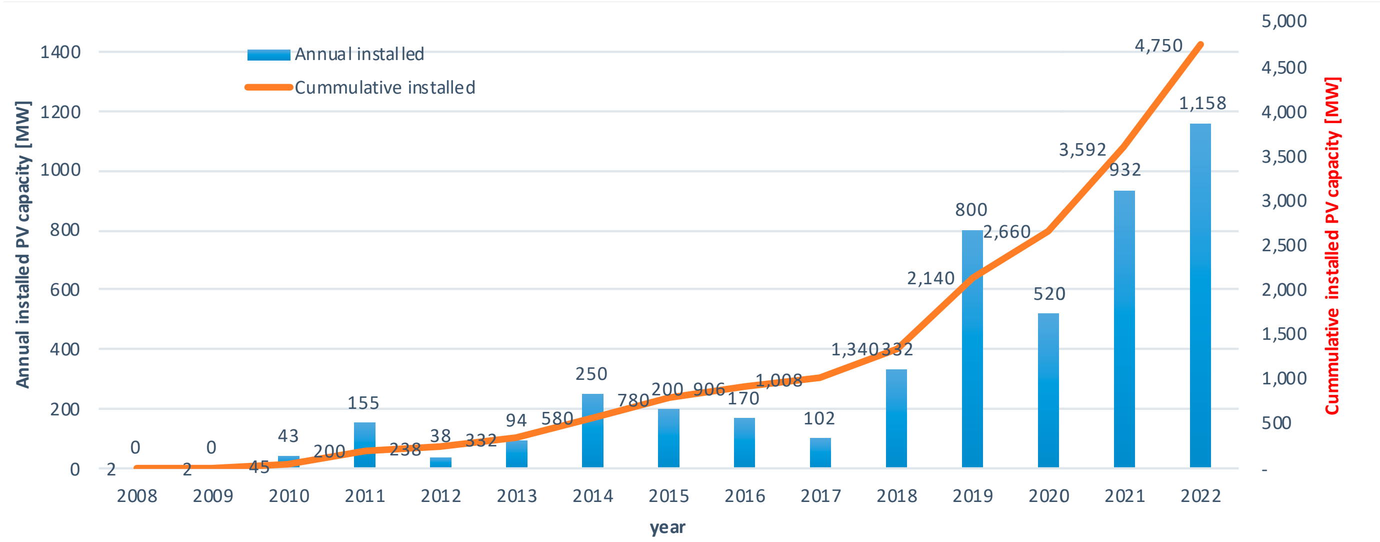

Fig.49 - Development of grid connected PV capacity in Israel through 2022

NATIONAL PV POLICY PROGRAMME

In 2021 the Ministry published its goal for reduction of 85% of greenhouse gas emissions by 2050 as well as an annual improvement of 1.3% in energy intensity.

During 2022, Israel published two important National Outline Plans, the first of energy storage for the improvement of utilization of the electricity grid. The second is national plant for over 130 agri-photovoltaic (AgriPV) pilot sites in Israel for the understanding of the AgriPV potential for dual use.

The Israeli Public Utility Authority (PUA) announced the publication of a Bilateral electricity market which will have a strong effect on the RE and storage sector. This represents an important step in opening the market for competition. By 2024 RE could directly sell energy to consumers.

In 2022, total RE capacity in Israel was increased by approximately 1 150 MW to a total capacity of ~4 750 MW. Overall, by the end of 2022 Israel reached a level of 10.1% RE electricity generation measured in potential terms (meaning taking the installed capacity at the end of 2022 and multiplying it by the average hourly production per installed MW).

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 Water4all, CETP & M-era net
- The Bird Energy fund is a Binational Industrial Research and Development (BIRD) Foundation that support joint US-Israel projects in the energy field.
- In 2022 the CSO has opened 2 national energy center in the fields of Energy storage and fusion.

In 2022 the Office of the Chief Scientist invested over 20 million USD in energy related R&D projects. Among the winning project are agriPV, green hydrogen, waste to energy and various application for dual use.

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

INDUSTRY & MARKET DEVELOPMENT

In 2022, the price of electricity increased by 6.2% to 45.98 ILS cents, excluding VAT, per KWh, still one of the lowest in the developed world.

TABLE 7: ISRAEL ELECTRICITY PRICES BETWEEN 2016 TO 2022 IN ILS CENTS (PUA REPORT)

2016	2017	2018	2019	2020	2021	2022
45.58	47.26	46.19	47.16	44.84	43.30	45.98

In 2022 the Israeli PUA published a fix tariff of 24.5 ILS cents per KWh for 100-300 KW instillations in dual use of land in order to accelerate their establishment. This price is for every marginal KW, meaning it benefits smaller installations.

In 2022 the PUA has published one competitive bid for PV with dual use of land. 815 MW were accepted at a tariff of 17.05 ILS cents (0.053$) per KWh.

Israel has approved a national outline plan for over 130 AgriPV sites, which are expected to be built in the last quarter of 2023.

A bilateral electricity market has been announced, which will have a strong effect on the RE and storage sector.

By 2024

renewable energy plants could

directly sell

energy to consumers.

ITALY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Ezio Terzini (ENEA); Salvatore Guastella (RSE)

NATIONAL PV POLICY PROGRAMME

The Integrated National Plan for Energy and Climate (PNIEC), supported by several actions of the National Recovery and Resilience Plan (PNRR), is the marked road to contribute to energy decarbonization in Italy. The main target by 2030 is a 30% Renewable Energy Systems (RES) energy share in the gross final energy consumption, with 52 GW of cumulative PV capacity, which implies new PV installations of about 27 GW to be added to the 25.05 GW cumulative power recorded in 2022. This objective must be increased in response to the new goals of Fit for 55% (+39 GW of new PV compared to 2022) and even further in the REPowerEU perspectives.

The government has moved on the fronts of economic support and structural reforms in order to foster the above PV targets. Some of the main measures are:

a) Economic support

- A tax break mechanism for the installation of residential plants (up to 20 kWDC) allows 50% of the PV installation costs to be paid back. An even more advantageous measure, the "Superbonus 110%" provides a tax credit of 110% of the cost of the plant if it is comprised within interventions stepping up two levels of building energy rating.
- A feed-in tariff mechanism, provided by the Ministerial Decree "FER1", is in place for supporting "mature" RES. This measure has promoted a total of 2.3 GW of new PV capacity in the period 2019-2022.
- A premium tariff for shared and self-consumed energy in Renewable Energy Communities (CER).
- A PNRR investment of 1.5 BEUR for the "Agrisolare Park", promoting PV installation on agricultural infrastructure roofs by contributions on installation cost up to 1 500 EUR/kWDC (size 6 kW < PW < 500 kW). The final target is the installation of 375 MW of new PV.
- A PNRR investment of 1.1 BEUR for agrivoltaics and floating PV for supporting the installation of at least 2 GW of PV on agricultural land and water basins.
- PNRR investment of 1 BEUR for industry and research to develop an international industrial and knowledge leadership in the main energy transition's value chains.

b) Structural reforms for an easier market penetration.

- Simplification and rationalisation of the environmental regulations relating to permitting procedures.
- No authorisation required for PV on roofs up to 200 kW, only a simplified communication to the grid operator (Modello Unico).
- Suitable special areas for PV installation have been stated by law (e.g. abandoned industrial areas, compromised and marginal areas, ceased quarries and mines, etc.).
- Reference criteria have been issued for the task of regional governments to localise regional "suitable areas" for PV installations.
- Decree for energy communities extending the participation limits to different subjects, increasing the single plant power limit to 1 MW and enlarging the perimeter to primary electric stations.

RESEARCH, DEVELOPMENT & DEMONSTRATION

One of the priorities linked to RES and in particular to PV, is to promote the development in Italy of competitive supply chains, in order to reduce dependence on imported technologies and strengthen research and development in the most innovative areas: photovoltaics, electrolysers, batteries. To that end, the PNRR gives support to Research, Development & Demonstration activities on new PV technologies, in which various research institutes and PV operators are active.

ENEA, a public research body, is focused on high efficiency solar cells based on a perovskite/c-Si tandem structure, on the development of module eco-design, on the advancement of PV system digitalisation and on agri-PV, giving technical and scientific support to the national Sustainable Agrivoltaic Association.

RSE, a private research company in the area of energy systems, is carrying out activities on 1) concentrating multi-junction solar cells, 2) advanced PV plant O&M strategies (through improved diagnostic and predictive techniques) to contribute to their optimal production and 3) Life Cycle Assessment (LCA) of the most promising innovative PV technologies.

Other major research organizations are **CNR**, a public research institution, active in the evaluation of innovative low-cost processes for thin film cells and **EURAC Research**, a private research organization, working on the improvement of PV plant performance and reliability, as well as on building integrated PV. The framework of research institutes is completed with the contribution of numerous university labs, in particular the CHOSE Centre of the University of Rome Tor Vergata, the University of Milano Bicocca and the University of Turin.

All the aforementioned research institutes and labs pursue the main purpose of facilitating the development of high-efficiency and low-cost photovoltaic generation systems, to contribute to the achievement of the PNIEC objectives by 2030, but also to provide technological support to companies in the sector.

Agrivoltaics is attracting great interest from Italian agricultural and photovoltaic operators.

These systems make it possible to build photovoltaic plants to achieve decarbonization objectives and at the same time guarantee the continuity of agricultural production, allowing the

maximum benefit

in land use

In the sector for the development and demonstration of solar cell technologies, many operators are active in the Italian photovoltaic market, covering the entire PV value chain, and growing year by year. In particular, several high-tech operators are increasing the performance and volume of their production related to cells/modules (mainly Enel Green Power), inverters and sun tracking systems, mostly for utility-scale plants. These improvements allow Italian operators to be present on the international PV market, even if with different industrial capacities.

Finally, it should be mentioned that in Italy many research institutes and photovoltaic operators actively collaborate via the National Photovoltaic Network for Research, Development and Innovation. The aim is to share initiatives related to photovoltaic projects and research infrastructure across the country, which results in active collaboration in the research and innovation activities mentioned above.

→ Italian Experts participate currently in 5 PVPS Tasks involving 10 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

An interesting sign of the recovery of the photovoltaic market in Italy comes from the recent numbers of registered installations. The scale of PV installations in 2022, totalling 2.48 GW, was more than double the value from 2021 (increase of 164%) and more than 5 time the average installation rate in the 2016-2019 period. This led to a total cumulative PV capacity value of 25.05 GW in 2022. The PV energy production in 2022 was 27.55 TWh which represented 8.7% of electricity consumption (see Figure 50) [1]. If this installation rate will continue, the PNIEC target by 2025 will be easily reached but still further acceleration is needed between 2025-2030 in order to meet the PNIEC (+74% needed) and 'Fit for 55' (+178% needed) targets, without considering the implications of REPowerEU goals.

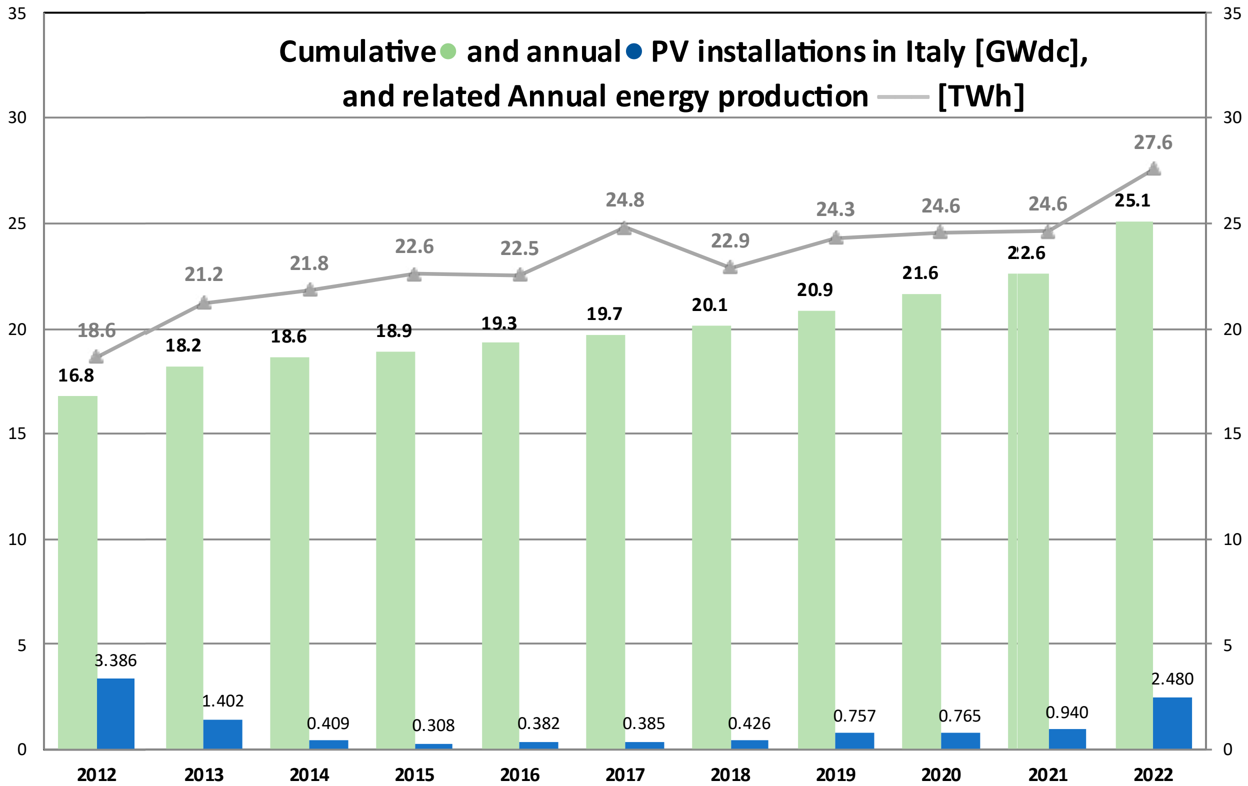

Fig.50 - Cumulative and annual PV installations in Italy [GWDC] and related Annual energy production [TWh] (data source: TERNA)

[1] This work has been financed by the Research Fund for the Italian Electrical System under the Three-Year Research Plan 2022-2024.

Among the initiatives by module manufacturers, noteworthy are those of FuturaSun, for setting up a module line of 1 GW, and of EGP for setting up a cell and module line of 3 GW at their Catania factory (Figure 51), with start-up is expected by 2023.

The topic of Agrivoltaics is attracting great interest from agricultural and photovoltaic operators. These plants (Figure 52), which on the one hand make it possible to build PV plants to achieve decarbonization objectives and on the other guarantee the continuity of agricultural production, allow for the maximum benefit to be obtained in land use. Recently, to facilitate the authorization procedures, as well as for the granting of PNRR funding to this sector, avoiding the risk of changing the vocation of the soil, specific documents have been published (i.e., Ministerial guidelines and Public Available Specification from the CEI - Italian Electrotechnical Committee).

Fig.51 - New EGP-3SUN heterojunction module produced at the Catania Factory, displayed at WCPEC-8 in Milan, September 2022 (Courtesy of EGP and PV Magazine)


Fig.52 - Cultivation of high-quality cedars and production of energy by agri-PV plant in Scalea (image by LeGreenHouse and EF Solare)

JAPAN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Mitsuhiro YAMAZAKI (New Energy and Industrial Technology Development Organization (NEDO)); Osamu IKKI (RTS Corporation)

Fig.53 - Demonstration facility connecting fuel cells, PV modules (approx. 570 kW) and batteries at Panasonic H2 KIBOU FIELD in Kusatsu City, Shiga Prefecture, Japan ©RTS Corporation

NATIONAL PV POLICY PROGRAMME

Based on the Sixth Strategic Energy Plan by the Ministry of Economy, Trade and Industry (METI) and the Plan for Global Warming Counter-measures by the Ministry of the Environment (MoE) approved by the Cabinet in 2021, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Ministry of Agriculture, Forestry and Fisheries (MAFF), and others have joined and these four ministries are promoting PV expansion, through laws, systems, measures, regulatory reforms, and budgets under their jurisdictions.

In 2022, the GX (Green Transformation) Implementation Council, chaired by Prime Minister Fumio Kishida, decided on the Basic Policy for the Realization of GX, which specifies that renewable energy and nuclear power will be used to the fullest, aiming to break away from fossil energy. Regarding renewable energy, it is aimed to surely account for 36-38% in the energy mix in FY (fiscal year) 2030 through the close cooperation among ministries and agencies. As for PV, by way of immediate actions, it was announced that PV introduction will be expanded to public facilities, houses, factories/warehouses, airports, railways, etc., and that renewable energy introduction will be promoted via the initiative of local communities.

Based on the enforcement of the Acts for Establishing Resilient and Sustainable Electricity Supply Systems, METI operates new schemes such as the Feed-in Premium (FIP) program, Certification Cancellation System, and Disposal Cost Reserve System. METI will enhance the establishment of the dissemination environment through tightening business discipline to introduce renewable energy in harmony with local communities, responding to grid constraints and output curtailment, reforming regulations on installation, and revising the Energy Conservation Act for expanding the use of renewable energy.

Based on the enforcement of the revised Law Concerning the Promotion of the Measures to Cope with Global Warming, MoE is taking the lead in prioritizing and maximizing renewable energy introduction, taking the initiative in PV introduction to public buildings by the national and local governments, introduction in harmony with local communities led by local governments through positive zoning, supporting the introduction of self-consumption type PV systems to private companies, and promoting the creation of leading areas of decarbonization based on the roadmap for local decarbonization. MoE plans to designate 100 locations nationwide as the leading areas of decarbonization, and in FY 2022, the first year, 46 locations were selected, encompassing a PV capacity of 300 MW.

Based on the MLIT Environmental Action Plan, MLIT enacted the revised Building Energy Efficiency Act, which requires houses to comply with energy-saving standards, and will expand PV introduction in public infrastructure facilities by expanding installations not only to airports but also to road and railway facilities.

MAFF is promoting the introduction of AgriPV systems and planning to set a target PV installed capacity based on the Act on Promoting Generation of Electricity from RE Sources Harmonized with Sound Development of Agriculture, Forestry and Fisheries, and the Green Food System Strategy.

Japan's installed PV capacity in 2022 is expected to be 6.5 GW (DC) (preliminary). While most of the installed PV capacity is under the FIT program, the installed capacity of the self-consumption type PV systems using the power purchase agreement (PPA) scheme with subsidies instead of FIT is also included.

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 & Technology (MEXT) and has been promoted mainly by the projects of the Japan Science and Technology Agency and the project to subsidize the Grants-in-Aid for Scientific Research.

NEDO is conducting research and technological development of film-type ultra-light solar cells, wall-mounted PV system technology, and PV modules for mobility under the Development of Technologies to Promote Photovoltaic Power Generation as a Main Power Source (FY 2020-FY 2024). NEDO is also conducting demonstration experiments to ensure safety of PV systems on slopes, AgriPV and floating PV systems, as well as formulating safety guidelines. NEDO is continuing to develop material separation and recycling technologies for PV modules, and in FY 2022, it adopted an additional survey for the smooth recycling of PV modules.

Regarding grid integration, NEDO is working on the extraction of technical issues and demonstration experiments to utilize PV as a dispatchable resource to mitigate grid impacts. In the area of metrology, NEDO is developing high-precision performance evaluation technology for new solar cells, as well as technology to forecast solar irradiation that supports the next-generation O&M.

In 2022, Sharp achieved a conversion efficiency of 32.65% on a prototype of practical-sized lightweight and flexible compound triple-junction PV module for mounting on vehicles.

As part of the government's Green Innovation Fund (GIF), NEDO is implementing the Next-Generation Solar Cell Development Project, and developing fundamental and commercial technologies of film-type perovskite solar cells (PSC). 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 started by FY 2025, aiming to achieve social implementation of these technologies. Toshiba achieved a conversion efficiency of 16.6% with a 703-cm^2 film-type PSC module. In 2022, three companies participating in this project announced plans to install film-type PSCs for demonstration in 2025 as joint projects with companies and local governments.

METI, NEDO and MoE are conducting demonstrations on PV utilization technology. METI is conducting demonstration projects on power grid control including PV and batteries. In 2022, five projects were selected for RE aggregation demonstration, in which about 80 companies including electric companies and VPP operators participate. Demonstration projects of Net Zero Energy Building (ZEB) and Net Zero Energy House (ZEH) for detached houses are also being conducted. Following the MoE's demonstration project of reuse and recycling of used PV modules, commercialization of reuse and recycling is progressing by businesses. MLIT is revising the technical standards for PV technology for road surfaces in the roads sector of the FY 2022 New Technology Introduction Promotion Plan.

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

INDUSTRY & MARKET DEVELOPMENT

While the majority of PV installations in Japan were supported by FIT, new business models and services are expanding against the backdrop of declining FIT purchase prices and growing consumers needs for renewable energy. For residential PV systems, the third-party ownership (TPO) model in which PV systems and storage batteries are installed as a service with no upfront cost has expanded, and efforts to promote ZEH have progressed. Daiwa House Industry will make ZEH a standard specification for its houses for sale from FY 2022.

In public and industrial applications, the introduction of PV systems on the roofs of factories and commercial facilities with the power purchase agreement (PPA) model has advanced. Chubu Electric Power Miraiz introduced a 2 870 kW PV system at AEON MALL Toki, a large-scale commercial facility, using an on-site PPA model. The introduction of solar carports in parking lots of stores, etc. has also progressed.

As renewable energy procurement has been promoted mainly by businesses that are members of international initiatives addressing climate change (e.g. RE100), off-site as well as on-site PPA initiatives have increased. Hokuriku Electric Power built a new 6.2 MW PV power plant and started supplying PV electricity to 303 Seven-Eleven convenience stores. As efforts to develop small-scale PV power plants advance, Clean Energy Connect signed a PPA with NTT Anode Energy for 700 non-FIT low-voltage PV power plants with the total generation capacity of 70 MW by FY 2030.

Efforts increase to use the self-wheeling system, whereby a company supplies power to its own off-site locations. Five companies, namely Mizuho Bank, Mizuho Securities, Mizuho Lease, AEON MALL, and Eco Style reached a basic agreement on self-wheeling of renewable energy electricity, and are developing 65 MW of low-voltage PV power plants.

A trend has been observed in up-take of the FIP program, which came into effect in April 2022 and specifies a rate above the current market price. Osaka Gas signed an agreement with Benex to purchase the electricity and environmental value of PV power plants using the FIP program over a long period of time.

According to the PV module shipment statistics released by the Japan Photovoltaic Energy Association (JPEA), the total shipments of PV modules from January to September 2022 was 3 535 MW, of which imports accounted for 86% with 3 040 MW. Foreign manufacturers are assumed to have occupied the highest ranks in the shipment volume as in the previous year. Major Japanese PV manufacturers withdrew from PV manufacturing, such as Solar Frontier discontinuing production of CIS thin-film PV modules at the end of June 2022, but they have continued to work on the PV business. In anticipation of future market expansion, some Japanese companies entered the PV module recycling business.

In the field of inverters, Diamond & Zebra Electric MFG and TEPCO Holdings jointly developed a multifunctional inverter system. Regarding storage, efforts to develop grid-scale batteries are underway, with Mitsuuroko Green Energy installing grid-scale batteries in Kitahiroshima City, Hokkaido Prefecture, and SB Energy installing such batteries in Nagasaki City, Nagasaki Prefecture. NGK Insulators received an order from Toho Gas for NAS batteries for power storage for grid-scale storage.

In 2022, Sharp achieved a conversion efficiency of

32.65%

on vehicles under a NEDO R&D programme.

KOREA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Donggun Lim (Korea National University of Transportation)

Fig.54 - Sound proof, solar energy-generating (2.6 MW) tunnel on Yeongdong Expressway, Suwon-si, Gyeonggi-do, Korea

NATIONAL PV POLICY PROGRAMME

The previous Korean government steadily increased its renewable energy targets over the past few years. The first significant step was taken in 2017 when the renewable energy target for 2030 was increased from 7% to 20% under the Implementation Plan for RE 3020 in 2019, a further target of 30-35% renewable energy by 2040 was introduced under the 3rd Energy Master Plan. Then, in 2020, the target was tightened again to 42% renewable energy by 2034 under the 9th Basic Plan for Electricity Supply and Demand. Korea prioritized a clean and safe environment by innovating its energy mix to meet public demands. However, under the new government led by President Seok-ryeol Yoon in May 2022, the energy policy shows a different tendency from the previous government. The new government's energy policy aims to establish a feasible and reasonable energy mix, including an expansion of nuclear energy to at least 30% by 2030, assuming that both current and under-construction nuclear plants operate normally. Renewable energy supply goals will be established based on rational and realistic supply conditions, and the optimal ratio of different power sources, such as photovoltaic (PV) and offshore wind energy, will be determined. A rational approach to phasing out coal will be taken, considering the supply-demand situation and system status, and the use of zero-carbon power sources will take technological circumstances into account. Finally, key goals for the power grids include timely construction, system stabilization measures aligned with renewable energy generation, efficiency-focused redesign, and high-tech grid construction.

The previous government had set a target to increase the Renewable Portfolio Standard (RPS) from 14.5% in 2023 to 17% in 2024, 20.5% in 2025, and 25% after 2026. However, the current government has lowered the annual RPS targets to 13% in 2023 and 13.5% in 2024. Due to the reduction in the target for supplying new and renewable energy under the 10th Basic Plan for Electricity Supply and Demand, the timeline for achieving the 25% RPS target has been postponed until after 2030. The 10th Basic Plan for Electricity Supply and Demand has set the target for the share of renewable energy generation in 2030 at 21.6%, which is 8.6% lower than the National Greenhouse Gas Reduction Target confirmed in 2021. As the target for renewable energy production decreases, power generation companies are now required to generate less renewable energy. However, despite this change, the RPS is expected to continue driving the installation of PV systems in Korea for the next few years.

TABLE 8: ANNUAL RPS TARGET

YEAR	2012	2017	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXISTING RPS TARGET (%)	2.0	4.0	12.5	14.5	17.0	20.5	25.0				
REVISED RPS TARGET (%)	2.0	4.0	12.5	13.0	13.5	14.0	15.0	17.0	19.0	22.5	25.0

In addition, the major PV distribution programmes in Korea are as follows:

- 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, geothermal, and small wind. Detached and apartment houses can benefit from this program, 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.

- Building Subsidy Programme: The government supports a certain portion (depending on the building type) of the installation cost for PV systems (below 50 kW) in non-residential buildings. Additionally, the government supports a maximum of 80% of the initial cost for special purpose demonstration and pre-planned systems to help the developed technologies and systems diffuse into the market.

- Regional Deployment Subsidy Programme: This programme aims to balance energy supply and 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 New and Renewable Energy (NRE) systems owned and operated by local authorities.

- 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 districts, etc. Consortiums of either local authorities or public enterprises with NRE manufacturers can apply.

- Public Building Obligation Programme: New buildings of public institutions with a floor area exceeding 1 000 m^2 are obliged by law to use more than 32% (in 2022) and up to 40% (by 2030) of their total expected energy usage from newly installed NRE resource systems.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Korea Institute of Energy Technology Evaluation and Planning (KETEP) controls the largest portion of the national PV R&D budget led by Ministry of Trade, Industry, and Energy and managed a total of 97.0 billion KRW in 2022. KETEP's main focus for 2022 includes reducing costs to enhance the competitiveness of the PV industry, developing high-efficiency technology, commercializing location diversification technology, and securing core technology for next-generation solar cells to target future markets. In terms of strategic direction for the PV R&D budget, 27.5% of the budget was invested in developing next-generation high-efficiency solar cells, 57.8% was allocated to exploring new markets and services, and 12.9% was invested in reducing costs. The R&D budget for the PV technology field allocated 46.0% of the budget for crystalline silicon solar cells, 36.1% for inverters and related services, and 16.5% for perovskite technology.

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

INDUSTRY & MARKET DEVELOPMENT

All ingot and wafer production in Korea has been halted due to the movement of these production sections overseas. Hanwha Solutions has a production scale of 4 500 MW for c-Si solar cells and 2 900 MW for modules. Hyundai Energy Solutions also has a production scale of 650 MW for c-Si solar cells and 1 400 MW for modules. LG Electronics has halted its PV businesses to focus more on its electronics core business. Shinsung E&G has stopped producing PV cells after a decision to expand investment in module production rather than replacing existing cell lines. Korea had a cell production capacity of 5 155 MW and a module production capacity of 9 905 MW in 2022.

The amount of annual PV installations in Korea increased significantly from 1.05 GW in 2016 to 1.58 GW in 2017, 2.59 GW in 2018, 3.92 GW in 2019, and 4.66 GW in 2020. However, the amount of annual installations decreased significantly to 3.92 GW in 2021 and 3.2 GW (estimated value) in 2022. It is too early to confirm the exact reasons for this trend, which will be explored in detail in this report next year.

Fig.55 - 2 MW Floating PV system at Yeongdong-gun, Chungcheongbuk-do, Korea

The previous Korean government
steadily increased
its renewable energy targets over the past few years.. However, the new government's energy policy shows a different tendency.

MALAYSIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Mohammad Nazri Mizayauddin, Saiful Hakim Abdul Rahman (SEDA Malaysia)

NATIONAL PV POLICY PROGRAMME

Following the Malaysia Renewable Energy Roadmap (MyRER) that has been launched late 2021, Malaysia has also been embarking on a serious energy transitioning chapter by launching a National Energy Policy 2022-2040 (Malaysia National Energy Policy). This living document will be periodically reviewed to ensure Malaysia keeps pace with current global trends in energy transition. Several targets have been outlined in the policy including a positive outlook to have 17% RE in the Total Primary Energy Supply by 2040 up from the current 7.2% (in 2018). This target will be further supported by a specific Strategic Thrust on optimizing energy resources to stimulate sustainable socioeconomic growth and a key action plan to enhance and unlock potentials of indigenous solar resources.

INSIGHTS ON SOLAR RESOURCES IN MALAYSIA NATIONAL ENERGY POLICY 2022-2040

Action Plan – Enhance and Unlock Potential of Indigenous Solar Resources

Key Objectives (For Implementation 2022-2025):

- Enhance RE penetration to increase fuel source diversification, enhance domestic energy self-sufficiency and environmental sustainability
- Enhance cost-competitiveness of energy production from solar resources to improve energy affordability, reduce environmental impacts of solar land use
- Unlock synergies with solar PV manufacturing industry and new solar-related value pools and business models such as solar leasing, peer-to-peer (P2P) trading and others

Description Of New Initiatives

- Long term pipeline of Large Scale Solar (LSS) projects to spur industry capacity building with indicative total package and lot sizes, optimised between large solar parks and smaller scale packages
- Incentivise dual-use agri-voltaic solar farms to increase land productivity and environmental sustainability
- Further explore high potential floating solar, includingsynergies between hydro and solar resources
- Increase availability and competitiveness of private capital for solar investments, with optimization of equity holding rules and by strengthening due diligence during bid evaluation process
- Extend Net Energy Metering (NEM) to continue encouraging industry development, before transitioning to other forms of compensation such as compensation on displaced cost rates as industry gains maturity
- Increase capital access for distributed solar with rooftop solar aggregation and unlock attractiveness of distributed solar with P2P and virtual Power Purchase Agreement (PPAs).
- Identify ecosystem opportunities to unlock synergies across the solar value chain, between upstream manufacturing and downstream development

Under Malaysia's Ministry of Natural Resources, Environment and Climate Change (NRECC), two statutory bodies are responsible to monitor all PV programs in Peninsular 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. In Sarawak, energy and utilities are governed and regulated by Ministry of Utility and Telecommunication Sarawak while in Sabah, the energy sector (gas and electricity supply) is governed by the newly formed Energy Commission of Sabah, a statutory body under the Sabah State Government.

In 2021, a total cumulative capacity of 1 832 MW PV was installed in Malaysia and the number increased by 821 MW in 2022, exceeding the 2 GW mark for the first time via four main mechanisms. The breakdown of the installations are shown in the table and chart:

MECHANISMS	2021 (MW)	2022 (MW)
LSS	910	1 361
FIT	323	322
NEM	427	752
OFF-GRID	35	37
SELCO	137	181
TOTAL	1 832	2 653

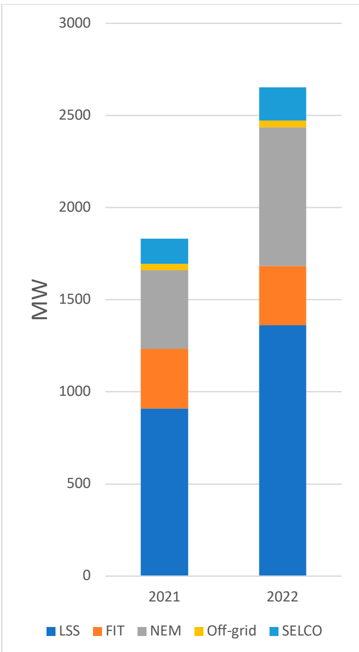

Fig.56 - Breakdown of PV Installations in Malaysia by support programme and system type

Fig.57 - Experience the beauty of sustainable development at Lumina, one of Sabah's largest solar power plants. Nestled amidst the breathtaking scenery of mountains and lush forests, this remarkable project by Tadau Energy Sdn Bhd powers Sabah with clean energy and inspires a greener future

Malaysia aims to position itself as the regional RE power distribution and trading hub with solar power plants as one of the key optional resources.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In ensuring that sustainable development encompasses the energy sector, the Malaysian Government has announced during the 5th International Sustainable Energy Summit (ISES) that three tourism islands in Peninsular Malaysia, namely – Redang, Perhentian and Tioman are to be 100% powered by Renewable Energy; a move to provide the local population and tourists a constant clean energy. The Green Energy Island project is expected to commence in April 2023.

Also during ISES 2022, the government announced new programs and initiatives to reform the country's electricity supply whilst supporting the energy transition, they include :

i) The approval of the allocation and redistribution of the RE quota of 1200 MW for solar under existing mechanisms such as New Enhanced Dispatch Arrangement (NEDA), Identify and explore new RE programs such as solar parks and supply of green electricity for the use of data centres as well as the generation of green hydrogen.

ii) Develop a frame work – Renewable Energy Certificates (REC) with clear and orderly governance to ensure that RECs produced in the country are credible, transparent and in high value.

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

INDUSTRY & MARKET DEVELOPMENT

Malaysia is currently reviewing its export ban on renewable energy, a move that will take Malaysia one step closer towards realizing the ASEAN Power Grid vision. A feasibility study on enhancing cross border power integration is also set to take place with the aim to position the country as the regional power distribution and trading hub, with RE to be exported in the interconnection line.

While this takes place, Malaysia is currently providing more options for the industry by offering a virtual power purchase agreement initiative called the Corporate Green Power Programme in which business entities may purchase green electricity from solar power producer via a virtual grid.

On top of this, Malaysia has also enhanced the current mechanism by offering more quota under the NEM Net Offset Virtual Aggregation (NEM NOVA) for non-domestic consumers following the increasing demand from the sector. Under this mechanism, any generation excess from a premise can be exported to up to three different premises via the supply system with a total quota of 800 MW.

To further support the growth of RE in Malaysia, NRECC and IRENA launched a joined report; Malaysia Energy Transition Outlook (METO) in which the outlook details a comprehensive pathway for the development of sustainable and clean energy system in Malaysia.

MOROCCO

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Soukaina Boudoudouh (IRESEN)

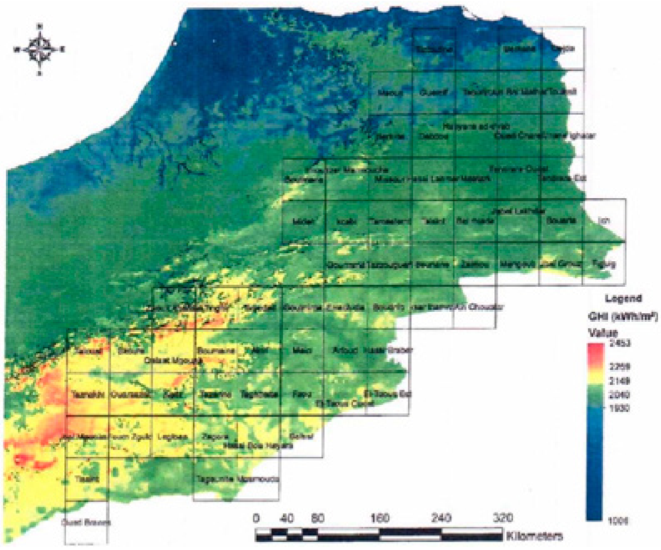

Fig.58 - The capacity of decentralized solar photovoltaic installations in Morocco reached 700 MW in 2022. A sample map from the Ministry of Energy Transition and Sustainable Development's publication of geographical areas that are allowed to host private solar power plants

NATIONAL PV POLICY PROGRAMME

The Moroccan Government developed in 2009 the National Energy Strategy, setting clear and precise objectives. The Strategy covers four main strands: optimize the fuel mix in the electricity sector; accelerate the development of energy from renewable sources, especially wind, solar and hydropower; make energy efficiency a national priority; and promote a greater regional market integration. Nonetheless, Morocco relies heavily on fossil-fuel imports. The electricity generation balance consists predominantly of thermal generation (coal, natural gas, oil) while an amount of the electricity demand is imported.

Morocco has demonstrated its commitment by establishing a series of public agencies and institutions which were set up as a means to better organize and structure the promotion of green and sustainable energy development. These include:

- The Moroccan Agency for Energy Efficiency
- The Moroccan Agency for Solar Energy (**MASEN**), which is a limited company with public funding
- The Energy Investment Company (**SIE**), founded in 2010
- The Research Institute for Solar Energy and New Energy (**IRESEN**) was founded in 2011 to promote the research, development and innovation of renewable energy technologies around the country.

These institutions and agencies are intended to support the National Climate Plan 2020-2030 which aims to strengthen the capacity to adapt and accelerate the transformation to a low-emission economy, the implementation of national climate policies at the local level, as well as encouraging innovation and awareness to better respond to the challenges posed by climate change.

The Moroccan National Energy Strategy has been supported by a comprehensive legal, institutional and regulatory framework including:

- **Law 16-08** (Dahir of 20 October 2008) on self-production
- **Law 13-09** on renewable energies allows for the supply and export of the electricity produced to the local market and/or through the national grid and interconnections with other countries
- **Law 54-14** allows self-producers with a global capacity of more than 300 MW to access the national grid and sell the surplus production exclusively to the National Office for Electricity and Potable Water (ONEE).
- **Law 48-15** in order to regulate the electricity sector by establishing the National Electricity Regulatory Authority (**ANRE**).
- Draft law n°40-19 in 2019, modifying and completing the law n°13-09 relating to renewable energies.

The Ministry of Energy Transition and Sustainable Development published in 2022 maps of the geographical areas that are allowed to host private solar power plants. These maps will open the possibility for developers to sell electricity to offtakers via **ONEE** (National Office of Electricity), within the framework of Law 13-09.

The capacity of decentralized solar photovoltaic installations in Morocco reached

700 MWp in 2022

RESEARCH, DEVELOPMENT & DEMONSTRATION

A strategy of innovation, applied R&D, and gradual and appropriate industrial integration can help Morocco reduce its technological dependence, move upmarket, and enable industrial development in the energy and related services and equipment sectors. Research and innovation are part of the 2009 National Energy Strategy, Morocco has defined a dedicated energy RD&I agenda with priority areas, to boost areas where the country has a competitive advantage. Today, RD&I activities are driven by an industrial policy agenda, private investment in renewable energy and technology transfer programs through a bottom-up approach.

To succeed in the energy transition by managing risks and controlling uncertainties, Morocco has developed national roadmaps on green themes, which are a way for Morocco to attract funding and partners on strategic themes.

The Kingdom of Morocco has initiated a regional dynamic that aims to create an economic and industrial sector based on green molecules, particularly hydrogen, ammonia and methanol, in order to consolidate its energy transition by helping to reduce the greenhouse gas emissions and support the decarbonization of partner countries.

Projects of a research platform aim to be a reference in terms of R&D at the national, regional and African continental levels, and deal with subjects related to the theme of Solar energy, Green buildings and "Power-to-X" including "Power -to-Hydrogen" and its applications. It is also a question of providing national economic operators with technical, technological tools and know-how, in order to take advantage of this very interesting economic sector with great export potential.

Morocco still meets the innovation barrier which includes:

Producers, who seek to maximize their profits, are not required to consider the damage they cause to the climate in their production and investment choices. In this context, they have no short-term interest in reducing their pollution and innovating on their own.

Thus producers innovate in the fields in which they have expertise. Most of the time, these are unfortunately CO_2 emitting sectors.

Innovation is often slowed down by a problem of appropriability: companies are reluctant to innovate if they cannot fully benefit from the financial spin-offs of their discoveries. This effect is likely to play a large role for green technologies, as they are particularly complex and involve cumulative processes in which spillovers are important.

A final obstacle to innovation is the difficulty of accessing adequate financing, due to the imperfection of financial markets. The fact that the market, left to its own devices, does not produce enough environmental innovations is a strong argument for public intervention.

→ Moroccan Experts participate currently in 1 PVPS Tasks involving involving 1 entity as listed here

INDUSTRY & MARKET DEVELOPMENT

Morocco is in the process of developing innovative green industries in Morocco, including solar thermal and photovoltaic, energy storage (electrochemical, thermal and hydrogen) and IOT and electric mobility. The Moroccan solar industry is taking a new step forward with the launch of the construction of a manufacturing plant for solar thermal collectors and solar water heaters. According to stakeholders, manufacturing could increase to 90 000 units. Other industrial investment projects underway in Morocco include a module and wafer manufacturing plant.

The capacity of decentralized solar photovoltaic installations in Morocco reached 700 MW in 2022. The total capacity data of the centralized market is yet to be confirmed at the time of writing.

The Ministry of Energy Transition and Sustainable Development MTEDD and the Office National de l'Electricité et de l'Eau Potable-ONEE, launched, on November 1, 2022, an original experiment to encourage energy saving which consists in encouraging end consumers to optimize their electricity consumption during the months of November and December 2022. Thus, consumers who have achieved savings in electrical energy, compared to the same period of 2021, will benefit in 2023, a bonus that varies in proportion to the savings achieved.

According to data provided by ONEE, the final consumption of electricity at the national level during the period of November-December 2021, all voltages included, is about 5.5 TWh. If this experiment allows to save at least 5% compared to 2021, then the energy saved during the period November-December 2022 would be equivalent to the consumption of a city like Tangier during the same period (about 275 GWh).

Beyond the expected savings, this original experiment will also allow to inculcate a certain culture of energy efficiency but also the launch of projects for the development of solar photovoltaic among industrialists in self-consumption.

OCP, a Moroccan producer of phosphates and fertilizers, is one of the largest fertilizer companies in the world. The phosphates and fertilizers produced will enable Moroccan exports to reach a record level of $9.5 billion in 2022. OCP has announced that it is investing to rely entirely on renewable energy by 2027.

NETHERLANDS

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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

Fig.59 - Floating PV project (338 kW) on ponds at seed supplier LimaGrain in Rilland. [Source RVO database]

NATIONAL PV POLICY PROGRAMME

On the doorstep of 2022 a new coalition agreement sharpened the Dutch climate goals from 49% CO_2 reduction to at least 55% CO_2 reduction in 2030. The actual policy was set on 60% in order to have a safe margin and make sure the goals of 2050 would be achieved. Several additional measures where taken (climate transition fund of 35 BEUR, additional means for isolation buildings) and a dedicated minister for climate was assigned at the Ministry of Economic Affairs & Climate.

The innovation policy does not mention goals for specific technologies as the principle reasoning is to achieve these in the most cost efficient way while maintaining energy security and a reasonable energy price as stipulated in the energy law. In 2022 all of these three objectives experienced serious setbacks mainly due to the energy crisis and the ongoing war in Ukraine.

Grid congestion for both TSO and DSO's already became an issue much sooner than anticipated by policy makers, regulators and the utilities. The Netherlands is the country with the second highest PV power per capita in the world, lower only than Australia. Since 2020 grid congestion has become more widespread. The resulting backlog in solar will only increase, despite additional and substantial budgets for grid reinforcement, since the planning cycles differ in elapsed time. Additional measures are taken such as frequency management, cable pooling etc. but forced curtailment has become a reality in the Netherlands in some regions.

Several support schemes are in place such as;

- Sustainable energy production subsidy (SDE+) for solar systems larger than 15 kWP
- Net metering is being debated intensely and will be phased out in steps probably after 2025.
- Postal code tax reduction scheme adjusted to the energy cooperatives subsidy (SCE)
- Tax return VAT for small PV systems
- Sustainable energy investment subsidy (ISDE) for small/medium enterprises up to 125EUR/kWp
- Cheap loans in many municipalities if they are signed up to a national fund

While it is clear that these support schemes vary in effectiveness for different groups of people, the rising energy prices and energy crises in general made "energy poverty" much more recognizable in 2022. The national institute for applied research TNO has published on the topic within the Netherlands and Europe recently.

In 2022, the discussion about bringing manufacturing back to Europe was re-initiated with mixed results. The Ministry of Economic Affairs & Climate has become involved in project proposals concerning the value chain in the Netherlands with a focus on solar integration and the new generation of high efficiency solar cells.

So while the current acceleration of the roll-out of solar is slowing down, the necessity is still increasing for several reasons, not only for energy security and reducing energy bills by self-consumption, but also because of the need for the generation of green hydrogen in the near future.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In 2022 the mission oriented R&D program targeted the following topics:

- Renewable energy production
- Energy saving
- Flexibility of the energy system
- Circular economy
- Natural gas free neighborhoods and buildings

Relatively large budgets were available in the existing subsidy schemes for demonstration and pilot projects, with the aim to accelerate market introduction, including the Demonstration Energy and Climate Innovation (DEI+), and the Renewable Energy Transition (HER+) subsidy scheme for CO_2 reduction. Most notable was the inclusion of the topic "offshore floating solar" in 2022.

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

In 2021 the "National Growth Fund" started with a budget of 20 BEUR up to 2025. In the first two calls no projects on solar were granted but preparations have been made in 2022 to file solar projects in the third call.

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 7 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

In 2022 the Dutch solar PV market stabilized at an estimated level of 3.8 GW installed capacity. This will lead to a total cumulative installed capacity of over 18 GW in 2022. These figures are extrapolated from early figures over the first half of 2022 and have yet to be determined by the Central Bureau for Statistics (CBS). The official figures are published and updated regularly by the CBS.

This shows a steady growth of over 3 GW a year but no further acceleration of the solar market. Some groups such as the Dutch Environmental Assessment Agency (PBL) expect a slowing down of the market due to congestion on the grid in the coming years, at least until 2030.

There is some history involved here. During the initial phases of the development of solar the conventional wisdom in the sector was that large solar parks would only be economically feasible in countries with a high solar irradiance, and the market in the Netherlands would be driven by roof top systems. Falling prices of solar panels worldwide as of 2014 and record low interest rates, however, put solar on the path to becoming the cheapest energy source, according to the IEA (2020). In the Netherlands it suddenly meant in 2016 that solar PV qualified in the SDE subsidy scheme (> 15 kWp systems) as the cheapest renewable energy option available, and large solar parks became a reality for both ground mounted and roof top systems.

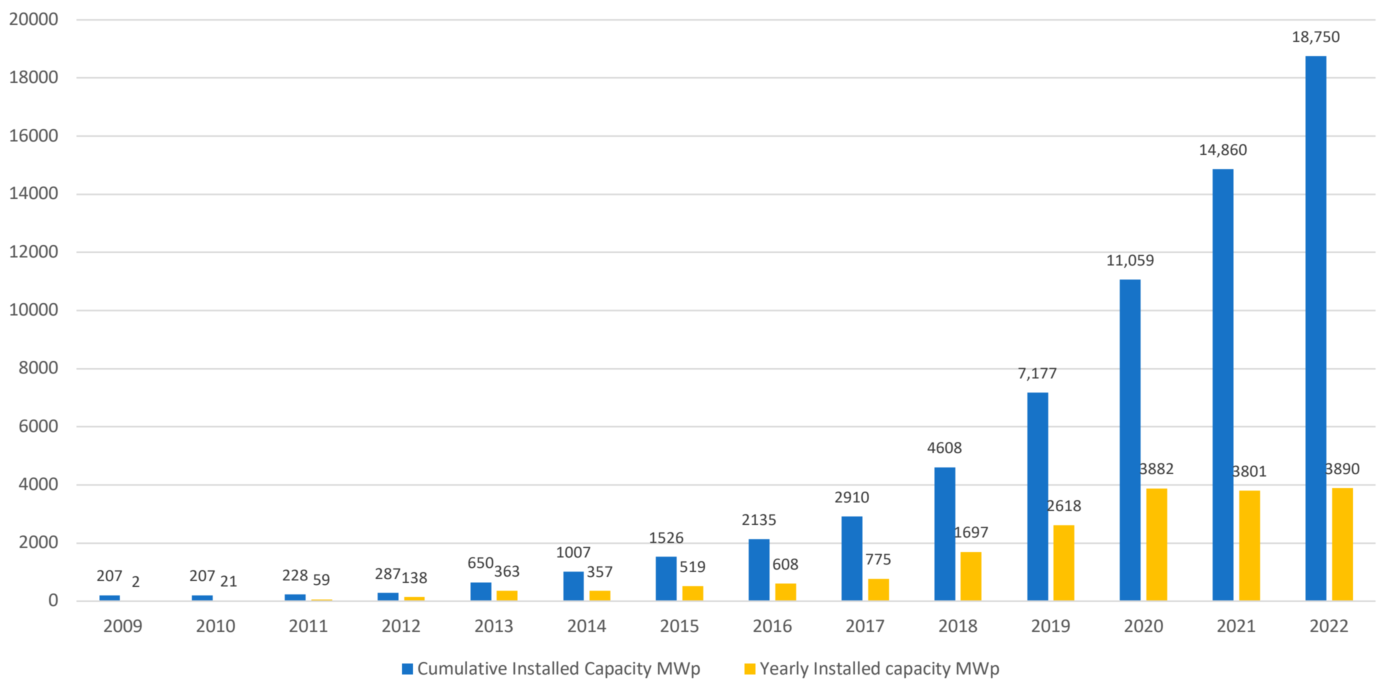

Fig.60 - Dutch annual and cumulative installed PV capacity in MW [Source: CBS, data estimated for 2022]

Grid congestion

for both TSO and DSO's already became an issue much sooner than anticipated by policy makers, regulators and the utilities.

In 2018 the first serious signs of grid congestion occurred with only a total fraction of 3% solar in the Dutch electricity grid, spurring a new debate on prioritizing new grid connections for essential services, specific economic sectors and how to socialize the additional costs of the inevitable grid reinforcements. In 2019 a framework of priorities was adopted in parliament for the deployment of solar panels, first on roofs and unused areas, which are hard to find in the Netherlands. This was in reaction to the growing amount of solar parks in agricultural landscapes and near natural parks. Today a steady amount of over 3 GW is installed annually, divided almost equally over roof and ground mounted systems, with an increasing back log of not realized solar parks due to congestion in the distribution grids (see figure 61).

National consortia are formed around integrated solar in the landscape, infrastructure, BIPV and the water (floating PV) both on-shore and off-shore. The scarcity of available surface area is the main driver of these integrated solar products. Solar is also becoming an integral part of so called "energy hubs" which have considerable storage capacities and deliver additional energy services.

While some of the remaining manufacturers in Europe look to upscale their operations and improve their technology, others turn to new products and ways of production. In the Netherlands, Morphotonics is an indirect spin-off company of Royal Philips, with experience in nanoimprint and microreplication, while Supersola offers an easy plug and play system.

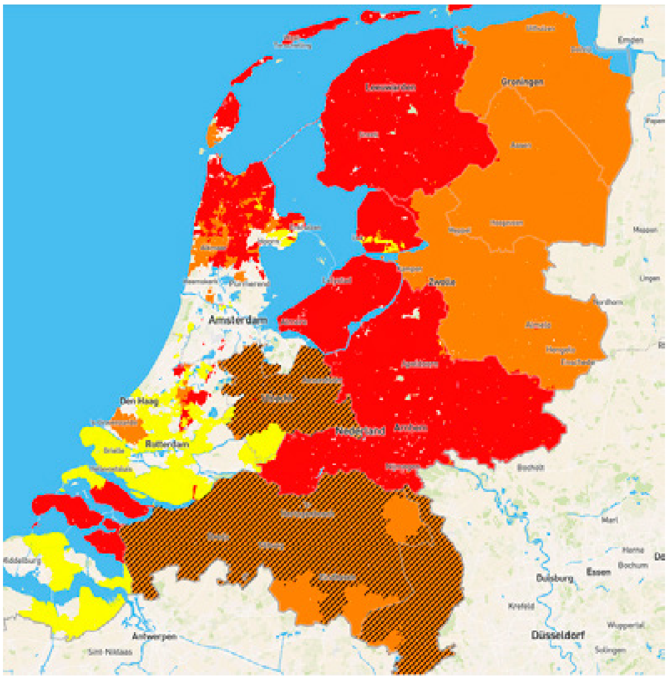

Fig.61 - Dutch electricity grid congestion map 2022
[Source Netbeheer Nederland]

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NORWAY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Trond Westgaard (Research Council of Norway); Jarand Hole (Norwegian Water Resources and Energy Directorate)

Fig.62 - A new development is Over Easy Solar's system for roof-tops with vertically mounted bifacial modules. At Northern European latitudes this gives a more even electricity production profile throughout each day and the year. (Photo: Trygve Mongstad, Over Easy Solar AS)

NATIONAL PV POLICY PROGRAMME

Norway's programmes in the energy sector are generally aiming for promoting renewable energy and increasing energy efficiency. Support for implementation of PV is integrated into these programmes.

Owners of small-scale PV installations are eligible for registering as prosumers. Prosumers are exempt from grid connection fees that are otherwise charged from electricity suppliers. Surplus electricity can be transferred to the grid at net electricity retail rates (i.e., excluding grid costs, taxes, and fees). If such installations exceed a limit of 100 kW AC electric power feed-in to the grid, excluding own consumption, grid connection fees will apply.

The public agency Enova SF subsidizes up to 35% of the installation costs for grid connected residential PV systems at a rate of 7 500 NOK per installation and 2 000 NOK per installed kW rated capacity up to 20 kW. This programme also includes leisure homes with grid connection.

The government agency Innovation Norway supports investments in PV systems in the agricultural sector. It is required that the PV system is used for the commercial operation of the actual farm.

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. The regulatory authority NVE-RME has prepared a proposal where PV plants up to 500 kW can share electricity production between local customers under certain conditions. This would apply within a building or a cluster of adjacent buildings at the same location as the PV plant. The proposal is waiting for government approval and it will, if implemented, contribute positively to the economics of PV installations.

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 cells 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 (www.susoltech.no), 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 (24 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 Nanotechology (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 4 separate entities as listed here

150 MWp

of PV capacity was installed in 2022, which is approximately

3 times

the volume installed in 2021

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 operations of some sites have been severely impacted by the European energy situation in 2022.

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.

There are also new initiatives, both in new and in existing enterprises, for developing new services or solutions for the PV market. Examples are BIPV products, roofing products for bifacial modules, or module designs adapted to Northern European conditions, e.g. Over Easy Solar's system with vertically mounted bifacial modules.

Norway's electricity supply is dominated by hydropower (88%) and wind (10%). Although the Norwegian PV market is small on an international scale it experienced very strong growth in 2022. 150 MWp of PV capacity was installed in 2022, which is approximately 3 times the volume installed in 2021. The total PV generation capacity by the end of 2022 was approximately 300 MWp, excluding off-grid installations. The steep increase in installation volume was caused by exceptionally high electricity prices throughout the year.

New rules for grid connection tariffs were implemented in 2022. The rules are believed to negatively affect the economics of PV installations, but they had almost no effect on installation volumes due to high electricity prices.

PORTUGAL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Ricardo Aguiar (Directorate-General of Energy and Geology)

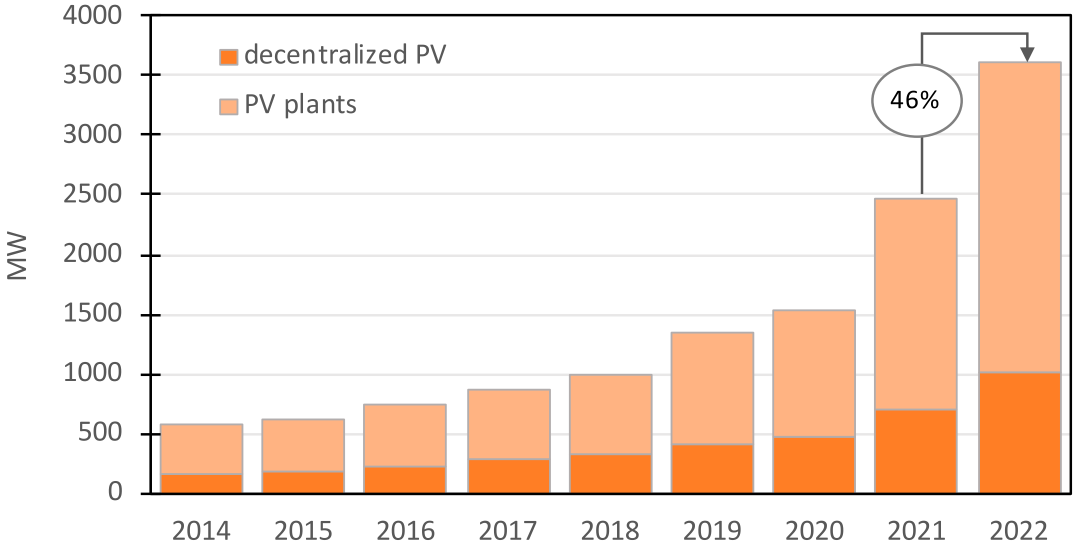

Fig.63 - Installed PV capacity in Portugal, 2014-2022. (Source: DGEG)

NATIONAL PV POLICY PROGRAMME

There is no specific PV strategy or plan in Portugal; it is the National Energy and Climate Plan 2030 (NECP), published in late 2019, that includes most of the policies and measures related to this technology. 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 role of PV by 2030 was set at 10 GW (30% of installed power capacity), or 63 PJ (25% of the electricity production).

During 2022, the NECP started to be reviewed and updated, as a draft new version must be presented to the European Commission by June 2023. This is appropriate, as indeed, the vision for the NECP as a whole and for the role of PV in particular has changed much during the 3 years since publication. Regarding electricity, the focus was initially on increasing as much as possible the renewable fraction. Meanwhile, the issues of energy system flexibility and security of supply gained much more weight. Already in 2020 the National Hydrogen Strategy (EN-H2) introduced hydrogen value chains in the vision of a future sustainable Portuguese energy system. For producing hydrogen via electrolysis, EN-H2 calls for additional installed capacity, independent of what is required to attend the national power grid. About 2/3 of this additional capacity would come from PV. In total it is foreseen to have, by 2030, 13 GW installed, or 105 PJ produced.

The estimated needs of PV capacity have grown even larger, considering that the output power of electrolysers by 2030 was initially seen as 2 GW in the EN-H2, but now 6 GW to 10 GW are expected. To meet the corresponding PV capacity seems ambitious but feasible, as there are about 20 GW of projects queuing for access to grid.

In terms of shorter-term policies, the Government approach is to let the existing feed-in tariffs 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. It is remarked that while the public perception was initially neutral on PV projects, 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. In April, a first auction for floating PV already awarded 183 MW.

Regarding legislation issued in 2022, there are two highlights. A first one was about streamlining the system of permits, both by bureaucratic simplifications and by defining the so called go-to areas. A second one was about extending the periods allocated to build the PV plants whose capacity was awarded in the 2019 and 2020, considering the difficulties posed by the Covid-19 pandemic – directly at national level as well as indirectly through disruption of international supply chains.

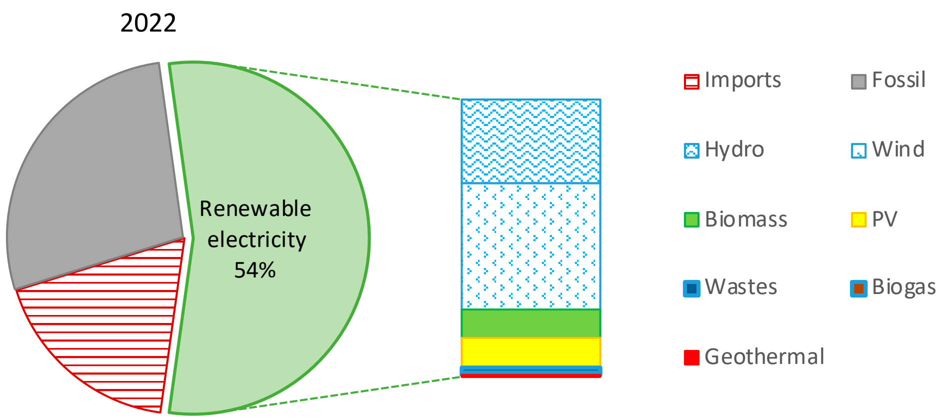

Fig.64 - Electricity generation by type of energy source in Portugal, 2021 (Source: DGEG)

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 silicon technologies namely ribbon cells, and modelling (at FCT); 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, Cu2O, Cu(In, Ga)Se2 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 2 PVPS Task involving 2 entity as listed here**

Renewable energy technologies were responsible for 28.9 TWh, 12% less than the 32.9 TWh value for 2021. This was due mainly to 2022 being a dry year, recording a 34% reduction of the hydroelectric production. In contrast, the evolution of the PV contribution was again remarkable, with a

55% increase

from 2 237 GWh to 3 471 GWh.

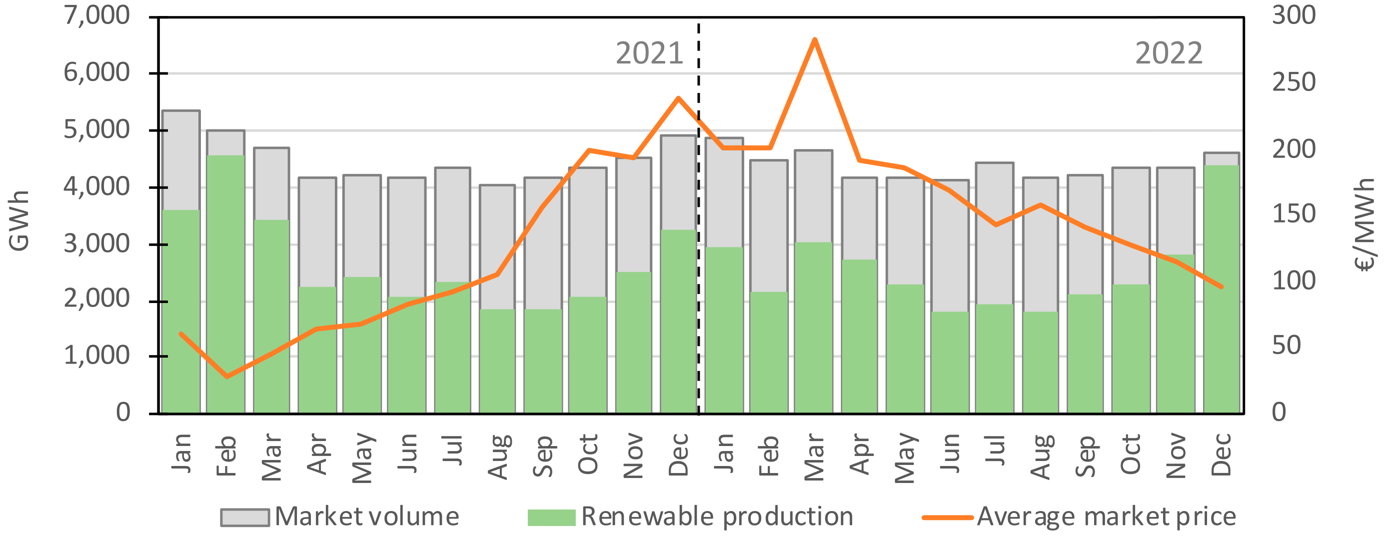

Fig.65 - Iberian Electricity Market Volume and Price for 2021-2022 (Source: OMIE)

INDUSTRY & MARKET DEVELOPMENT

As the impact of the COVID-19 pandemic dissipates, gross electricity demand in the country stepped from 53.0 TWh in 2021 to 54.8 TWh in 2022, ie. a 3.5% raise.

Renewable energy technologies were responsible for 28.9 TWh, 12% less than the 32.9 TWh value for 2021. This was due mainly to 2022 being a dry year, recording a 34% reduction of the hydroelectric production. In contrast, the evolution of the PV contribution was again remarkable, with a 55% increase, from 2 237 GWh to 3 471 GWh.

Indeed, as can be appreciated in Figure 63, the PV capacity continues to increase at a fast pace. The additional capacity installed during 2022 was 1 128 MW, corresponding to 814 MW at power plants and 314 MW at decentralized systems, a 46% increase over 2021. The installed PV capacity now totals 3.6 GW. Although fossil (28%), hydro (16%) and wind (25%) technologies still dominated the electricity production mix in 2022 (see Figure 64), the penetration of PV continues to rise, from 3.3% in 2020 to 4.4% in 2021 and 5.9% in 2022.

The annual average market price in the Integrated Iberian Electricity Market (OMIE) has risen very much, from 112 EUR/MWh in 2021 to 168 EUR/MWh in 2022. However, the seasonal behavior tells a different story, as can be seen in Figure 65. The monthly average price started 2022 in a continuation of the high levels of the end of 2021 but peaked by March at around 283 EUR/MWh. Then, it entered a declining trend until the end of the year, reaching around 97 EUR/MWh in December. Two factors certainly contributed to this decrease: the ceiling imposed to the price of gas used in NGCC power plants (aka "Iberian price cap"), and more hydroelectric production towards the end of the year. Nonetheless, the increased PV penetration in the electricity production mix seems to have had also a role in this pattern, with the additional 1.1 GW entered in operation, as mentioned before. This role should continue to grow, as the PV capacity auctioned in 2019 and 2022 starts to come online, as more 1.5 GW of centralized PV was licensed during 2022, and as 2.4 GW are known to be very near completion of the licensing process. These optimistic perspectives may however be moderated by international supply chain problems.

SOLAR ENERGY RESEARCH INSTITUTE OF SINGAPORE (SERIS)

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Dr Thomas Reindl (Deputy CEO), Eddy Blokken (BD Manager), Dr Xu Xiaoqi (Research Fellow)

Fig.66 - Photograph of Singapore's Tengeh reservoir showing the MW-scale floating solar testbed (front part) designed and built by SERIS in close collaboration with PUB and EDB. SERIS' scientific evaluations of the 1-MWp testbed were vital for the large-scale deployment of Floating PV in Singapore, including a 60-MWp floating solar farm in Tengeh reservoir built by Sembcorp Solar (one segment can be seen in the back). (Image credit: Sembcorp Industries)

SINGAPORE'S NATIONAL PV PROGRAMME

Singapore is actively participating in the global efforts to promote the transition to clean and sustainable energy. With limited space as a city-state and few renewable energy options (no hydropower potential, low wind speeds around the equator), solar photovoltaics (PV) is the only viable renewable energy resource. To further its goal of becoming a more sustainable city, the government introduced the Singapore Green Plan 2030. This plan outlines the transformation of Singapore into a "Global City of Sustainability" by the end of the decade, which includes a substantial expansion of its solar PV capacity. The goal is to have 1.5 GWp of photovoltaic power installed by 2025, and to increase that to beyond 2 GWp by 2030. Total installed PV capacity at the end of 2022 was close to 800 MWp.

In addition, the country aims to work with neighbouring countries to import reliable, low-carbon electricity on a competitive basis, with a target of 4 GW of total imports by 2035. This relates to a current system peak demand of approximately 7.5 GW.

To date, SERIS has established close links and R&D collaborations with

more than 100

companies in Singapore, Asia Pacific, and beyond.

COMMERCIAL AND INDUSTRY DEVELOPMENT

Singapore is home to a large number of companies across the solar PV value chain, from solar manufacturing to EPC companies, project developers and associated services (e.g. green financing, legal, O&M). The most prominent industry players in Singapore are REC Solar, which operates a GW-scale solar cell & module manufacturing plant, Maxeon Solar (f.k.a. Sunpower Corp), which has established a R&D Center, Sembcorp, which owns & operates several hundred MWp of solar assets (including the 60 MWp Floating Solar system on Tengeh reservoir, see Fig.66) and home-grown developer Sunseap, which was acquired by EDPR from Portugal for SGD 1.1 billion in 2022.

Fig.67 - SERIS' colourful cultural-themed BIPV module ("Peranakan module")

RESEARCH, DEVELOPMENT & DEMONSTRATION

The National Research Foundation Singapore (NRF) implements the research programmes and funding schemes directed to the industry, research institutes, universities and polytechnics. The current Research, Innovation and Enterprise (RIE) 2025 Plan provides R&D investments of about 1% of Singapore's GDP, or a total of SGD 25 billion for the timeframe 2021 - 2025. Solar energy research falls under the Urban Solutions and Sustainability (USS) domain which addresses the challenges of climate change and resilience, including heat island effects, climate change, decarbonization, healthy cities, and transformation of the built environment.

The Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS) is the city-state's national institute for applied solar energy research. Founded in 2008, it has emerged as one of the leading solar energy laboratories in the world. SERIS is supported by NUS, the National Research Foundation Singapore (NRF), the Energy Market Authority of Singapore (EMA) and the Singapore Economic Development Board (EDB).

SERIS' RD&D activities cover a broad range of topics and span across the entire solar PV value chain from solar cells to modules and systems, as illustrated in Fig.68.

Core research areas are the three so-called "flagship projects": Tandem solar cells, building-integrated PV (BIPV), and Floating PV (FPV), which are supplemented by research topics that address the specific challenges for deployment of solar PV systems in mega-cities (space constraints) and in tropical climate conditions (high temperature and humidity throughout the year). Examples of research outcomes in 2022 are colourful BIPV modules in local cultural design (see Fig.67) and a fully operational real-time solar forecasting system for PV grid integration and electricity market support in the presence of an increasing share of variable solar PV generation in Singapore's power system.

→ **SERIS Experts participate currently in 3 PVPS Task involving 4 entity as listed here**

SERIS AND PVPS

SERIS joined the IEA PVPS programme in 2022 as a sponsor member and is actively involved in Tasks 1, 13, 14 and 15, with the purpose of sharing its know-how with other experts and fulfilling its vision of contributing to global sustainable development.

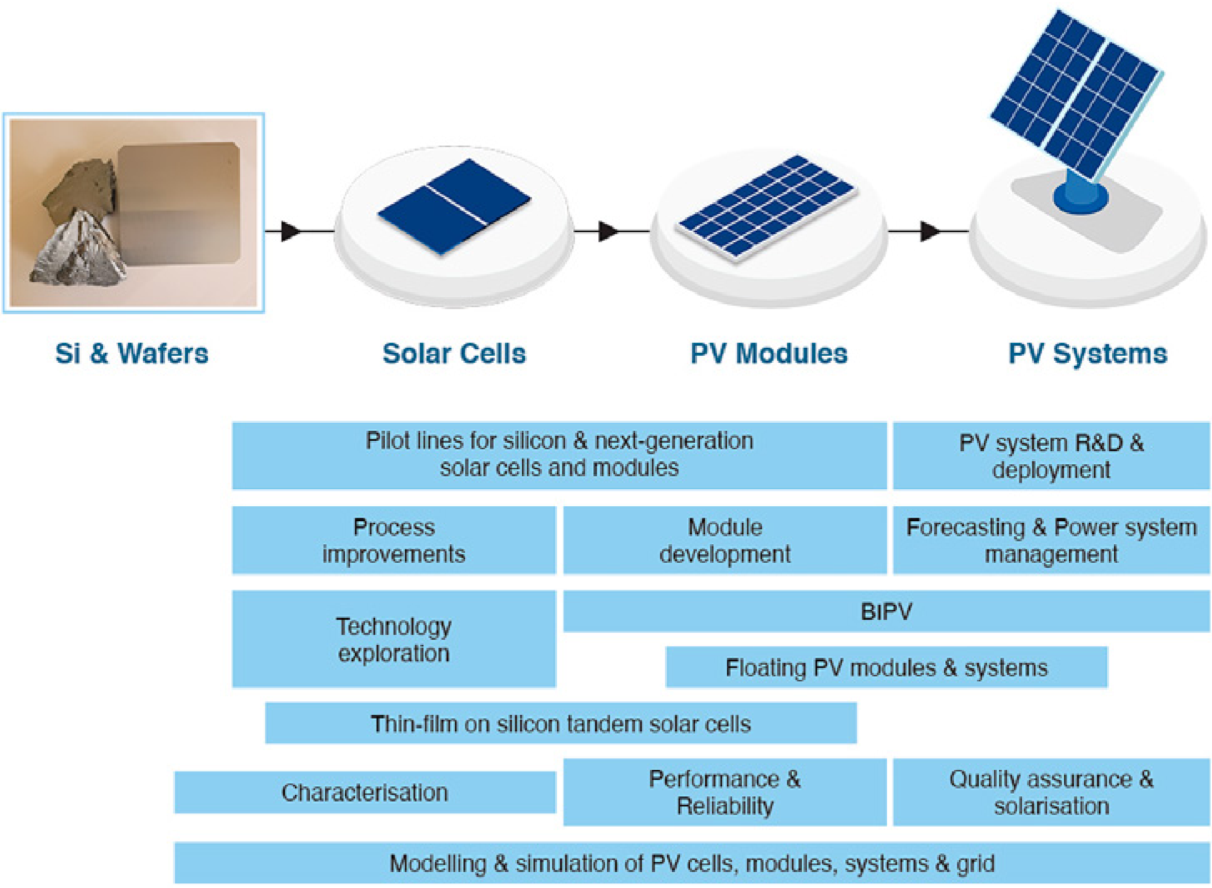

Fig.68 - Overview of SERIS' RD&D activities in the areas of solar cells, PV modules and PV systems

SOLAR POWER EUROPE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Walburga Hemetsberger, CEO; Dries Acke, Policy Director; Raffaele Rossi, Head of Market Intelligence (SolarPower Europe)

PV POLICY PROGRAMME

2022 was the year when solar power displayed its true potential in the EU, driven by record high energy prices and geopolitical tensions that largely improved its business case. No longer constrained by major supply chain bottlenecks and COVID-19 related restrictions, the 27 EU Member States saw 41.4 GW of new solar PV capacity connected to their grids, a 47% increase compared to 2021 and close to 100% increase compared to 2020.

2022 was also the year where the political recognition and attention for solar PV matured. In May, the European Commission published a dedicated solar strategy as part of its REPowerEU agenda, in response to the war in Ukraine and the gas crisis. That strategy set a new, bold agenda for solar including:

- New solar ambition of at least 400 GWDC by 2025 and 750 GWDC by 2030, still below SolarPower Europe's 1 TW objective.
- A new European Solar Rooftops Initiative, including a solar mandate on all new public and commercial buildings from 2026, on all existing public and commercial buildings from 2027 and all new residential buildings from 2029. This is currently in co-decision in the European institutions, likely to land in spring 2023.
- New permitting rules for renewable energy projects, with firm permit-granting timelines and go-to areas. This agenda was boosted by a dedicated Emergency Measures tool adopted by EU leaders in late December. This is an exceptional legislative instrument that allows Member States to already speed up permitting rules before the new Renewables directive comes into play. Basically, not to lose time in these exceptional circumstances where solar and wind are so important for Europe's economy and security.
- A new renewables skills agenda in full recognition of the bottlenecks for solar PV deployment with installers and electricians.
- A new EU Solar PV Industry Alliance aiming for at least 30 GW of EU manufacturing by 2025. SolarPower Europe is on the Steering Committee of this initiative. This agenda was raised to top priority for EU leaders, especially in reaction to the US Inflation Reduction Act. Europe had to scale up quickly to the next level, not to miss out on strategic value chain investments like solar manufacturing. This culminated in Commission President Ursula von der Leyen presenting a new Green Deal Industrial Plan on February 1st 2023.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In 2022, SolarPower Europe published the report Solar, *Biodiversity, Land Use: Best Practice Guidelines*. The study helps stakeholders navigate through relevant EU legislation on solar projects; outlines key actions for appropriate land identification; provides best practice examples on nature-positive solar sites across the EU and recommendations on how to incorporate environmental considerations across different solar PV project phases. This landmark study was developed through a series of workshops featuring key actors in the biodiversity protection space, including BirdLife, who co-authored the report. This new report adds to SolarPower Europe's Solar Best Practices Guidelines series, which are available online in a brand-new website.

Fig.69 - SolarPower Europe's Solar, Biodiversity, Land Use: Best Practice Guidelines (2022). Available at: https://www.solarpowereurope.org/insights/thematic-reports/solar-biodiversity-land-use-best-practice-guidelines

In 2022, SolarPower Europe also assumed the Secretariat of the ETIP PV, which saw a renewal of the platform's leadership around the chair Rutger Schlatmann (Helmoltz HBZ). The ETIP PV renewed activities are seeing a greater presence to promote the PV R&I priorities and ensure the adequacy of European policies to achieve them. The platform structured around 5 working groups (LCOE, Integrated PV, Digital PV and Grid, Industrial PV, Reliable & Circular PV) is adding a 6th one on Social PV, with the objective to provide an encompassing and transdisciplinary vision of PV potential contribution to a 100% renewable and decarbonised European economy by 2050, through the development and deployment of innovative technologies and solutions.

→ SolarPower Europe Experts participate currently in 3 PVPS Task involving 1 entity as listed here

2023 is set to be another record year for European solar: the new EU ambitions set under the REPowerEU plan, along with the need to tackle the current high electricity prices, will drive the sector to

53.6 GW in 2023

according to our Medium Scenario.

INDUSTRY & MARKET DEVELOPMENT

Our EU Market Outlook 2022-2026, published last December, assessed that with 41.4 GW of newly connected solar PV capacity and a 47% year-on-year. growth, 2022 was the best year in history for the EU solar market. Such a steep increase did not seem possible one year ago, when the market had already expanded by 41% to 28.1 GW, breaking all previous records. Growth is widespread across the bloc: 26 out of 27 EU Member States deployed more solar than the year before. According to our EMO data from December, it seemed that Germany would again be Europe's biggest solar market in 2022 with 7.9 GW of newly installed capacity, followed by Spain (7.5 GW), Poland (4.9 GW), the Netherlands (4.0 GW) and France (2.7 GW) – although the latest available data shows that Spain exceeded our expectations and took the #1 spot. The EU PV power generation fleet grew by 25% to 208.9 GW, from 167.5 GW in 2021. Total solar capacity across the EU has now exceeded 200 GW, only four years after it passed the 100 GW milestone in 2018. With 68.5 GW Germany maintains its role as the largest operator of solar power plants in the EU. Spain is now ranked 2nd, reaching a total of 26.4 GW thanks to an extraordinary market growth. When it comes to solar power per capita, the Netherlands continues to lead the way: in 2022, not only it reached the remarkable milestone of more than 1 000 Watt of installed solar power per inhabitant; it also widened the distance to Europe's powerhouse, Germany, which had 816 W/capita installed at the end of 2022.

This year's EU solar market scenarios 2023 to 2026 show continuous, two-digit annual growth rates that are all significantly higher than in our previous edition (Fig.70). At a 29% annual growth rate, 2023 is set to be another record year for European solar: the new EU ambitions set under the REPowerEU plan, along with the need to tackle the current high electricity prices, will drive the sector to 53.6 GW in 2023, according to our Medium Scenario. New additions will bring total solar capacity to 262 GW in 2023 and 484 GW in 2026, more than doubling today's operating fleet. This pathway is also more or less aligned with the REPowerEU interim target of 400 GW (320 GWAC) by 2025. In the period 2027-2030, we expect that additional growth will take place thanks to improved policy conditions and further technology cost reductions. The total solar fleet in the EU is projected to reach 920 GW under a Medium Scenario and 1 184 GW under a High Scenario. Both scenarios significantly surpass the 750 GW solar by 2030 target set in the EU Commission's REPowerEU strategy, by 24% and 58% respectively.

Our revised assessment of PV developments in the context of the EU Member States' National Energy Climate Plans (NECPs) shows that 21 EU Member States will have already reached their 2030 PV goals no later than 2025, while the remaining 6 Member States will do so no later than 2027. According to our forecast, the NECP aggregate target will be reached already in 2025 under business-as-usual conditions. While this is very positive news for the sector, and for the entire EU, it also indicates that the ambition should be raised further at both the EU and Member State Level. Reaching the Terawatt milestone by end of the decade would pave the way for a multi-TW solar development towards 2050 that is needed for the EU to remain on track to deliver on its climate ambitions.

A deep-dive analysis on the EU solar market in 2022 is available on SolarPower Europe EU Market Outlook 2022-2026.

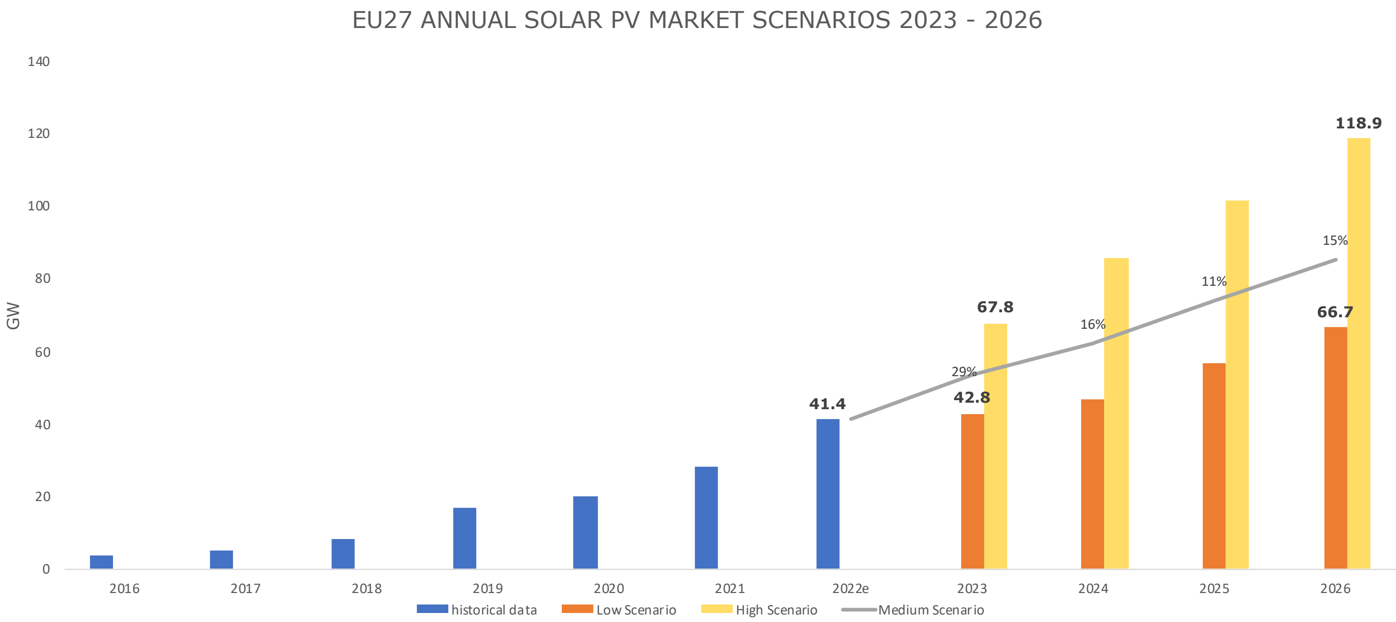

Fig.70 - EU27 annual solar PV market scenarios 2023-2026. © SolarPower Europe 2022

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.71 - Agrivoltaic solar farm. Courtesy of Soltec

NATIONAL PV POLICY PROGRAMME

The Strategic Energy and Climate Framework defines the energy transition route to achieve Spain's climate neutrality by 2050. This energy transition process will modernize the economy, reinforce its competitiveness, generate sustainable jobs, improve people's health and quality of life, and protect our environment. The "Integrated National Energy and Climate Plan" (INECP 2021-2030), approved in 2020, represents a key pillar in this framework, reflecting Spain's commitment to achieve climate neutrality by 2050. Spain's shorter-term objectives for 2030 include a 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. This plan anticipates 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. This plan is currently under revision to adapt to the new Fit for 55 and REPower EU targets, which have included proposals to review a wide range of regulations, including the Renewable Energy and Energy Efficiency Directives, setting more ambitious targets. In this regard, a public consultation was launched in the summer of 2022 and a final text is expected to be finalized in 2023.

Urgent measures needed to be put into effect during the year 2022 to cope with the consequences of Russia's invasion of Ukraine and the resultant increase in electricity prices. In this regard, Royal Decrees 6/2022, 10/2022 and 11/2022 were approved in 2022, outlining a national response plan to the economic and social impacts of the war in Ukraine, setting a limit for the price of bilateral gas, introducing accelerated environmental assessment procedures, launching temporary mechanisms for adjusting production costs to reduce the price of electricity on the wholesale market, and the modification of the water law for the introduction of floating plants, among others.

The Self-consumption Roadmap, implemented as a response to the National Self-Consumption Strategy, defines the objectives of self-consumption (i.e. distributed generation, 'behind the meter') for the period 2021-2030. The target scenario defines an objective of 9 GW while the high penetration scenario sets a target of 14 GW. In addition, in May 2022 the Guide for Municipalities for the Promotion of Self-Consumption was published. The guide, developed by IDAE and UNEF, provides advice and best practices to help municipalities improve their procedures applicable to self-consumption installations. 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. Due to these incentives and the high electricity prices, the self-consumption installations increased by 108% in 2022, with respect to 2021.

Finally, it is to be mentioned that the government is also working on the National Floating PV Strategy, which is soon to be published.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Ministry of Science and Innovation defines the framework of action in the field of research, development and innovation policy 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]. The total budget of EUR 10 357 million has been complemented with an extraordinary 6 060 million from the Plan for the Recovery, Transformation and Resilience.

The research and development projects approved during 2022 cover almost the whole value chain of photovoltaics. For example, proposals financed by the National Research Agency in the Public Private Collaboration and Strategic Lines calls, range in topic from multifunctional coatings to improve PV efficiency, to projects for optimizing the integration of PV in building and automotive elements, self-consumption projects, and also agrivoltaic, and floating projects.

Concerning Horizon Europe's Cluster 5 supported projects, the Spanish participation in 2022 was focused on two topics: perovskite technology and floating PV. Regarding perovskite technology, the following projects received financing: **PEPPERONI**: Pilot line for European Production of PEROvskite-Silicon TaNdem modules on Industrial scale; the **SuPerTandem**: Sustainable materials and manufacturing processes for the development of high efficiency, flexible, all-Perovskite Tandem photovoltaic modules with low CO_2 footprint; **SUNREY**: Boosting Sustainability, reliability and efficiency of perovskite PV through novel materials and process engineering, and finally the **VALHALLA**: Perovskite solar cells with enhanced stability and applicability, coordinated by the Universitat of Valencia. Regarding floating PV, the **NATURSEA-PV**: Novel eco-cementitious materials and components for durable, competitive, and bio-inspired offshore floating PV substructures, coordinated by Fundación Tecnalia Research & Innovation; the **SUREWAVE**: Structural reliable offshore floating PV solution integrating circular concrete floating breakwater, and the **PLOTEC**: PLOCAN Tested Optimised Floating Ocean Thermal Energy Conversion Platform, coordinated by Consorcio para el diseño, construccion, equipamiento y explotacion de la plataforma oceanica de Canarias, were funded.

Besides the above mentioned projects, many projects related to self-consumption and energy communities were funded by Next Generation funds.

In December 2022 the addendum to the National Recovery and Resilience Plan was approved, to adapt the objectives of the REPowerEU Plan, mobilising 7.7 billion in additional transfers and 84 billion in loans, as well as 2.6 billion from the Repower Plan. This new budget will support the "Renewables PERTE" the "Circular Economy PERTE" and the creation of the new "Industrial Decarbonisation PERTE", which aims at providing companies with a framework of support in facing high energy costs and accompanies them through the adoption of energy transition measures.

→ **Spanish Experts participate currently in 8 PVPS Tasks involving 18 separate entities as listed [here]**

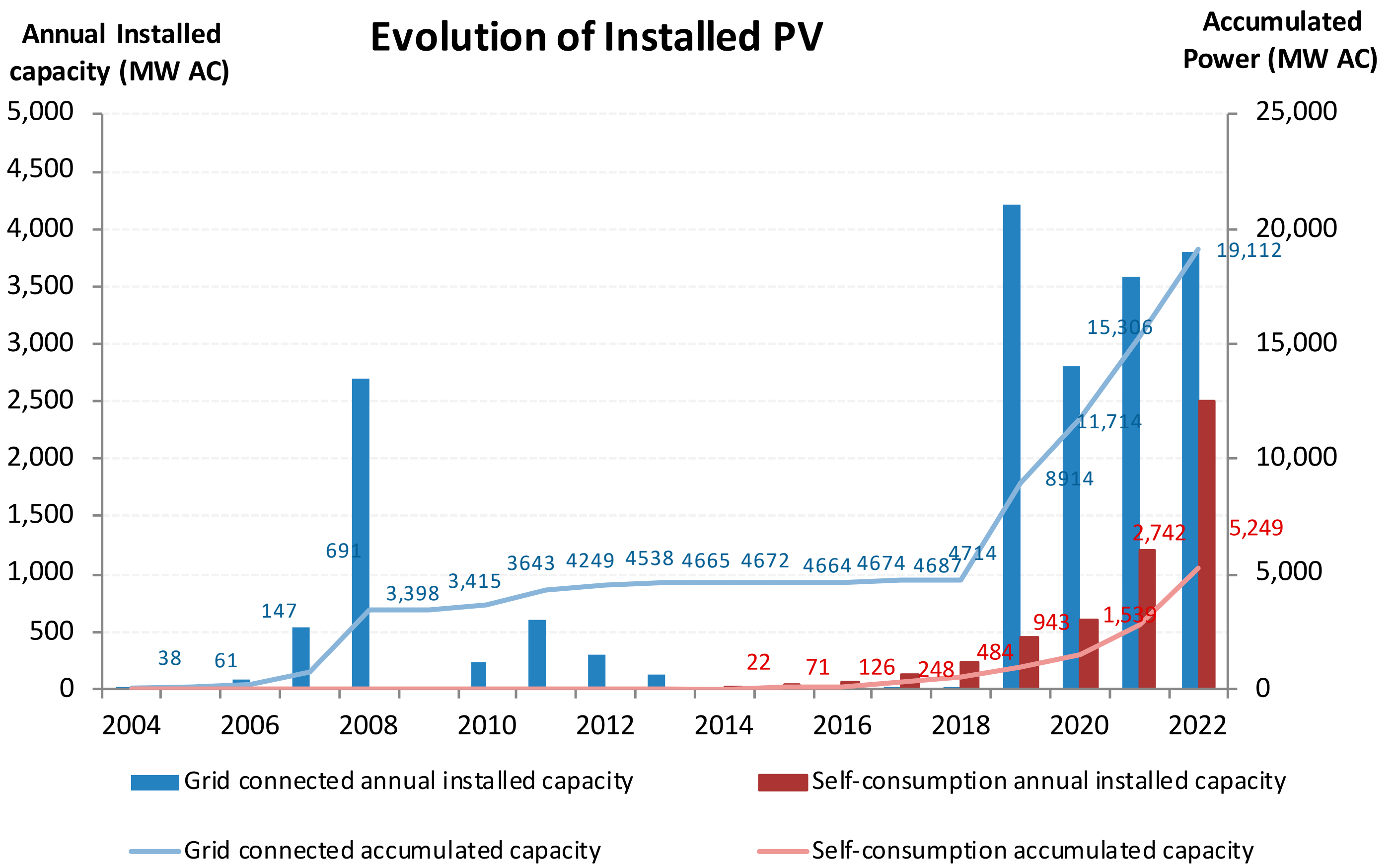

Fig.72 - Evolution of installed PV 2005 – 2022, including grid-connected and self-consumption
(Note: figure data is presented in AC but the DC MWp numbers can be found in the text)

INDUSTRY & MARKET DEVELOPMENT

Over the past decades, Spain's PV industry has been able to develop and maintain a leading position in the PV value chain, especially in the manufacture of structures, trackers, and power electronics. Besides, plenty of relevant players are to be found among the developers, engineering, distribution, construction and operation & maintenance companies. Several Spanish companies are active in the PV module manufacturing sector, including Atersa, Aurinka, Escelco, Ferrosolar (Silicio) and BSQ, together with the BIPV solution provider Onyx. Also worth mentioning in this respect is Mondragon Assembly, a leading company in the production of technological equipment for the manufacturing of PV modules.

In 2022, the European Solar Manufacturing Council (ESCM), together with the European Solar Initiative, launched an IPCEI (Important Project for Common European Interest) for reestablishing a viable PV manufacturing industry in Europe. In this regard, Spain stood as a candidate to lead and coordinate the PV-IPCEI process, which was later confirmed by IDAE. Following this statement several announcements of new and old players, such as Siliken, to address the vertical production of PV modules, have been released. It is expected in the year 2023 that an official decision from the Government will be announced.

During 2022 Spain continued with the impressive PV installation trend, adding a total of 8 266 MWp, in comparison to 5 638 MWp installed in 2021. This included 5 258 MWp of newly installed centralized PV plant capacity (in comparison to 4 195 MWp installed in 2021) and a remarkable increase in distributed self-consumption installed capacity, from 1 443 MWp in 2021 up to 3 008 MWp in 2022, as can be appreciated from Figure 72 (note the figure data is presented in AC and is provided by the operator Red Eléctrica de España, REE and from UNEF for self consumption). Altogether, this amounts to an accumulated large scale centralized installed capacity of 23 481 MWp and 6 298 MWp of small scale distributed self-consumption in Spain. The high electricity prices motivated by the invasion of Ukraine, as well as the boost provided by the funding mechanisms, led to self-consumption breaking a new record in Spain.

The share of the peninsular electricity demand covered by PV in 2022 represented an 11.6%, in comparison to an 8.2% share in 2021 (Figure 73). The year 2022 was noticeably marked by very high prices of the spot electricity, increasing to an average price of 168 EUR/MWh in comparison to the 111 EUR/MWh average price in 2021, which was already considered high at that time.

2022's fourth auction round, held on 22 November, for large-scale wind and solar energy projects, ended up empty for PV, while the Spanish government expected to allocate 1.8 GW of Solar in the 3.3 GW procurement exercise. Some of the reasons for this might be found in the low reserve price (45 EUR/MWh), the inflation and also the increase in interest rates.

Self-consumption surpasses the milestone of

6 GWp

of installed capacity.

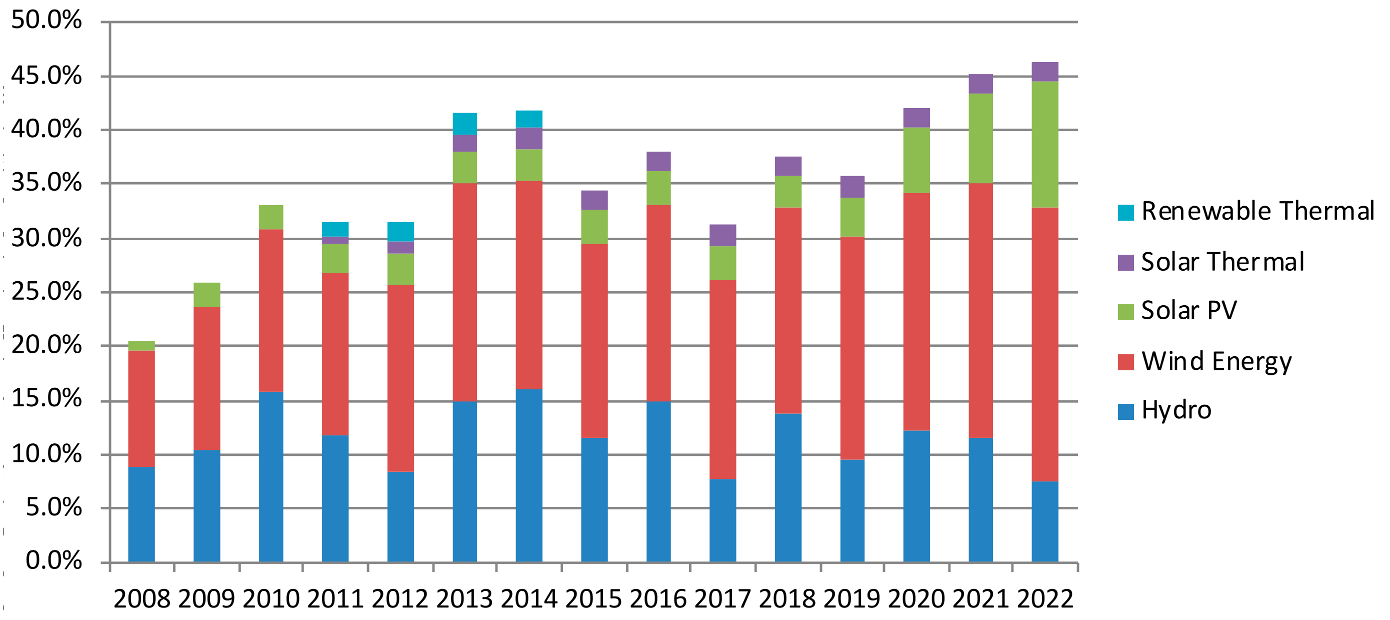

Fig.73 - Percentage of demand coverage from renewable energies in Spain

SWEDEN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Jonas Pettersson (Swedish Energy Agency)

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 reached 8 years in advanced. By the year 2021 the share was exceeding 60%, which is the highest amount in the European Union (see Eurostat Renewable energy statistics).

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 relatively to GDP.

The Moderate Party and Christian Democrats left 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 31 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. For private individuals the capital subsidy for PV installations is since 2021 replaced by a tax deduction for installation of green technology. Through this incentive a 20% deduction for labor and material costs associated with PV installations can be applied. The tax deduction has a cap of 50 000 SEK per year.

In 2015 a new tax credit scheme on small-scale renewable electricity production was introduced. 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. You cannot however receive credit for more kWh than the amount of electricity you consume from the grid. There is a cap on the tax credit of 18 000 SEK per year.

The Swedish Energy Agency has developed a proposal for a national strategy to promote solar electricity. The proposal came out in 2016 and suggests that a yearly 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 and is the largest funding source for research and innovation projects within PV.

In 2016 a research and innovation program ("El från solen") covering PV and solar thermal electricity (STE) focused on solar energy, was launched. The budget for the entire program (2016-2023) is about 280 MSEK. It includes both national and international research and innovation project. International projects are conducted in the EU collaborations SOLAR-ERA.NET.

In 2022 a new program called "Framtidens elsystem" was launched. This is a broad program covering topics ranging from electricity production and the electricity grid to questions related to electricity use. Initially the budget for the entire program period (2022–2027) is 552 MSEK.

In addition to the research funding distributed by the Swedish Energy Agency, the Swedish Research Council, the Swedish Governmental Agency for Innovation Systems, and the Swedish Foundation for Strategic Research also support PV related research. In total, about 110 MSEK was distributed from these four major actors to Swedish PV research in 2021.

The Swedish solar cell related research consists largely of fundamental research into new types of solar cells and photovoltaic materials. Several of the research groups in this category are at the forefront and are highly regarded internationally. Furthermore, there are some smaller groups that focus on PV systems and PV in the energy system-oriented research. Details on the active research groups are shown in the National Survey Report-of PV Power Applications in Sweden 2021.

→ Swedish Experts participate currently in 4 PVPS Tasks involving 8 separate entities as listed here

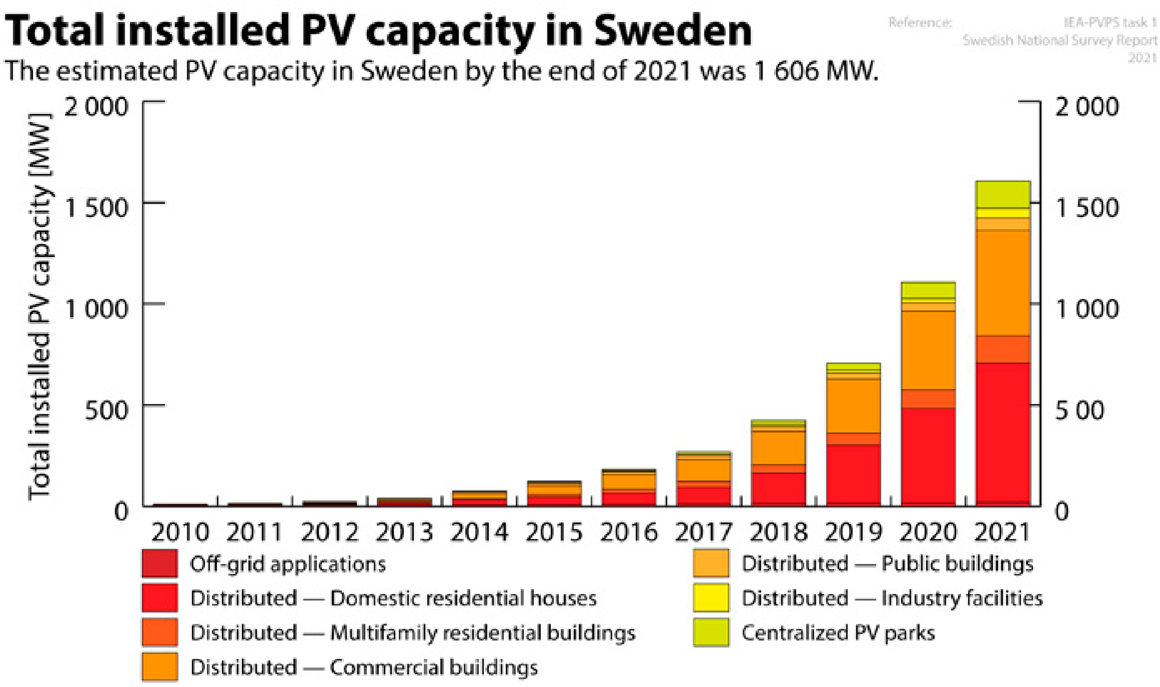

Fig.74 - Development of total installed PV capacity in Sweden between 2010 and 2021

INDUSTRY & MARKET DEVELOPMENT

The cumulative installed grid-connected PV power has grown from only 250 kW in 2005 to almost 1 600 MW in 2021. The annual market for PV in Sweden grew by 25% in 2021, as 500 MW was added. Despite this, PV still accounts for only about 0.7% of the total Swedish electricity production (166 TWh during 2021), 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, which corresponds to a potential ~24% of the total Swedish electricity consumption.

The Swedish PV market is dominated by decentralized PV systems and by customers who buy and own their PV systems. However, large and centralized PV parks are now becoming more common. The two to date largest PV parks are located in Sjöbo and Skurup, in southernmost Sweden, each having an estimated annual electricity production of 19 GWh.

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 2021.

By the end of 2021, there were two active module manufacturing companies in Sweden (although the production volumes were small), 19 companies in manufacturing of production machines or balance of systems components, and at least 11 R&D companies. An overview of the Swedish PV industry is found in the National Survey Report-of PV Power Applications in Sweden 2021.

The cumulative installed grid-connected PV power has grown from only 250 kW in 2005 to almost 1 600 MW in 2021. The annual market for PV in Sweden

grew by 25%

in 2021, as 500 MW was added.

SWITZERLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Stefan Oberholzer (Swiss Federal Office of Energy SFOE)

Fig.75 - Solar PV power from the Alps to increase winter production has become a much-discussed topic in Switzerland at the moment. In 2022, framework conditions were adjusted accordingly and a number of different larger projects are in the planning stage. The photo shows the alpine PV-test facility by ZHAW/ EKZ/SLF in Davos-Totalp (Photo: Jürg Rohrer, ZHAW)

NATIONAL PV POLICY PROGRAMME

The Swiss "Energy Strategy 2050" forms the basis to transform the Swiss energy system in a sustainable and climate-friendly way. It is 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. Following the rejection of a total revision of the CO_2 Act containing specific measures to achieve these targets in Spring 2021 by the Swiss electorate, the Swiss parliament in 2022 came up with a new compromise as a counter-proposal to a popular climate initiative (the so-called "Glacier Initiative") with the goal of net zero emissions in 2050. The Parliament approved this compromise, which adopts many elements of the initiative and for the first time defines a reduction path with legally binding interim targets. However, the final decision will be taken only in a popular referendum in mid-2023.

At the same time and within the context of the discus-sion on security of supply related to the pan-European situation, a "solar offensive" focused on large-scale (> 20 GWh production per year) alpine photovoltaic installations was launched by the parliament in autumn 2022 to contribute to security of supply in winter. The corresponding amendments to the Energy Act, valid until end of 2025, are intended to simplify the approval of such large-scale photovoltaic plants and define subsidies with a one-off compensation of up to 60% of the investment costs, to be determined on a case-by-case basis. These facilitations would apply, according to the law, up to a total annual production of 2 TWh throughout Switzerland with the goal of substantial winter contribution (details to be defined). The mandatory use of solar PV power for newly constructed buildings is a second pillar of the offensive.

In order to prevent a power shortage in winter, an auction was launched in 2022 for a hydropower reserve for the winter 2022/2023 and bids amounting to 400 GWh were accepted. In addition, gas-fired backup power plants are to help secure electricity supply in the coming winters (1 GW of additional reserve capacity by 2025, 250 MW already in 2023).

In the innovative race to increase the efficiency of solar cells with tandem concepts, an efficiency

larger than 30%

for perovskite-on-silicon-tandem has been demonstrated for the first time in summer 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. A large part of these funds is deployed competitively through various funding sources, with projects in the European context accounting for a large share. 113 projects are currently (3.2.2023) ongoing in various technology areas. Funding levels for ongoing projects are around CHF 11.3 million (39.1%) in the area of "solar cell technology", around CHF 4.9 million (16.8%) in the area of "modules and building-integrated photovoltaics (BIPV)", around CHF 7.0 million (24.1%) in the area of "systems technology" and around CHF 5.8 million (20%) in the area of "other (LCA, solar resources...)".

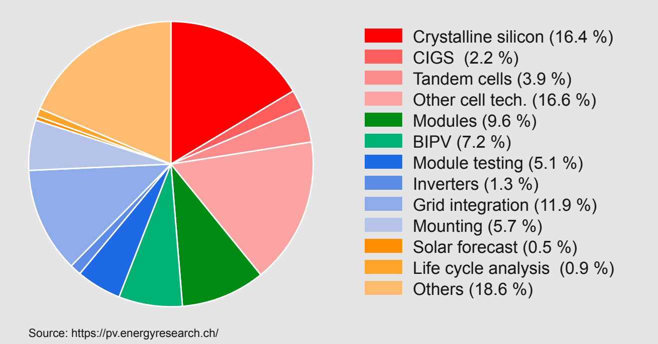

Fig.76 - Thematic breakdown of ongoing photovoltaic RTD projects in Switzerland weighted by the level of funding

The Photovoltaics RTD Programme of the Swiss Federal Office of Energy (SFOE) involves a broad range of stakeholders and is part of long-standing support for RTD in 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.

In the innovative race to increase the efficiency of solar cells with tandem concepts, an efficiency larger than 30% for perovskite-on-silicon-tandem has been demonstrated for the first time in summer 2022 in a joint effort from scientists at the Swiss Federal Institute of Technology Lausanne (EPFL) and Centre Suisse d'Electronique et de Microtechnique (CSEM). Although tremendous progress has been made in the stability of halide perovskites, further improvement is needed to render perovskite cells viable for application like in tandem solar cells. In a very detailed analysis, Swiss re-searchers reported a series of experimental observations that demonstrate the vulnerability of perovskite devices to boundary effects associated with ion migration.

In 2022, several specialised photovoltaic research conferences were held in Switzerland, such as the 10th SOPHIA Workshop PV-Module Reliability or the International Conference on Simulation of Organic Electronics and Photovoltaics, SimOEP 2022.

→ Swiss Experts participate currently in 7 PVPS Tasks involving 10 separate entities as listed here

INDUSTRY & MARKET DEVELOPMENT

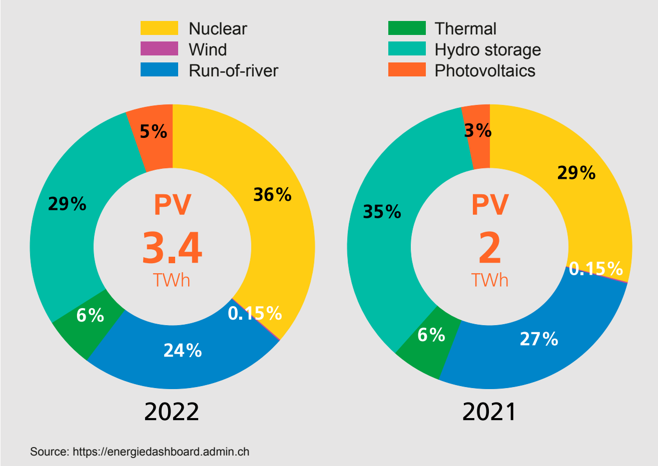

Fig.77 - Composition of Swiss electricity production in 2021 and 2022. The share of PV electricity has increased drastically. With a record turnover of 5.3 billion euros, Switzerland trades a lot of electricity with neighbouring countries. Especially in winter season, Switzerland relies on electricity imports from France and Germany

The expansion of renewable energy capacities picked up speed in 2022. For the first time, solar energy reached or exceeded the 1 GW mark in terms of new capacity added in one year. Around 30 000 new installations were added. Swiss electricity generation in 2022 was made up of 24% run-of-river power, 29% hydro storage power, 36% nuclear power, 6% thermal power plants (combined heat and power, thereof one half renewable) and 5% photovoltaic production. The fragmentation of the Swiss energy policy landscape remains high and, together with difficulties in the supply chains and the shortage of manpower, may pose a serious barrier to the accelerated deployment of PV. Discussions are ongoing for a nationwide tax harmonisation for PV installations as well as for a uniform minimum return feed-in tariff.

Industry players in Switzerland are grouped along a large portion of the photovoltaic value chain. The Swiss solar cell and module manufacturer Meyer Burger achieved the targeted production volumes in Germany last year. The company sees itself on track with further expansion steps and confirms the target of a production capacity of around 1.4 GW by the end of 2023. In parallel, research and innovation in Switzerland is being pursued. Other module manufacturers such as 3S Swiss Solar Solutions or Megasol are producing especially for the Swiss market.

THAILAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

(Department of Alternative Energy Development and Efficiency, Ministry of Energy of Thailand); (King Mongkut's University of Technology Thonburi)

NATIONAL PV POLICY PROGRAMME

In order to comply with carbon neutrality target by 2050 pledged in the COP26 by the Prime Minister, Thailand was undergoing a major revision of our main energy plans. The so-called National Energy Plan 2022 was introduced in response to the country's energy transition period. The target of new PV installation is likely to increase from the previous plan that had set 9 290 MW solar installation and 2 725 MW from floating target by 2037. The final target of the National Energy Plan 2022 is yet to complete but it should include at least 50% renewable electricity including solar power plants (compared with 41% previous target).

In 2022, an additional 10 year action plan (2021-2030) revision 2 was implemented to the current Power Development Plan 2018 (Rev.1) that will set the target of PV installation capacity to 7 087 MW by 2030 (90 MW solar rooftop for residential project, 997 MW solar floating, 1 GW solar ground-mounted with battery energy storage system, and 5 GW solar ground-mounted).

In 2020, Thailand's total PV installed capacity was 3 939.8 MW. In line with the global world energy transition, the PV market in Thailand has also shifted to an increasing decentralization trend.

In 2022, 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 ($0.064 USD/kWh) for selling excess electricity back to the grid. The target of 2022 project was set to be 10 MW (5 MW metropolitan area + 5 MW provincial area). In 2021, there was a total of 2.27 MW contracted capacity installed under this scheme.

Moreover, in 2022, the concept of solar rooftop projects for government hospitals, academic institutes, and agriculture was implemented. The FiT of this program was 1 THB/kWh ($0.029 USD/kWh). The initial target of this program is 10 MW in total. In 2021, there were total 1.87 MW of systems with contract capacity under this scheme.

RESEARCH, DEVELOPMENT & DEMONSTRATION

There are small parts of area in Thailand that are still unelectrified. In order to reach this 0.03% unelectrified portion due to some legal complications and very remote locations, a number of projects had been implemented (from both public and private attempts) to solve the problem. In 2022, Department of Alternative Energy Development and Efficiency had conducted the support program to provide renewable energy systems (such as solar mini-grid system, solar water pump, solar dome, biogas system, and biomass stoves) to the Royal Initiative Projects, which mostly are located in the remote area e.g. high mountain and country border.

Since 2021, the Office of Energy Regulatory Commission has signed an MOU with the Ministry of Public Health to conduct the targeted power production promotion project from renewable energy (Public Health Organization) using the ~6 MUSD (207 MTHB) Power Development Fund in 2021 to support the installation of solar PV in 69 hospitals nationwide (capacity <100 kW per hospital, max 87 500 USD, 3 MTHB per hospital). In 2022, the continual of the project supported approximately a total of 9.7 MUSD (330 MTHB). The total installation capacity under this program was 26.75 MW.

Some demonstrations and research projects are as follows:

- King Mongkut's University of Technology Thonburi conducted a demonstration project on sustainable renewable electricity for the national park and wildlife reserve of Thailand at Tarutao National Park in the southern island region of Thailand. The project exploited hybrid solar PV, wind energy, and BESS that can reduce an equivalent of 84 000 kg CO_2 per year.
- Global Power Synergy Public Company Limited (GPSC) and the National Science and Technology Development Agency (NSTDA) demonstrated the application of nano-coating technology on PV panels at Sakaeo College of Agricultural and Technology to enhance solar panel efficiency, improve dust resistance, prolong durability, and reduce maintenance costs.
- NSTDA and the PV Panel Standard Academic Committee developed the draft Preparation and Inspection Standard of Second Life PV. The process has undergone public hearing in September 2022 and the dissemination of the study is ongoing.

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

Thailand has set a target of PV installation capacity at

over 7 GW

by 2030 including 5 GW ground-mounted, 1 GW ground-mounted with battery storage, 1 GW floating plus

90 MW

residential rooftops.

INDUSTRY & MARKET DEVELOPMENT

The institute of Industrial Energy (The Federation of Thai Industries), in cooperation with the Metropolitan Energy Authority and Provincial Energy Authority, has developed a demonstration of renewable projects and a carbon credit scheme. The objective was to develop a database that can be further exploited for carbon trading from renewable energy sources. It was expected to be integrated with the public Thailand Greenhouse Gas Management Organization (TGO) database platform under the support of ERC Sandbox phase 2 program. Additionally, in order to support the achievement of the program, the Office of National Higher Education Science Research and Innovation Policy Council (NXPO) has participated in capacity building to provide support for carbon credit and carbon verification processes.

TÜRKIYE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Dr. Ömer Faruk (TUNÇBİLEK); Dr. İbrahim ATEŞ (Clean Energy Research Institute, TENMAK)

NATIONAL PV POLICY PROGRAMME

In Türkiye, renewable energy related activities are carried out in accordance with the renewable energy resources legislation. The two main sources of this legislation are the Electricity Market Law and the Law on the Use of Renewable Energy Resources for Electricity Generation. Regulations, Presidential Decisions, Decisions of the Energy Market Regulatory Authority, Communiqués, Procedures and Principles, and other legislation including regulations on the electricity market, prepared in the light of the aforementioned two laws, constitute the legal infrastructure regulating the electricity and renewable energy market [1].

According to the Strategic Plan of the Ministry of Energy and Natural Resources (ETKB) covering the years 2019-2023, it is aimed to increase the ratio of domestic and renewable electricity sources from 59% to 65% of the total installed power. As part of these efforts, it is aimed to increase the solar installed capacity to 10 GW by 2023 in order to strengthen the market position of renewable energy sources. In line with this purpose, according to the December 2022 Installed Power Report published by Turkish Electricity Transmission Corporation (TEIAS), the installed power of solar power plants in Türkiye has reached 9.43 GW as of the end of December 2022. In 2022, the installed solar capacity increased by 1.61 GW compared to the previous year. According to the National Energy Action Plan published by ETKB in the last days of December 2022, it is aimed to install 52.9 GW of solar power by 2035.

In order for ETKB to achieve these goals, three different investment models have been created in the field of renewable energy in Türkiye. These models are Licensed Generation, Unlicensed Generation and Renewable Energy Resource Area (YEKA). With the YEKA model, on the one hand, the cost of electricity purchased from renewable energy production facilities will be reduced, on the other hand, the development of domestic production in renewable energy technologies and the increase in the capacity of qualified human resources will be ensured. To date, YEKA competitions have been held only for the establishment and operation of Wind (RES) and Photovoltaic Solar (GES) power plants. Efforts are underway to apply YEKAs, which have successfully progressed in the fields of solar and wind, to other renewable energy sources in the coming period [1].

The Renewable Energy Resources Support Mechanism (YEKDEM) was launched by the government in 2011 in order to make investments more attractive within the scope of Turkish domestic and national energy policy. With this mechanism, the State guarantees the investor to receive the energy produced from renewable energy sources. The Presidential Decison, which reveals the details of the current support mechanism for electricity generation facilities based on renewable energy sources, was published in the Official Gazette dated January 30, 2021.

The Renewable Energy Source Guarantee Certificate (YEK-G) Regulation, which was established for consumers who want their electricity consumption to be provided completely from renewable energy sources, was published in the Official Gazette dated 14 November 2020. This regulation, which came into force in June 2021, covers the provisions regarding the participation of the electricity supply companies to the renewable energy resource guarantee system, which will certify that the electricity to be supplied to the consumers is entirely renewable energy source, and the functioning of the system to be created.

RESEARCH, DEVELOPMENT & DEMONSTRATION

R&D activities for the advancement of photovoltaic technologies in Türkiye are carried out by universities, public and private sectors. Although the investments made by the private sector in R&D activities are increasing day by day, they are still not at the desired level.

Established in 2020 under the Ministry of Energy and Natural Resources, the Turkish Energy, Nuclear and Mineral Research Agency (TENMAK) conducts, supports and coordinates scientific research in order to increase and sustain Türkiye's competitiveness in energy-related issues. The Clean Energy Research Institute, one of TENMAK's five institutes, was founded in 2022 and is still in the process of establishing infrastructure for solar energy research, which is within the scope of work. With the TENMAK R&D Incentives Hydrogen Technologies and Fuel Cell Call, published in November 2022, it is aimed to develop commercializable technologies by bringing together public, university and industrial institutions in the fields of hydrogen and fuel cell technologies. Among the topics to be evaluated within the scope of the call is the green hydrogen topic, where hydrogen is produced through electrolysis using renewable energy sources.

The development of photovoltaic cells, panels and systems is among the 2022-2023 Priority R&D and Innovation Topics under the title of Clean, Accessible and Safe Energy Supply which is published by the Scientific and Technological Research Council of Türkiye (TUBITAK). In this context, both fundamental and applied research as well as technology development and innovation projects will be supported. Priority topics include light, flexible and cost effective cells and panels with high efficiency and life span that can be integrated synergistically and ergonomically with applications such as buildings, vehicles, agriculture and water surface development. The following topics in crystalline silicon module studies will also be supported: the development of production technologies of modules with 72 whole or 144 half cells in 2025, 78 whole or 156 half mono- or bifacial cells in 2030, module design to achieve an efficiency from cell to module of 99% in 2025 and 100% in 2030, glass and antireflective development studies; power targets per square meter of module designs to be 2010-2015 W/m^2 in 2025 and 2020-2025 W/m^2 in 2030.

Türkiye Photovoltaic Technologies Platform (TFTP) was established under the leadership of Middle East Technical University - The Solar Energy Research and Application Center. The consortium consists of 9 different institutions and companies. In the near future, it is aimed to establish a technological infrastructure that will increase the domestic content to 80% in solar power plant technologies, which are expected to play an important role in Türkiye. The mission of TFTP is to increase the technology readiness level of high-efficiency Si-based solar cell types, advanced materials used in photovoltaic systems, photovoltaic panel technologies and photovoltaic power systems technologies and transfer them to the industry in Türkiye.

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

INDUSTRY & MARKET DEVELOPMENT

The interest in renewable energy plants is increasing due to reasons such as environmental concerns that may occur after the use of fossil resources, the desire to meet the increasing energy needs and ensuring supply security. Solar energy production is supported by the public and NGOs with various grants and incentives. The most well-known of these supports are Agriculture and Rural Development Support Institution, Small and Medium Enterprises Development and Support Administration, Rural Development Investments Support Program, Türkiye Technology Development Foundation, Türkiye Sustainable Energy Financing Program.

There are currently more than 30 photovoltaic module manufacturers in Türkiye and these manufacturers mainly manufacture panels in mono, perc and poly technologies. Activities for domestic production have also created a sub-industry in the renewable energy sector, and eva (polyethylene film), glass, junction boxes, ribbon (transmission wire) and frames have become domestically fabricated. However, these components, which are used in domestic module production due to cost, quality and technical suitability, can be imported, which reduces the domesticity rate of the products subject to installation in the market and creates an obstacle to the development of domestic fabrication. Currently, there are four cell manufacturer companies in the solar energy market; In addition, there are different companies that plan to manufacture cells [2].

There are also various initiatives on domestic inverter fabrication. Currently, it is known that approximately 73% locality rate has been reached in inverters below 50 kW. In addition, the construction, which is the production component, is also manufactured locally and is exported. In Türkiye, due to the advanced steel and aluminum sectors and high market volume, domestic construction production has been an advantage for investments. More and more successful and widespread applications are being made in the field of construction at the international level [2].

According to the data of the Ministry of Energy and Natural Resources, as of 2022, Türkiye has created a capacity of approximately 8 000 MW in solar module production [3]. It is predicted that Türkiye will increase its production capacity to 10 000 MW with the investments to be made in 2023. With the President's Decision published in the Official Gazette dated October 15, 2022, project-based government support was given to the photovoltaic solar panel production facility investment to be made in İzmir. At the end of the 4-year investment period, it is aimed to produce photovoltaic solar panels with a capacity of 2 048 MW per year. Thus, starting from silicon ingot production, a significant capacity will be reached in the production of wafers, cells and photovoltaic solar panels in the country.

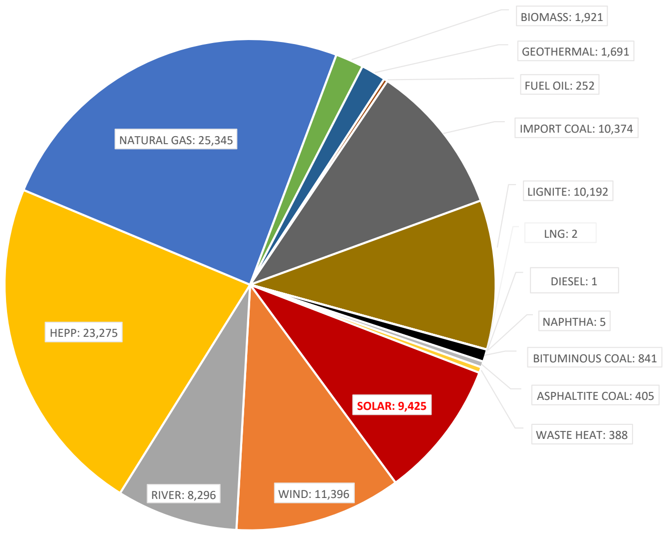

Fig.78 - Installed Capacity (MW) in Türkiye as of the end of December 2022. Source: TEİAŞ

Based on the National Energy Action Plan, the total installed solar power is targeted to be

52.9 GW

in total electricity generation in 2035.

THE UNITED STATES OF AMERICA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Christopher Anderson (Solar Energy Technologies Office, U.S. Department of Energy); David Feldman (National Renewable Energy Laboratory)

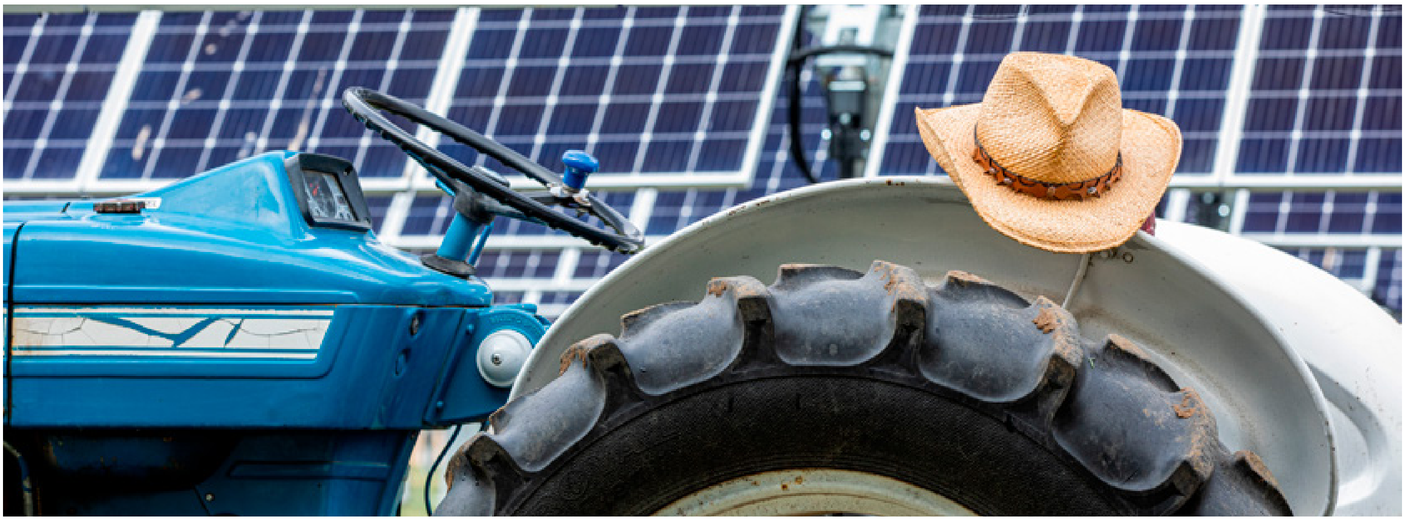

Fig.79 - April 24, 2021 - A tractor among the solar array added to the theme during the farming ground-breaking event at Jack's Solar Garden in Longmont, Colo. (Photo by Werner Slocum / NREL)

NATIONAL PV POLICY PROGRAMME

In the United States, photovoltaic market development is supported by both national and state-level financial incentives, though state and local policies vary in form and magnitude. There is now a national-level deployment mandate, President Biden's Executive Order 14057, signed in late 2021, sets an Executive Branch goal of a carbon pollution free electricity sector by 2035 and net zero emissions economy-wide by 2050. Furthermore, as of November 2022, 29 states established renewable portfolio standards (RPS), which require or encourage electricity suppliers to provide their customers with a stated minimum share of electricity from eligible renewable resources (11 of which have a mandate of 50% renewable energy or greater). Six of those 29 states have also passed clean energy standards (CES), which are similar to an RPS, but allow a broader range of electricity generation (e.g., nuclear) resources to qualify. 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. At the end of Q4 2022, the U.S. is expected to have reached 139.1 GWdc of cumulative installed capacity, an increase from 120.4 GWdc in 2021, and 96.3 GWdc in 2020 [1]. This deployment translated to an AC capacity of 105.7 GWac through October 2022, increasing from 88.5 GWac in 2021, and 73.9 GWac in 2020 [2].

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 utilities. Historically, national incentives had been provided primarily through the U.S. tax code, in the form of an 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%. Credits were set to drop again to 22% for all projects starting construction in 2023 before expiring for residential markets and decreasing to 10% for commercial and utility markets starting construction in 2024 or placed in service after 2025. Renewable energy credits were altered considerably by the passage of the Inflation Reduction Act (IRA) in August 2022, which made the single largest investment in climate and energy in American history. Most of IRA's record $369B investment into renewables will be in the form of tax credits for deployment and manufacturing. It extended the ITC at 30% through at least 2032, after which is steps down to 26% in 2033, and 22% in 2034, before expiring in 2035. For certain large projects, to receive the full credit, the project developer must satisfy certain prevailing wage and apprenticeship requirements. Bonus credits, which add an additional 10% each, can be received for meeting domestic content requirements, or siting in certain types of disadvantaged communities. Tax credits are also provided to PV manufacturers producing modules, cells, wafers, polysilicon, inverters, and racking material, as well as batteries. Tax exempt entities, such as non-profits and local governments, may be eligible to benefit under IRA's direct payment option.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The U.S. Department of Energy (DOE) is one of the primary U.S. agencies that supports research, development, and demonstration (R,D&D) of solar energy technologies in the U.S. In 2017, DOE announced that it had met its benchmark utility-scale 2020 cost goal of 6 USD cents per kilowatt-hour and set a new target of 3 USD cents per kilowatt-hour by 2030 However, to address 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, DOE accelerated its goal to 2 USD cents per kilowatt-hour by 2030.

By funding a portfolio of complementary R,D&D concepts, DOE promotes transformation in the way the U.S. generates, stores, and utilizes solar energy. These R,D&D activities fall into five broad categories:

1. Photovoltaic 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 equitable 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 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 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 13 separate entities as listed here

The passage of the Inflation Reduction Act (IRA) in August 2022… made the single

largest investment

in climate and energy in American history.

INDUSTRY & MARKET DEVELOPMENT

After several record years of installation growth, the first three quarters of 2022 saw an overall decrease in PV installation growth in the U.S., falling from 15.9 GWdc in 2021 to an estimated 13.3 GWdc by the end of 2022 [1]. The decline in 2022 was driven by supply chain constraints and tariff uncertainty in the utility sector, leading to a decline in installer confidence. The residential sector is likely to have had a record year, driven by costlier electricity and an increase in both frequency and severity of power outages.

Tariffs placed on imported cells and modules in January 2018 under section 201 of the 1974 Trade Act (often referred to as "Section 201 tariffs") had been set to expire in 2022. In February 2022, President Biden extended these tariffs through 2026 at 15%, with a bifacial exclusion and a 5 GWdc cell exclusion. A separate tariff, the Uyghur Forced Labor Prevention Act (UFLPA), signed into law in 2021, went into effect in June 2022. UFLPA requires manufacturers in Xinjiang province, which was one of the main sources of metallurgical grade silicon and polysilicon for the Chinese PV industry, to prove to U.S. customs officials that their products are not made using forced labor. This led to a significant drop in module imports from China. In March 2022, the U.S. Department of Commerce (DoC) announced a formal investigation into the circumvention of anti-dumping and countervailing duties (AD/CVD) by companies in Cambodia, Vietnam, Thailand, and Malaysia, which together account for 80% of crystalline-silicon module imports into the U.S. Since AD/CVD tariffs may be applied retroactively, this caused significant uncertainty in the U.S. solar supply chain. In December 2022, DoC issued a preliminary determination, affirming the complaint against several Chinese companies (though finding that others had not circumvented the duties). However, the President issued an executive order in June 2022 putting a hold on AD/CVD tariffs related to circumvention for two years, regardless of the outcome of the investigation. In the first half of 2022, 11% of imported modules (1.2 GWdc) reported a tariff.

In November, California's Public Utility Commission issued a revised Proposed Decision for their next generation of net metering tariffs ("NEM 3.0"). The new proposal eliminated the previously proposed grid participation charge, but it sets solar export rates for systems installed and approved for interconnection after April 15, 2023, at levels much lower than under the current system, which should favor behind-the-meter storage. Overall, this shift is expected to reduce California's residential PV market by 39% in 2024 [1].

The United States installed approximately 11.1 GWh of energy storage onto the electric grid in the first nine months of 2022, an increase of 88% y/y [3].

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

OBJECTIVES

Task 1 is dedicated to Strategic PV Analysis & Outreach, carrying the double role of expertise (on PV markets, industry, and policies) and 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 shares this role with the Executive Secretary, compiling the agreed-on PV information in the PVPS countries.
- Task 1 contributes to the cooperation with other organizations and stakeholders.

SUB-TASK STRUCTURE

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 follows PV development and its evolution, analyzing drivers, enablers and supporting policies. It aims at advising PVPS stakeholders onimportant developments in the programme countries and globally, focusing on facts, accurate numbers and verifiable information in order to give the best possible image of the diversity of PV support schemes in regulatory environments around the globe.

Subtask 1.2 Think Tank activities

Serving as the PVPS programme's Think Tank, Task 1 provides the Executive Committee and specific PVPS tasks with ideas and suggestions on how to improve the research content of the PVPS programme; this is where upcoming focus subjects are discussed and confirmed.

Subtask 1.3 Communication activities

In this activity, Task 1 assists the Executive Secretary in communicating about the main findings of its experts through the most adequate communication channels, whilst organizing Task 1's own meetings and communications

Subtask 1.4 Cooperation activities

Cooperation with external stakeholders remains a cornerstone of the PVPS programme, providing pathways to gather adequate information and to disseminate the results of research within Task 1. 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.

PUBLICATIONS (NON-PVPS)

The first of PV Magazines new monthly columns from PVPS experts was provided by Task 1, with a focus on the social acceptability of photovoltaics. This article summarized the main impacts of past decisions and new issues discussed with the task members over the past year, titled "Roadmap to increase solar acceptance" and published in November 2022.

TASK 12

OBJECTIVES

Within the framework of PVPS, the goal of Task 12 is to foster international collaboration and knowledge creation in PV sustainability, as a crucial element 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, circular economy pathways, 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 can help to further improve the uptake of photovoltaic energy systems, enabling the global energy transition. On the supply-side, environment, circular economy and social 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.
2. Investigate circularity 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.

SUB-TASK STRUCTURE

SUBTASK 1: PV Circularity

The main objectives within this subtask are:

- Assist the development of PV circularity infrastructure by examining and evaluating other industries (e.g., electronics, liquid crystal displays).
- Enhance the interaction among industry players so they share information and resources for PV circularity.
- Show the technical and cost feasibility of circular activities.
- Identify common tasks where knowledge 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, the environmental sustainability of PV systems.
- Document trends of the PV environmental profile by certain indicators (e.g., EPBT, GHG emissions, waste reduction, recycling, etc.).
- Maintain global guidelines for PV LCA and Net Energy Analysis, resource utilization, etc.

SUBTASK 3: Other PV Sustainability Topics

The main objectives within this subtask are:

- Develop risk factors and compare PV with other energy technologies.
- Assess the environmental profile of new PV applications like PV colocation and floating PV.
- Carry out studies on the social impact of PV systems and its supply chain.
- Analyze PV sustainability and associated standards and their impacts.

TASK 13

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 modules and 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 modules and 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 reliability and performance. 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 several impactful ways including: technical reports, workshops, webinars, and scientific papers at conferences and in journals.

SUB-TASK STRUCTURE

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

Subtask 1: Reliability of Novel PV Materials, Components and Modules

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 module 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 technologies and PV plus battery systems 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 and Durability of PV Applications

Overall Subtask 2 deals with the performance and durability of emerging PV applications as well as with supporting technologies that enable and improve PV applications. This Subtask focuses on the following emerging applications; the integration of PV modules and mounting structures on water surfaces "Floating PV" (ST2.1) and the integration of PV technology into agriculture "Agrivoltaics" (ST2.2). Performance and durability of improved bifacial PV tracking systems (ST2.3) are investigated and best practices developed.

Furthermore, activities on digital integration and digital twinning (ST2.4) as well as on module level power electronics (ST2.5) complete this Subtask, providing best practices and guidelines.

Subtask 3: Techno-Economic Key Performance Indicators

This subtask deals with the definition of techno-economic Key Performance Indicators (KPIs) and how to map them in an effective way. In particular the focus is on the impact in terms of performance due to severe weather events (ST3.1) and climate stressors (ST3.2) in order to analyse case studies, provide examples of best practices and define guidelines in terms of best technology combination for specific climatic conditions. A dedicated activity (ST3.3) will instead deal with the impacts of decisions along the value chain of PV to define best practice flowcharts for PV projects and contribute towards the de-risking leveraging also on the results of the previous Task 13 periods. The bottom-up information from ST3.1, ST3.2, and ST3.3 will stream into ST3.4 which is focused on the mapping of the techno-economic KPIs and thus in the visualization of performance related data to provide benchmarks for the PV sector.

PUBLICATIONS (NON-PVPS)

1. Werner Herrmann, Gabriele C. Eder, Boris Farnung, Gabi Friesen, Marc Koentges, Bernhard Kubicek, Oliver Kunz, Haitao Liu, David Parlevliet, Ioannis Tsanakas, Jan Vedde: REVIEW OF ON-SITE INSPECTION TECHNIQUES FOR THE QUALIFICATION OF PV POWER PLANTS, 8th World Conference on PV Energy Conversion (WCPEC-8), Milan, Italy, 29 September 2022 (Oral and Paper).

2. Sascha Lindig, Atse Louwen, Lukas Koester, Alexander Astigarraga, David Moser: Detailed Performance & Degradation Assessment Technologies with more than 10 Years Lifetime, 8th World Conference on PV Energy Conversion (WCPEC-8), Milan, Italy, 29 September 2022 (Oral and Paper).

3. Magnus Herz, Gabi Friesen, Ulrike Jahn, Marc Koentges, Sascha Lindig, David Moser: IDENTIFY, ANALYSE, MITIGATE – QUANTIFICATION OF TECHNICAL RISKS IN PV POWER SYSTEMS, Progress in Photovoltaics: Research and Applications, PIP3633, October 2022.

TASK 14

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.

SUB-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", 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", 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" 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.

PUBLICATIONS (NON-PVPS)

1. S. Chen, F. Ebe, J. Morris, H. Lorenz, C. Kondzialka, and G. Heilscher, 'Implementation and Test of an IEC 61850-Based Automation Framework for the Automated Data Model Integration of DES (ADMID) into DSO SCADA', Energies, vol. 15, no. 4, Art. no. 4, Jan. 2022, https://doi.org/10.3390/en15041552

2. C. Kondzialka et al., 'Technical solutions and business prospects for the participation of small PV systems in the balancing energy market', in 2022 18th International Conference on the European Energy Market (EEM), Sep. 2022, pp. 1–6. https://doi.org/10.1109/EEM54602.2022.9921005

3. C. Kondzialka et al., 'Field testing and demonstration of a smart grid ready charging park', in CIRED Porto Workshop 2022: E-mobility and power distribution systems, Jun. 2022, vol. 2022, pp. 339–343. https://doi.org/10.1049/icp.2022.0723

4. A. Jäger-Waldau, G. Kakoulaki, N. Taylor, and S. Szábo, 'The Role of the European Green Deal for the Photovoltaic Market Growth in the European Union', in 2022 IEEE 49th Photovoltaics Specialists Conference (PVSC), Jun. 2022, pp. 0508–0511. https://doi.org/10.1109/PVSC48317.2022.9938529

Further contributions from Task14 Experts:

- May 2022: Task 14 Utility Workshop (Fachtagung Netzanschluss) hosted by Berner Fachhochschule BFH in Burgdorf, Switzerland
  - Presentation by Christof Bucher(BFH, Switzerland), Standardization Grid connection of PV inverters: Do they behave as they should?
  - Presentation by G. Heilscher (THU, Germany), Communication systems for the grid connection of decentralized generators and storage facilities
  - Presentation by Denis Mende (Fraunhofer IEE, Germany), PV systems and battery storage as service providers for distribution and transmission grids
- October 2022; IRED Conference 2022, Adelaide, Australia
  - Poster contribution by Gerd Heilscher (THU, Germany), 'Integrating PV systems into Smart Grids',
- October 2022Solar Integration Workshop, Den Haag
  - Presentation by Shuo Chen (THU, Germany) Automated data integration of residential and commercial PV systems into DSO SCADA utilising IEC 61850 compliant comprehensive data model
  - Towards Standardised Testing Procedures for Inertia Provision of Grid Forming Inverters
- November 2022 IEEE ISGT Asia, Singapore
  - Keynote speech by Thomas Reindl (SERIS, Singapore), 'The impact of resource forecasting on the integration of variable renewable energies into electric power grids',

TASK 15

OBJECTIVES

Building-Integrated PV (BIPV) can help to reduce CO_2 emissions in the building sector, which is responsible for nearly 40% of total direct and indirect CO_2 emissions. On the path towards zero-energy buildings, BIPV can help to meet the remaining energy demand in a way that respects architectural, aesthetic, environmental, economic, and technical requirements. BIPV elements as electricity-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 within both the PV and the building markets. Bringing the PV industry and the construction sector together requires action by several stakeholders. 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 aspects.

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 and different applications, as well as scale difference from single-family dwellings to large-scale BIPV applications in offices and utility buildings.

In its current workplan (2020-2023), Task 15 addresses barriers to 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.

SUB-TASK STRUCTURE

Task 15 is divided into 5 main subtasks

A: Technical Innovation System (TIS) Analysis for BIPV

Subtask A identifies strengths and weaknesses of the BIPV innovation ecosystem and value chain, using the Technological Innovation System framework. It specifically examines the BIPV market development, and suggests policy and strategic measures for governments, individual firms and industry collectively.

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 energy-relevant, economic, ecological, and aesthetic aspects has been developed. This methodology is applied to selected BIPV plants to allow a structured assessment of the multifunctional performance of BIPV systems.

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).

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. Requirements are collected for digital product data models and information modeling/ management strategies, aiming for an effective digital process to improve interoperability along the value chain.

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.

PUBLICATIONS (NON-PVPS)

- N. Martín-Chivelet, K. Kapsis, H. R. Wilson, V. Delisle, R. Yang, L. Olivieri, J. Polo, J. Eisenlohr, B. Roy, L. Maturi, G. Otnes, M. Dallapiccola, W.M. P. Upalakshi Wijeratne. Building-Integrated Photovoltaic (BIPV) products and systems: A review of energy-related behavior. Energy & Buildings 262 (2022) 111998.
- Martín-Chivelet, Nuria, Jesús Polo, Carlos Sanz-Saiz, Lucy Tamara Núñez Benítez, Miguel Alonso-Abella, and José Cuenca. 2022. "Assessment of PV Module Temperature Models for Building-Integrated Photovoltaics (BIPV)" Sustainability 14, no. 3: 1500.
- H. Zhou, J. Peng, H. R. Wilson, M. Wang, J. Jonsson, T. Ma, B. Wu, B. Wu, G. Fu. "Investigation of decoupling of thermal and electrical performance of semi-transparent photovoltaic windows based on the external quantum efficiency". Energy & Buildings 277 (2022) 112539.
- B. Roy, A. Gagné, V. Delisle. "Thermal assessment of the Varennes Library building-integrated photovoltaic rooftop system". In COBEE Proc. 2022
- S. Jazouli, H. R. Wilson, J. Eisenlohr, K. Kapsis. "Building-Integrated Photovoltaic Performance Modelling: Evaluation of the System Advisor Model (SAM) based on Experimental Data from a Grid-Connected Rainscreen System". In COBEE Proc. 2022
- Bonomo, P, Parolini, F, Corti, P, Frontini, F, Bellenda, G, Caccivio, M. Impact resistance of BIPV systems: new testing procedure for performance assessment of multifunctional products. Energy Sci. Eng. 2023; 11: 22- 47. doi:10.1002/ese3.1364
- Polo, J., Martín-Chivelet, N., Sanz-Saiz, C., 2022. BIPV Modeling with Artificial Neural Networks: Towards a BIPV Digital Twin. Energies 15, 4173. doi:10.3390/en15114173

TASK 16

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.

SUB-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.

The following list includes the slightly updated plan for the 3rd phase from mid 2023 till 2026.

Subtask 1: Methodologies for resource data generation:

- Radiation measurements
- Radiation models
- Benchmarking solar datasets
- Additional meteorological parameters

Subtask 2: Enhancement of data & value-added products:

- Data quality & format
- Climate change and long-term variability
- Products for the end-users
- Products for upcoming, integrated technologies

Subtask 3: Solar forecasting:

- PV power forecasting at different spatio-temporal scales
- Probabilistic solar forecasting
- Cloud image based nowcasting (0-6 hours)
- Firm power generation

Subtask 4: Dissemination and Outreach:

- Webinars, workshops, publications and training
- Update of the solar resource handbook
- Practical guide to solar data processing and modelling
- Update basic knowledge for a broad public (e.g. Wikipedia)

PUBLICATIONS (NON-PVPS)

- Blanc, Philippe et al. 2022. Data sharing of in-situ measurements following GEO and FAIR principles in the solar energy sector: An end-to-end implementation example in the solar energy domain ranging from data encoding up to search and discovery. 2022. ffhal-03811628f, https://hal.archives-ouvertes.fr/hal-03811628/document
- Lorenz, Elke. et al. 2022. High resolution measurement network of global horizontal and tilted solar irradiance in southern Germany with a new quality control scheme. Sol. Energy 231, 593–606 (2022).
- Pierro, Marco et al. 2022: Progress in regional PV power forecasting: A sensitivity analysis on the Italian case study, Renewable Energy, Volume 189, 2022, Pages 983-996, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2022.03.041.
- Pierro, Marco et al., 2022: Ancillary Services via Flexible Photovoltaic/Wind Systems and "Implicit" Storage to Balance Demand and Supply. Sol. RRL 2022, 2200704. DOI: 10.1002/solr.202200704
- Remund, Jan, et al. 2022. Firm PV power generation for Switzerland. SFOE report. https://www.aramis.admin.ch/Default?DocumentID=68985
- Visser, L. R. et al. 2022. Regulation strategies for mitigating voltage fluctuations induced by photovoltaic solar systems in an urban low voltage grid. Int. J. Electr. Power Energy Syst. 137, 107695 (2022).

TASK 17

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-powered 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, 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.

SUB-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.

PUBLICATIONS (NON-PVPS)

Journals

1. B. Robisson, S. Guillemin, L. Marchadier, G. Vignal, A. Mignonac, "Solar Charging of Electric Vehicles: Experimental Results", Applied Sciences, vol. 12, no.9, pp 4523, 2022, https://doi.org/10.3390/app12094523
2. S. Cheikh-Mohamad, M. Sechilariu, F. Locment, "Real-time power management including optimization problem for PV-powered charging station", Applied Sciences, vol. 12, no.9, pp 4323, 2022, https://doi.org/10.3390/app12094323
3. Y. Krim, M. Sechilariu, F. Locment, A. Alchami, "Global Cost and Carbon Impact Assessment Methodology for Electric Vehicles PV-powered Charging Station", Applied Sciences, vol. 12, no.9, pp 4115, 2022, https://doi.org/10.3390/app12094115S

Conferences

1. A. Alchami, N. Darene, M. Sechilariu, F. Locment, "Social Acceptability and Acceptance of Photovoltaic Powered Charging Stations", Colloque InterUT Systèmes Sûrs et durables, Paris, 2-3 fev 2023, accepted
2. S. Cheikh-Mohamad, M. Sechilariu, F. Locment, "Electric Vehicle Charging and Power Grid Issues Scenarios versus PV-powered charging stations", Colloque InterUT Systèmes Sûrs et durables, Paris, 2-3 fev 2023, https://hal.science/hal-04011818/document
3. 2. M. Sechilariu, S. Cheikh-Mohamad, F. Locment : "Electric Vehicle Charging and Power Grid Issues Scenarios versus PV-powered charging stations", Conférence invitée: Colloque InterUT Systèmes sures et durables, Paris 2-3 fév. 2023, https://hal.science/hal-04011877/document
4. S. Cheikh-Mohamad, M. Sechilariu, F. Locment : "PV-Powered Charging Station: Energy Management with V2G Operation and Energy Cost Analysis" The 7th International Conference on Smart and Sustainable Technologies, IEEE SpliTech 2022, Split and Bol (island of Brac), Croatia, 5-8 July 2022, DOI 10.23919/SpliTech55088.2022.9854343
5. M. Sechilariu : "Energy Efficient Design for PV-Powered Electric Vehicle Charging Stations to increase PV benefits", RENEWABLE MEET2022, International Conference on Renewable and Sustainable Energy, Dubai 21-23 March, 2022. Keynote Speaker

TASK 18

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.

SUB-TASK STRUCTURE

Task 18 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

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