Technology Collaboration Programme
by IEA

International Energy Agency
Photovoltaic Power Systems Programme

PVPS

ANNUAL REPORT 2023

PHOTOVOLTAIC POWER SYSTEMS TECHNOLOGY COLLABORATION PROGRAMME

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

ANNUAL REPORT 2023

Cover photo: (Source: Voltalia)

PV plant owned by Finerge with 9.6 MWp installed in Coruche, Portugal.

Finerge report that this PV horse-grazing project has been very successful. The horses are always free to circulate throughout the field, including open field areas, between the PV arrays and near the electrical transformers. No incidents or damage have been registered so far; however, it is paramount to provide an environment where the horses feel calm.

COLOPHON

Task Status Reports
PVPS Task Managers
Member Status Reports
Executive Committee Delegates
Editor
PVPS Communications Team
Graphic Designer
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MESSAGE FROM THE CHAIR

A REFLECTION ON OUR PROGRESS

In 2023, once again, solar photovoltaic could have been renamed as the "king of global power markets" as Fatih Birol said in 2022 about this technology. Indeed, energy global photovoltaic capacity grew to 1.6 TW from 1.2 TW in 2022, with 446 GWp of new PV systems commissioned. China led with a record 235 GW of new installations, contributing over 60% to global capacity. Module prices dropped significantly due to oversupply, despite previous concerns about material and transport costs. This maintained the competitiveness of PV, even as electricity prices decreased after peaking in 2022.

PV technology is now considered as a real game changer of energy balance in the World. For instance, the number of countries having a theoretical contribution of PV to electricity consumption over 10% doubled in 2023 to 18. As PV penetration continues its rapid global increase, the challenges to be overcome are increasingly non-technical, including necessary regulatory reform. Policy changes aimed at facilitating permitting and administrative procedures have been implemented by an increasing number of countries, whilst indirect support, such as building regulations, mandatory solar requirements, or local manufacturing incentives continues to be adopted.

Among PVPS, we see a wide spectrum of new and innovative applications for PV, which present an inspiring image of how the future power landscape will be configured. Now that hundreds of GWp are planned, applications beyond ground and classical roof-top systems will become progressively more and more present and for some of them even possibly mainstream. Exciting developments are taking place in the areas of active power management, cost competitive building-integrated PV, floating PV and agrivoltaics.

Accordingly within PVPS, new activities are being developed, searching to be always one step in advance, with the focus shifting toward PV applications and sector coupling. Regarding agrivoltaics, a new PVPS Action Group will launch in mid-2024 to run a series of stakeholder workshops and assess the global trends in agrivoltaics. In January 2025, a renewed PVPS Task will kick off work on the grid integration of PV. A third new PVPS activity is under development to collaborate with the IEA's Wind and Hydrogen technology collaboration programmes on the topic of energy hubs and green hydrogen. Also the existing PVPS Tasks go from strength to strength, attracting new Experts, developing new work plans and taking on fresh challenging topics. The scope of the existing tasks covers PV markets, sustainability aspects, system reliability & performance, BIPV, VIPV, solar resource, grid integration and off-grid systems.

2024 will be a very busy year for our programme, with over 50 new PVPS reports expected to be published! If you don't want to miss out on announcements, then follow us on LinkedIn or sign up for our Newsletter.

The PVPS programme is pleased to announce the expansion of our Communications Team and an increase in our efforts to communicate the important work of our Tasks to key target audiences.
In particular, we have set ourselves the goal to better reach and inform policy makers with the use of fact sheets, infographics, articles, policy briefings, videos and webinars, which will all be advertised on our website and other channels. Look out for our mid-monthly column in the 'Opinions & Analysis' section of PV Magazine and visit us at our booth at the 41st EU-PVSEC exhibition in Vienna or the PVSEC-35 in Numazu.

I am honoured to chair this excellent international research programme at such an important and exciting time for the global PV sector. Our Experts, our Task Managers and our Executive Committee continue to work hard to maximise our impact in supporting PV development. In this Annual Report, we provide an overview of the recent work of our programme, as well as insights into the status of the PV sectors within our member countries.

Enjoy your reading!

Daniel Mugnier
Chair

April 2024

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PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Fig. 1 - PVPS Task Experts and Executive Committee Delegates at the Whole-of-Programme Meeting hosted by University of Adelaide, Mawson Lakes campus.

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 2023, eighteen Tasks were established within the PVPS programme, of which eight are currently operational. The thirty-one PVPS members include twenty-five countries: Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America; plus six sponsor members: the European Commission, Solar Power Europe, the Smart Electric Power Alliance, the Solar Energy Industries Association, the Solar Energy Research Institute of Singapore and Enercity SA.

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

IEA PVPS OBJECTIVES

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

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

IEA PVPS CURRENT TERM 2023 – 2028

In its 7th term from 2023 to 2028, IEA PVPS continues its commitment to advancing international cooperation in the field of photovoltaic technology. With 31 member countries contributing to its success over the past 29 years, PVPS outlines a strategic orientation aimed at supporting the overarching goals of IEA in terms of energy security, climate change mitigation, and economic competitiveness. The focus of this strategic plan is to empower photovoltaic technology to not only meet but surpass the targets outlined in the IEA's "Net Zero 2050 Scenario."

The significance of photovoltaic technology has been steadily rising, with its emergence as one of the most cost-effective means of electricity production. Its attributes including rapid deployability, ease of installation, and minimal maintenance costs have positioned it as a key player in the global transition towards clean energy systems. Moreover, PV's impact extends beyond the energy sector, infiltrating various domains such as buildings, transportation, agriculture, and industrial processes.

Under it's strategic framework, IEA PVPS participants are undertaking collaborative efforts encompassing research, development, demonstration, analysis, and information exchange related to photovoltaic power systems. Emphasizing both technical and non-technical aspects, the aim is to facilitate the large-scale and sustainable deployment and operation of PV. This includes integration into energy systems and infrastructure while embracing the emerging concept of circularity.

Looking beyond 2030, the strategic plan anticipates addressing forthcoming challenges such as physical, technical, and economic integration, alongside policy, regulatory, and social acceptance considerations. Collaboration with stakeholders from diverse energy sectors, networks, storage, and digitalization arenas will be intensified to foster innovation and address evolving needs effectively.

NEW CONTENT

- Action Group on Agrivoltaics

In April 2024 IEA PVPS is starting a new Action Group on Agrivoltaics, which marks the introduction of a new activity structure within the programme, aiming to foster interdisciplinary collaboration on cross-cutting topics. This activity seeks to harness the synergy between agriculture and photovoltaic power generation, aiming for a more sustainable and resilient future. The Action Group's primary objective is to assess the current landscape of agrivoltaics globally and foster international collaboration to unlock its full potential. Through interdisciplinary efforts, it aims to optimize land use efficiency, enhance agricultural resilience against climate change, and promote social consensus for solar energy development. Led by Alessandra Scognamiglio from ENEA, Italy and Jordan Macknick from NREL, USA, the Action Group will produce a comprehensive public report titled "Status quo and global trends in agrivoltaics," accompanied by internal recommendations for future IEA PVPS initiatives in this domain. By synthesizing existing research, coordinating across IEA PVPS Tasks, and establishing common metrics and definitions, the group endeavors to pave the way for widespread adoption and advancement of agrivoltaics. Through it's 3 phases of formation, stakeholder workshops, and synthesis reporting, the Action Group sets out on a two-year journey to drive meaningful progress in this promising field.

- Task 19

The new IEA PVPS Task 19 aims to address critical challenges in integrating grid-connected PV into electric power systems. The Task is currently in formation, with experts signed up from various institutions globally so far and more still expected to join. The overarching goal is to facilitate the transition towards energy systems based on 100% Renewable Energy Systems (RES) while emphasizing the pivotal role of PV Systems in electricity grids. Key objectives include promoting the adoption of grid-connected PV, providing comprehensive international studies to stakeholders, showcasing the full potential of grid-integrated solar PV, and linking technical expertise within Task 19 with complementary initiatives and other IEA TCPs. The Task will address issues such as permitting and connection delays, investment in grid extension, integration of variable renewables, and weather-dependent electricity supply, among others. By leveraging international expertise, Task 19 aims to support the operation of RES-based power systems and enhance grid management, stability, digitalization, and resilience. Through joint research activities, streamlined working structures, and collaboration with other IEA initiatives, Task 19 seeks to advance solutions for effectively integrating solar PV into the energy transition.

- Task 20

IEA PVPS Task 20, titled "Integrated Solar and Wind Hybrid Plants for Green Hydrogen Production and Sector Coupling," is a collaborative initiative, acknowledging the pivotal role of solar and wind power in driving the transition towards a sustainable energy future. It emphasizes the need for coupling these sources with green hydrogen production to enhance system flexibility and enable long-term energy storage. The development of the Task concept has been led by Otto Bernsen from the Netherlands, with a Task Manager yet to be appointed. The Task brings together expertise from the IEA TCPs—Wind, Hydrogen, and Solar—to accelerate the adoption of green hydrogen as an energy carrier and facilitating its integration into diverse sectors beyond traditional electrification. Task 20 will follow a multi-faceted approach encompassing various work packages, including project and information management, digital and technical hybrid plant design, energy hub use cases, benchmarking and best practices synthesis, environmental impact assessment, and legal framework analysis. Through collaborative research, data collection, and knowledge sharing, the initiative aims to provide valuable insights, guidelines, and recommendations for the design, operation, and implementation of integrated solar and wind hybrid plants worldwide.

Key objectives include advancing sector coupling strategies, optimizing the utilization of renewable energy resources, and engaging local stakeholders to ensure the successful deployment of energy hubs. By addressing technological, economic, regulatory, and societal aspects, Task 20 endeavors to overcome barriers and pave the way for a more resilient, sustainable, and inclusive energy transition.

TASK 1

STRATEGIC PV ANALYSIS & OUTREACH

Task Managers:

Mr Gaëtan MASSON
Becquerel Institute, Belgium

Ms Izumi KAIZUKA
RTS Corporation, Japan

Fig. 2 - Task 1 members at the Menorca, Spain meeting in April 2023, credit « José Denoso/UNEF »

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.

➤ Read about the objectives and structure of Task 1 in the Annex

2023 KEY ACCOMPLISHMENTS

National Survey Reports

A key component of the collaborative work carried out within the PVPS Programme are the National Survey Reports (NSR) , providing a detailed look into what has happened in the specific country over the year. These reports, written (and funded) by the country teams, build on Task 1 discussions on effective data collection across various subjects, from national market frameworks, public budgets, the industry value chain, prices, economic benefits, and new initiatives including financing and electricity utility interests. Twelve reports covering 2023 were published on the IEA-PVPS website over the 2nd semester, with the first becoming available from June.

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 communicated by Task 1 participants to their identified national target audiences, at selected conferences and meetings and can be downloaded from the IEA-PVPS website with all previous editions. A summary is published in PV Magazine, and its results are disseminated widely in industry media.

A 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. In particular, the 2023 edition was developed with an improved methodology for compiling market data, with a critical regard on the essential conversion from AC to DC power of systems depending on country and expert reporting protocols.

Exploring the impact of grid constraints on future PV deployment

Task 1 members explored the potential risk to deployment of photovoltaics around the world due to grid constraints – from rising grid connection costs and cost sharing schemes to grid capacity and mechanisms to increase grid capacity. Comparative policies, constraints and opportunities were presented at EU PVSEC, whilst Task 1 members contributed to discussion around the parameters and mission of the future Task 19 on grid integration.

Cooperation with other Tasks

The October 2023 All Tasks meeting in Adelaide, Australia, was an opportunity to further explore cooperation and exchanges with different Tasks. With Task 15 (BIPV), Task 1 members were able to provide expertise on the essential requirements for accelerated market uptake based on lessons learnt across different countries in the past 20 years, assisting Task 15 in developing a plan for investigating increased penetration of BIPV products, whilst reaffirming the possibilities for cooperation. With Task 17 (VIPV), the Task 1 proximity with industry and market actors, and the previously studied social acceptance issues allowed a fruitful discussion on the importance of crossing market and policy visions with the in Task expertise.

OUTLOOK FOR 2024

Task 1 activities in 2024 will continue to focus on supporting experts in other PVPS tasks, policy and decision makers, as well as market and industry stakeholders with quality information and effective communication. This involves analyzing subjects ranging from support policies and market trends to industry developments, providing reliable, accurate and pertinent information. Specifically, Task 1 will concentrate on market intelligence and data collection, with an emphasis on identifying emerging trends and upcoming subjects.

As market uptake continues at unprecedented speeds in much of the world, 2024 work will include a continued closer examination of industry developments, prices, and social acceptance barriers. Additionally, closer collaboration with Task 15 (BIPV) and Task 17 (VIVP) is envisaged within the framework of Task 1 publications.

All Task 1's PVPS Publications are available here.

TASK 1 HIGHLIGHT

TRENDS IN PV APPLICATIONS 2023

Main Authors: Gaëtan Masson (Becquerel Institute), Melodie de l'Epine (Becquerel Institute France) Izumi Kaizuka (RTS Corporation).
Analysis: Izumi Kaizuka (RTS Corporation), Elina Bosch, Philippe Macé, Gaëtan Masson (Becquerel Institute), Caroline Plaza (Becquerel Institute France), Arnulf Jäger-Waldau (EU-JRC), Johan Lindahl, Amelia Oller Westerberg (Becquerel Institute Sweden).

PVPS_Trends_Report

Task 1 Webpage

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.

The graph (Fig.3) highlights the increasing gap between annual manufacturing and installation volumes – over-capacity is having a significant impact on module prices; over 2023 it eased the impacts of high polysilicon prices, and is a significant contributor to the unsustainably low prices of late 2023 and early 2024..

Historically, module spot prices have varied as a function of installed capacity, whilst 2 significant events have slowed the price learning curve. This graph (Fig.4), on a double logarithmic scale, demonstrates the rapidity and coherence of price drops and allows for future estimates in many cases.

Trends is published (Fig.5) 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.

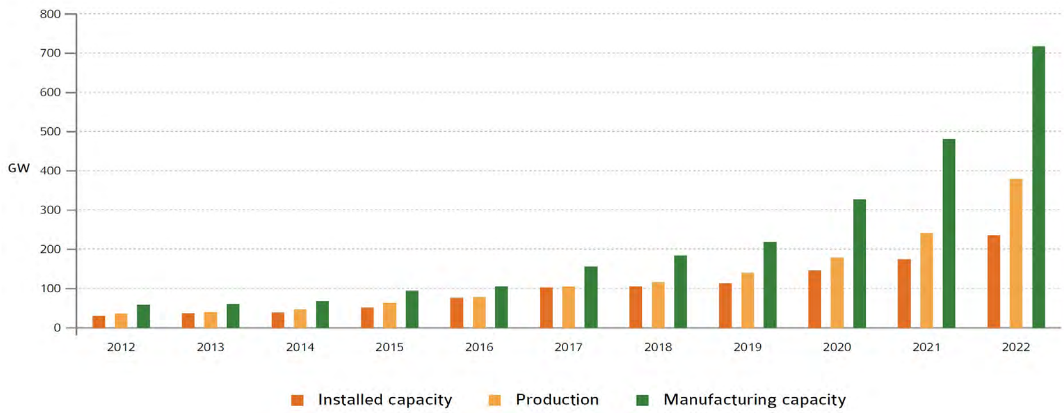

Fig. 3 - PV modules spot price learning curves (1992-2022)

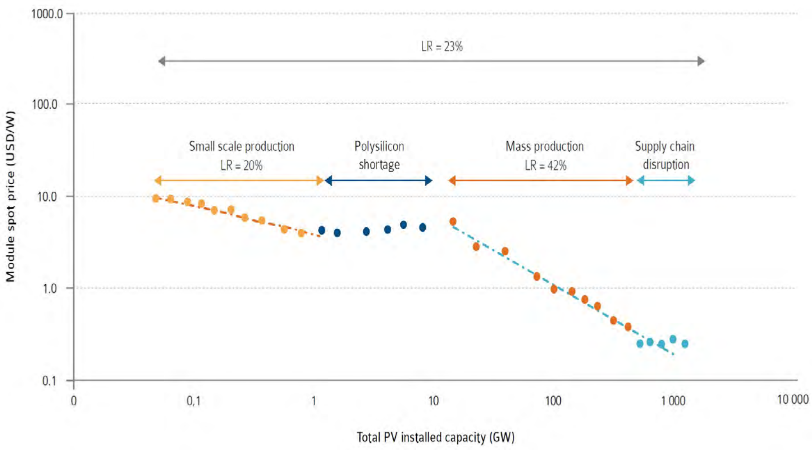

Fig. 4 - Market recap infographic – Trends in applications 2023.

Fig. 5 - Market recap infographic – Trends in applications 2023.

TASK 12

PV SUSTAINABILITY ACTIVITIES

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Fig. 6 - Task 12 members

INTRODUCTION

Within the framework of PVPS, Task 12 endeavors to promote international collaboration, facilitate information exchange, and drive knowledge creation in the realm of PV sustainability, encompassing both environmental and social dimensions. It generates, compiles, and disseminates both primary and secondary information to technical experts, the public, and policymakers alike. Accurate information regarding the environmental and social sustainability of photovoltaic technology is essential for various purposes, be it conducting due diligence to navigate risks and opportunities associated with PV systems or educating consumers and policymakers about their impacts and benefits. By enhancing consumer confidence and garnering support from policymakers, this information contributes to the broader adoption of PV energy systems, thereby advancing the global energy transition.

➤ Read about the objectives and structure of Task 12 in the Annex

2023 KEY ACCOMPLISHMENTS

In 2023, Task 12 achieved remarkable progress in advancing photovoltaic (PV) sustainability, fortified by a series of noteworthy accomplishments and the integration of esteemed experts into its collaborative efforts. One standout achievement was the publication of the "Life Cycle Assessment of Crystalline Silicon Photovoltaic Module Delamination with Hot Knife Technology" report, a pivotal contribution offering invaluable insights into augmenting the sustainability of PV modules. Furthermore, several reports, including the analysis of take-back and recycling of PV modules in Germany, life cycle assessments of PERC technology, and the carbon footprint of Floating PV, underwent rigorous evaluation under ExCo review, underscoring Task 12's commitment to robust research and assessment practices.

The task force welcomed a cadre of distinguished experts, each bringing unique perspectives and expertise to enrich Task 12's initiatives. Notable additions include Jordan Macknick from NREL (USA), whose specialization in agrivoltaics promises to enhance understanding and implementation in this burgeoning field. Etienne Drahi, representing TotalEnergies (France), brings comprehensive expertise in agrivoltaics, floating PV, and end-of-life considerations. Matthias Stucki from ZHAW (Switzerland) significantly bolsters Task 12's capabilities with his profound knowledge in life cycle assessment (LCA), providing invaluable insights into assessing the environmental impacts of PV technologies. Additionally, Task 12 welcomed Nieves Espinosa from Universidad de Murcia (Spain), whose expertise in PV sustainability adds depth to the task's research endeavors. Raffaelle Rossi, representing SolarPower Europe, brings a wealth of knowledge in PV policies and circular economy, crucial for shaping sustainable industry practices and regulations. Malte Vogt from TU Delft (The Netherlands) provides invaluable contributions with his expertise in PV sustainability, contributing to the task's multidisciplinary approach towards sustainability challenges in the PV sector. Cara Libby from EPRI (USA) enriches Task 12's expertise with her specialization in circular economy, offering insights into optimizing material use and resource efficiency in PV systems. Finally, Nicolas Defrenne from SOREN (France) contributes expertise in circular economy, enhancing Task 12's capacity to address resource management and recycling challenges in the PV industry.

Furthermore, Task 12 intensified its external communication efforts, exemplified by the organization of a parallel event at EUPVSEC 2023 in Lisbon, titled "Advancing Environmentally Positive PV Systems." This event served as a pivotal platform for fostering knowledge exchange and collaboration within the PV community on an international scale, reaffirming Task 12's commitment to driving innovation and sustainability in the global PV industry.

OUTLOOK FOR 2024

The upcoming reports for 2024 outlines the ambitious goals and collaborative efforts within Task 12 across various subtasks:

Concerning Subtask 1 – Circular Economy (CE), initiatives include assessing global PV recycling status, patent reviews of PV recycling methods, and studies on repair of PV panels and waste management in France.

Concerning Subtask 2 – Life Cycle Analysis (LCA), activities range from updating LCI data and study and comparison of life cycle indicators from commercial PV recycling pilots and plants as well as conducting LCA of thermochemical and mechanical recycling.

Concerning Subtask 3 – Ecosystem Integrated PV (ecoPV), focus areas includes field research methods for agrivoltaic applications and contribution to agrivoltaics Action group.

Concerning Subtask 4 – Broader Sustainability Topics (BST), Research involves studying public acceptance of PV modules and expanding human health risk assessments for landfilling of CdTe PV.

Overall, the anticipated report for 2024 reflects the ongoing dedication and interdisciplinary collaboration within Task 12 to advance the sustainability of photovoltaic technology and drive the global energy transition.

All Task 12's PVPS Publications are available here.

TASK 12 HIGHLIGHT

LIFE CYCLE ASSESSMENT OF CRYSTALLINE SILICON PHOTOVOLTAIC MODULE DELAMINATION WITH HOT KNIFE TECHNOLOGY

Authors/Contributors: Rolf Frischknecht, Keiichi Komoto, Taisuke Doi

KEY MESSAGE

LCA of Hot Knife Technology

Task 12 webpage

The hot knife delamination technology efficiently recovers aluminum and glass while separating the backsheet containing cells/EVA, contributing minimally to the environmental footprint of PV electricity (0.3% or less), with potential reductions of 80-98% in life cycle impacts when using recovered materials in new module production.

OBJECTIVE

This study aims to conduct a life cycle assessment (LCA) of a new technology that uses hot knife technology to separate the front glass and backsheet of crystalline silicon (c-Si) photovoltaic (PV) modules. This step is critical in module recycling, influencing process selection, economic value of materials recovered, and environmental performance.

METHODOLOGY

A questionnaire was sent to the manufacturer of the hot knife technology to gather data on energy and material consumption, as well as the quantity and quality of recovered materials. This information was utilized to create a life cycle inventory (LCI) for hot knife delamination of c-Si PV panels, based on pilot plant data from 2018. The complete life cycle assessment of c-Si PV panels includes production and installation data from the International Energy Agency Photovoltaic Power Systems Program Task 12 LCI update 2020 database, with weighted averages for multicrystalline and monocrystalline Si PV modules based on their global installed capacity in 2018. For processes lacking specific data, the Federal Department of the Environment, Transport, Energy, and Communications (UVEK) LCI database DQRv2:2022 is used.

Fig. 7 - Separated materials after the hot knife technology (Photo courtesy of NPC Incorporated)

The heated cutter adds heat to the EVA and separates it from the glass. There is no need to crush the glass, and the equipment collects the laminate, including the cells, the tabbing, the EVA layers, and the backsheet.

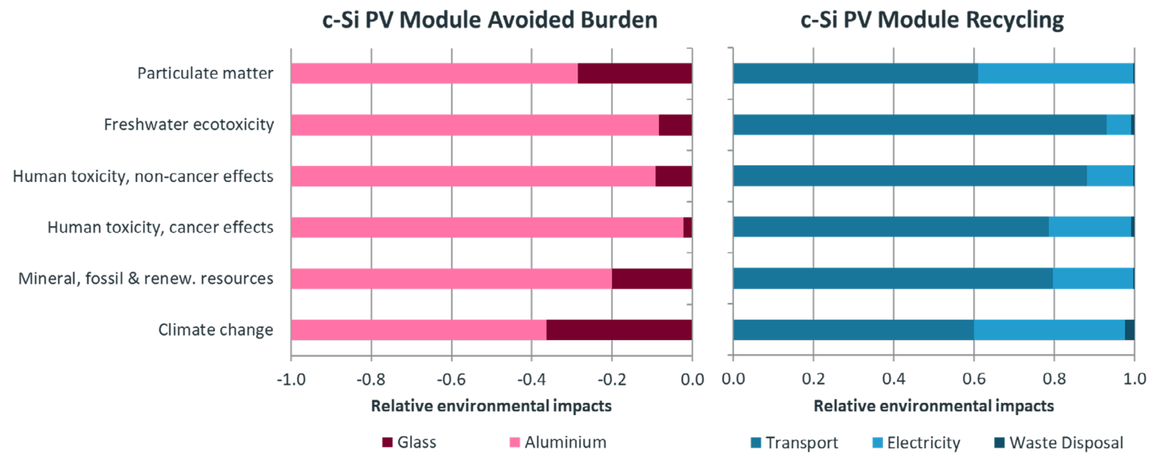


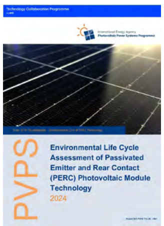
Fig. 8 - Relative contributions of recovered glass and aluminum to the potential benefits (left) and relative contributions of the delamination processes to the environmental burdens (right) of the hot knife technology c-Si PV module delamination

The relative contributions of the recovered materials in the potential benefits and the shares of the processes in the environmental impacts are shown in the figure. The potential benefits due to recovered aluminiumaluminum have the highest impact in all indicators. The environmental impacts of c-Si PV panel delamination are mainly caused by the transport of the used panels to the delamination facility (200 km total) and by electricity supply. Waste disposal is hardly visible in terms of impact. The contribution of transport varies with shipping distance.

TASK 12 HIGHLIGHT

ENVIRONMENTAL IMPACTS ASSOCIATED WITH PERC TECHNOLOGY USING A LIFE CYCLE ASSESSMENT (LCA)

Authors/Contributors: A. Danelli, E. Brivio, P. Girardi, N. Baggio, J. Libal



LCA of PERC Modules

Task 12 webpage

KEY MESSAGE

This report investigates the potential environmental impacts associated with PERC technology using a life cycle assessment (LCA) approach and compares them with those related to monocrystalline silicon technology (Al-BSF) for both fixed tilt and 2P single axis tracking systems installed in North and South of Italy.

OBJECTIVE

Assess life cycle environmental impacts of a utility scale PV plant based on PERC technology. Two possible configurations are considered: modules at fixed tilt and modules on a single axis tracker.

Enhancing awareness on the crucial role played by current PV technologies in the decarbonization of the energy sectors, based on Carbon Footprint and LCA studies.

METHODOLOGY

LCA study covering the entire life cycle of an 84.73 MW PV plant, including: components (cells, modules, inverter and trackers) manufacturing, plant installation, operation phase and end of life (limited to the disposal of the panels)

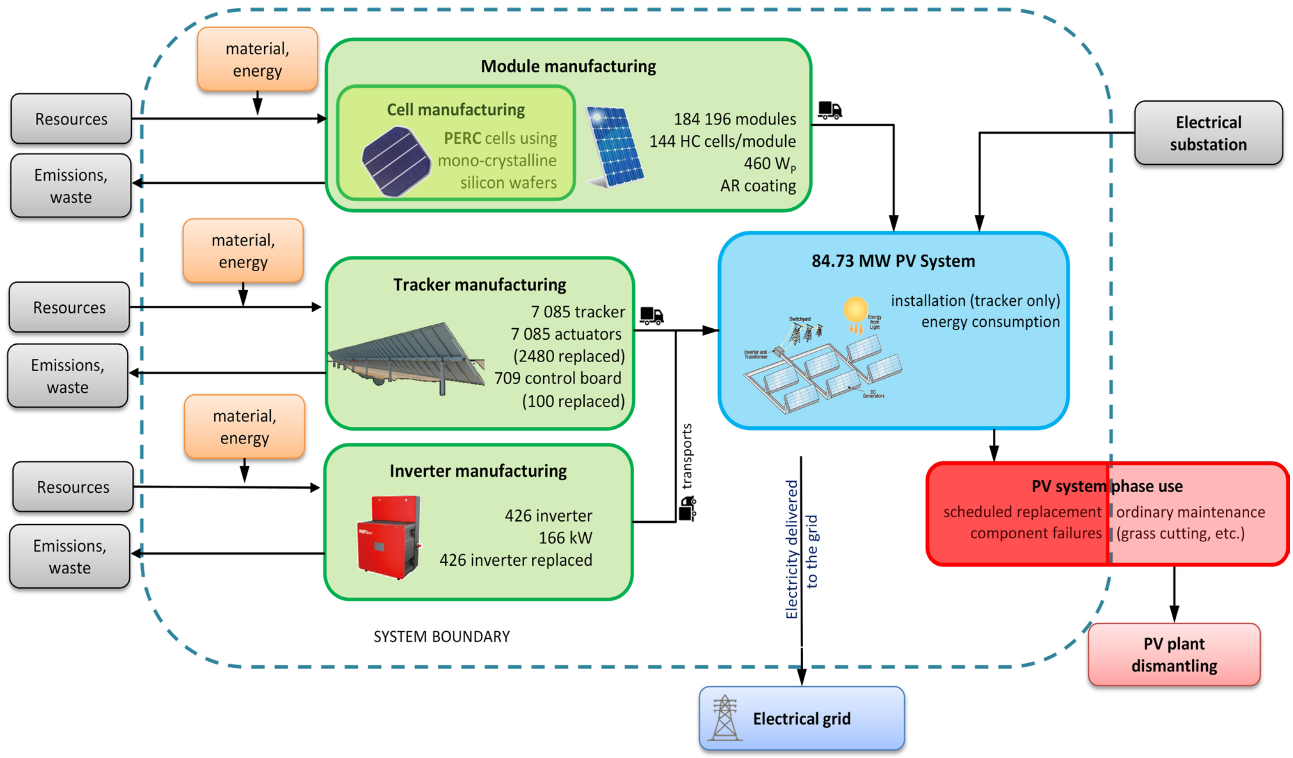


Fig. 9 - Outline of system boundary with the unit processes included in the LCA study

The analysed PV plant includes 184 ,196 mono-facial modules characterised by a nominal power of 460 Wp (21.16% of efficiency) and an area of 2.17 m², 7 ,085 trackers realised in low alloy weathering steel (26 modules each, 13 x 2 portrait) and 426 inverters with a nominal power of 166 kW (replaced after 17 years). In the operating phase of the PV plant, it is supposed that 1 ,772 actuators and 709 control boards of the tracker are replaced due to failures.

Table 1: Environmental impacts of ground mounted PV system located in Italy and based on PERC technology (460 W mono-facial module with 144 half-cut PERC cells and an efficiency of 21.16%).Results related to two different solutions: modules on a solar tracker and modules at fixed tilt.

Impact category	South Italy (GHI 1,819 kWh/m2/y)		North Italy (GHI 1,368 kWh/m2/y)	
	tracker	fixed tilt	tracker	fixed tilt
Climate change (kg CO_2 eq.)	1.71E-02	2.07E-02	2.28E-02	2.57E-02
Ozone depletion (kg CF11 eq.)	1.50E-09	1.81E-09	1.99E-09	2.25E-09
Photochemical ozone formation (kg NMVOC eq.)	6.57E-05	7.86E-0W5	8.75E-05	9.78E-05
Respiratory inorganics (disease inc.)	1.12E-09	1.35E-09	1.50E-09	1.68E-09
Acidification (mol H+ eq.)	1.05E-04	1.24E-04	1.40E-04	1.54E-04
Freshwater eutrophication (kg P eq.)	6.81E-06	7.94E-06	9.07E-06	9.88E-06
Marine eutrophication (kg N eq.)	2.73E-05	3.25E-05	3.64E-05	4.04E-05
Terrestrial eutrophication (mol N eq.)	2.25E-04	2.70E-04	2.99E-04	3.36E-04
Land use (Pt)	3.25E-01	3.98E-01	4.33E-01	4.94E-01
Resource use, energy carriers (MJ)	2.08E-01	2.51E-01	2.77E-01	3.12E-01
Resource use, mineral and metals (kg Sb eq.)	8.04E-07	9.33E-07	1.07E-06	1.16E-06

This table presents the different impact categories number for the investigated systems and locations.

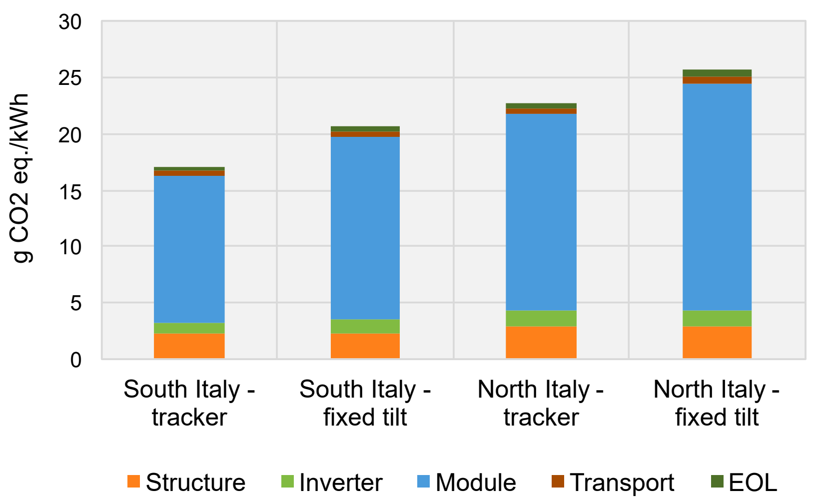


Fig. 10 - Climate Change impact category for the difference configurations

In all the configurations analysed, the impact associated with the module production (i.e., from the raw material extraction to the module production) covers more than 70% of the total impact in the Climate Change impact category. The tracker component covers approximately 10% of the impact due to metal extraction and processing.

TASK 13

RELIABILITY AND PERFORMANCE OF PHOTOVOLTAIC SYSTEMS

Task Managers:

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Ms Laura BRUCKMAN
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Fig. 11 - Task 13 Meeting of IEA PVPS Whole-of-Programme, with 25 in-person experts and 60 remote experts, in Adelaide, South Australia, 23-26 October 2023 (c/o U. Jahn).

INTRODUCTION

Task 13 of the PVPS program aims to support market actors in improving the operation, reliability, and quality of PV components and systems. The operational data collected from PV systems across different climates during the project will enable conclusions about reliability and estimated yield.

Task 13 will continue to be necessary for the foreseeable future and is critical to the well-being of the PV industry. The reliability of PV systems, modules, and components remains a concern for investors and operators. The PV industry is experiencing rapid changes, not only in terms of size with global capacity doubling approximately every three to four years but also in the adoption of new technologies such as changing cell thicknesses, the introduction of TOPCon and SHJ technology, and bifacial cells, as well as new deployment locations and applications like floating PV and agricultural PV.

These combined impacts indicate that the reliability and performance of PV modules and systems need further investigation to ensure that PV remains a viable investment. The past performance of similar technologies cannot be considered a complete or reliable predictor of future performance for new installations and integrated PV applications.

➤ Read about the objectives and structure of Task 13 in the Annex

2023 KEY ACCOMPLISHMENTS

Experts will conduct a survey among asset owners and other stakeholders about the scope 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 to reducing the risk of PV investments. Data from various plant typologies and configurations will be benchmarked in terms of techno-economic KPIs.

Performance and Reliability of Second Life PV

The second life of PV modules is emerging as a new market and research area. This field concentrates on repairing modules that are damaged after production and operation. Task 13 ST1.2 is also keen on learning from module manufacturers about repairing modules with production defects or damages. Second life PV focuses on developing methods for identifying modules in the field that can be repaired and then reinstalled in a secondary market, extending their lifetime and preventing PV modules from entering the waste stream. Globally, less than 10% of PV is recycled, and there is an estimated 1.7-1.8 megatons of PV waste expected by 2030. Second life PV needs to concentrate on the triage and classification methods for modules, repair/refurbishment methods, and the future outlook for standardization, market, and technology. Repair/refurbishment methods need to be developed and standardized for damages like broken glass, cells, delamination, broken interconnects, junction box issues, detached or broken frames, leakage current, faulty bypass diodes, cracked backsheets, and other damages. Additionally, it is crucial to justify the technical/economic viability of PV second life, addressing the volume of PV modules, the reliability and remaining efficiency of the second life products, and their integration into the current PV and O8M value chain.

Cracked backs have proven promising for on-site repairs and repairs to retrieved modules. The backsheets are cleaned with mechanical wiping with a damp towel, dried, and then coated with a crack-filling and continuous deck coating to protect the backsheet. This is typically done in the field in a horizontal position using a brush or spray coating. The coating should be at least 50 to 100 µm thick. This method may serve as preventive maintenance to prevent microcracks from developing into macrocracks.

Extreme Weather Events and their Multiple Impacts on PV Power Plants: Risks, Failure Mechanisms and Mitigation Strategies

The ongoing increase in the frequency and intensity of severe weather events - linked to global climate change - poses a growing risk to photovoltaic (PV) systems worldwide. These risks range from outright power plant destruction to long-term performance losses due to accelerated component and system degradation. While the risks are widespread, the threats are both local and global. Some weather events may be geographically limited but have high per-event economic losses (e.g., hail), whereas others may be widespread but not as economically destructive (e.g., tropical cyclones). Yet, without specific hardening strategies, severe weather increasingly threatens the robustness and availability of photovoltaic generation globally. Defensively stowing a PV module during a hail or wind event can mitigate the risk of damage but requires appropriate response time for trackers. Snow presents a unique challenge to PV systems, causing power losses and requiring design optimization.

Our anticipated Task 13 Report will focus on 1) the categories and geographic distribution of storms threatening PV systems globally; 2) the types of damage and costs associated with each storm category; 3) storm-specific mitigation strategies and post-event best practices; and 4) opportunities for global cooperation and information-sharing to align PV power production with a changing climate. The report will focus on specific weather events, including high wind events (e.g., hurricanes, typhoons), convective storms, snowstorms and blizzards, dust storms, heatwaves, floods, and wildfires, and the risks they pose for PV power plants. This report aims to raise awareness of climate change implications for a solar-intensive energy economy and describe strategies for designing and siting storm-resilient PV systems, providing stakeholders in the PV value chain (project developers, insurers, investors) with information on failure mechanisms and their root causes.

OUTLOOK FOR 2024

Task 13 of the PVPS program aims to support market actors in enhancing the operation, reliability, and quality of PV components and systems. The operational data collected from PV systems in various climates during the project will enable conclusions about reliability and the estimated yield.

Task 13 will continue to be essential for the foreseeable future and is crucial to the well-being of the PV industry. The reliability of PV systems, modules, and components has been and will remain a concern for investors and operators. The PV industry is experiencing rapid changes, not only in terms of size (global capacity doubles approximately every three to four years) but also in the adoption of new technologies (e.g., changing cell thicknesses, introduction of Topcon and SHJ technology, and bifacial cells) and new deployment locations and applications, such as floating PV and agricultural PV.

These combined impacts indicate that the reliability and performance of PV modules and systems need further investigation to ensure that PV remains a viable investment, as past performance of similar technologies is not a complete or reliable predictor of the future performance of new installations and integrated PV applications.

The development of new solar cell and PV module designs has been changing rapidly in recent years. Therefore, Task 13 experts from the most important PV manufacturing countries (China, USA, and Europe) will outline the challenges, compare sequential and combined test procedures, and propose potential mitigation solutions to address the currently known degradation mechanisms in new PV module technologies. This will cover degradation modes in recent PV technologies as well as degradation in future technologies based on Perovsties. We will also analyze strategies for how old or defective PV modules may be repurposed. As batteries have become an integral part of PV systems, we will begin to assess their reliability.

Task 13 experts will focus on novel PV applications. Emerging PV applications include floating PV and Agrivoltaics. Experts will collaborate on energy yield modeling, specific loss mechanisms, field performance, and reliability as well as operation & maintenance challenges and best practices. An overview and definitions for these integrated PV applications will be provided. PV systems with bifacial modules and trackers are gaining market share, as are systems with module-level power electronics.

Task 13 will conduct a global survey of PV tracking technologies to collect information on their tracking algorithms and how they enhance bifacial PV performance and system designs. Best practices on performance evaluation will be compared and developed. The impact of shading conditions on performance due to module-level power electronics in the PV system will also be investigated. Finally, the role of digitalization in cost and performance optimization of PV systems and best practices will be 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.

All Task 13's PVPS Publications are available here.

TASK 14

SOLAR PV IN THE 100% RES POWER SYSTEM

Task Managers:

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Austrian Institute of Technology (AIT), Austria

Mr Gerd HEILSCHER
Technical University of Ulm, Germany

INTRODUCTION

PV has emerged as a significant player in the electricity systems of many countries, and the integration of increasing shares of variable renewables into power systems is now a global challenge. Amidst uncertainty in the electricity sector, investments in Solar PV have become more economically viable. This rapid deployment has further highlighted challenges associated with grid connection and system integration.

In numerous markets, PV has transformed into a genuine game changer at the bulk power system level, emphasizing the need to tackle key issues. These include the variable nature of PV generation, the connection through static power electronics, and the proliferation of small-scale systems within distribution grids.

Task 14 focuses on these challenges and shares global experiences and best practices to enable full integration of PV into the power system. This includes catering to local loads and ensuring PV acts as a reliable resource for the interconnected transmission, distribution, and generation system.

➢ Read about the objectives and structure of Task 14 in the Annex

2023 KEY ACCOMPLISHMENTS

In 2023, Task 14 focused on finalizing joint reports and publications intended for experts from the electricity and smart grid sector, specialists in photovoltaic systems and inverters, equipment manufacturers, and other specialists concerned with the interconnection of distributed energy resources.

Active Power Management Report

To achieve a sustainable energy supply, substantial capacities of Solar PV must be connected to the electricity grids, often exceeding the hosting capacity. Depending on the situation, various grid integration measures can be implemented. One of the most effective measures is the management of the AC power fed into the grid. The main outcomes of the report include:

- Active power management as a viable grid integration measure
- Power peak limitation to reduce stress on electricity networks
- A hierarchy of measures to limit curtailment losses
- An overview of different active power management methods tailored to specific use cases

Reactive Power Management Report

This report provides a management summary on the state-of-the-art, best practices, and recommendations for reactive power management amid the increased penetration of distributed energy resources (DERs), with key messages highlighting:

- The need for updated regulatory frameworks
- The potential of Distributed Energy Resources as a source for reactive power services to improve power system efficiency and reliability
- The further integration of PV in Smart Grids enabling enhanced coordination between Transmission and Distribution System Operators

Dissemination

In Europe, Task 14 showcased its work at the 22nd Wind and Solar Integration Workshop, part of the Renewable Energy Grid Integration Week in Copenhagen, Denmark, in September 2023. Additionally, at the PVPS-Industry-Day in Adelaide, Australia, in November, outcomes of Task 14 were presented to a selected audience of Australian stakeholders.

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

Complementing the dissemination efforts and progress in the reports, the Task 14 management team diligently worked on defining the new Task related to the Grid Integration of Solar PV. This new Task is slated to continue the work post the conclusion of Task 14 at the end of 2023. Significant progress was made during Task Definition workshops at major solar events, including Intersolar Europe, where the basic concept and scope of the new task were developed, covering main topics such as:

- National PV targets versus peak load and grid capacity
- Bill of rights and obligations of Prosumers
- PV in Smart Grids
- Approval and commissioning processes for the interconnection of PV systems with the electricity network
- Active power management
- New inverter capabilities
- Aggregators, local markets, and energy communities
- Local energy management at the Prosumer level
- Energy economy in a 100% RES-based power system

In 2024, a series of dedicated online task definition workshops are planned to develop a focused and targeted strategy and work program for the new Grid Integration of Solar PV Task.

OUTLOOK FOR 2024

Following the conclusion of Task 14 in 2023, efforts are underway to establish a new Task to continue supporting the grid integration of Solar PV. The process of defining this Task, initiated in 2023, is expected to be completed in 2024. It will tackle major challenges facing Solar PV in a 100% RES (Renewable Energy Sources) power system, such as:

- Balancing 100% renewable energy targets with limited grid capacity
- The rights and obligations of Prosumers
- PV integration in Smart Grids and Digitalization
- Streamlining approval, commissioning, and registration processes
- Managing curtailment, power management, and firm power
- Utilizing new inverter capabilities, including grid-forming capabilities
- The role of aggregators, local markets, and Energy Communities in local energy management
- Redesigning energy markets for a 100% renewable power system

In 2024, multiple Task Definition workshops are planned, which will invite expert stakeholders from various sectors. The new Task is anticipated to officially begin at the end of 2024.

All Task 14's PVPS Publications are available here.

TASK 14 HIGHLIGHT

ACTIVE POWER MANAGEMENT OF PHOTOVOLTAIC SYSTEMS STATE OF THE ART AND TECHNICAL SOLUTIONS

Editor: Ch. Bucher, BFH, Switzerland - **Contributors**: Ch. Bucher, S. Chen, G. Adinolfi, R. Guerrero-Lemus, Y. Ogasawara, G. Heilscher, I. McGill, M. Said El Hamaoui, C. Kondzialka, D. Mende, J. Wiemer, R. Bruendlinger, A. Ghennioui, M. Said Elhamaoui, K. Ogimoto, E. Omine, Y. Ueda, J. Remund, A. Benazzouz, G. Graditi, T. Key.

Active Power Management

Task 14 Webpage

OBJECTIVE

To reach the goal of a sustainable energy supply, large capacities of Solar PV must be connected to the electricity grids, exceeding the hosting capacity by far. Depending on the situation, different grid integration measures can be taken. One of the most effective measures to achieve this goal is the management of the AC power fed into the grid.

KEY MESSAGE

Active power management of photovoltaic systems is a powerful grid integration measure and the key to an increased PV hosting capacity in the grids.

METHODOLOGY

Different methods of PV power management and their application in electric power grids are presented and discussed. The findings are targeted to technical experts from the utility sector, project developers as well as technical consultants, seeking for technical solutions and experiences on the implementation level

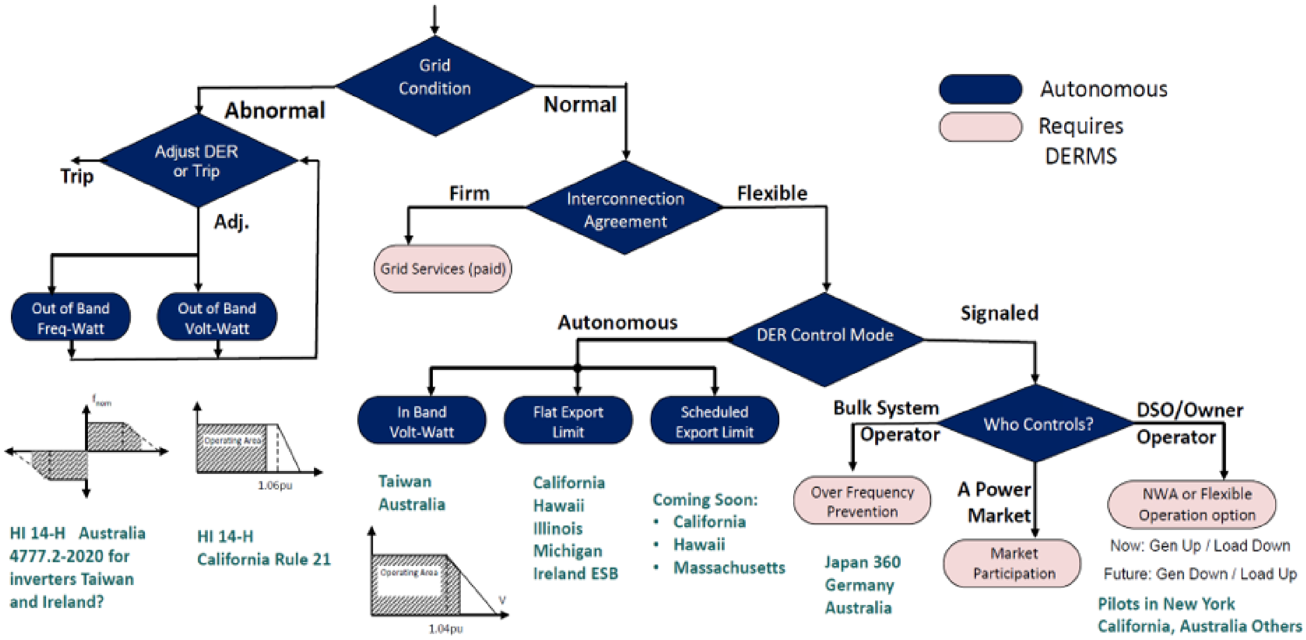


Fig. 12 - Why PV Curtailment is a Reasonable Grid Integration Measure (Source: C. Bucher and D. Joss, "Grid connection of 50 gigawatts photovoltaic systems in Switzerland: Discussion paper on solutions for the grid integration of solar power," 2023.

Of all electrical power sources, PV systems have the lowest capacity factor (equals lowest annual nominal hours of operation or the highest peak power to energy ratio). Limiting power peaks will therefore reduce stress on the power grid more than for all other power generating technologies.

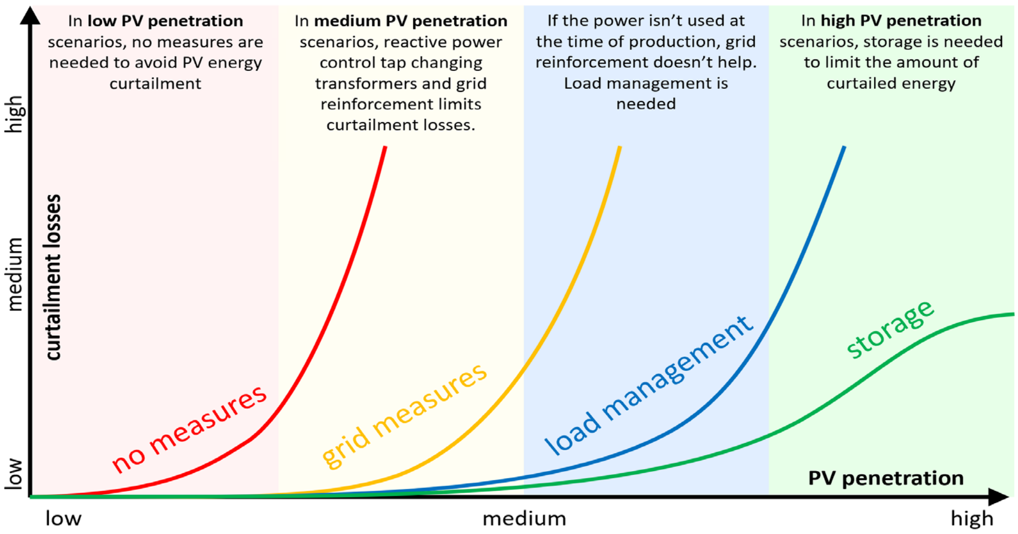


Fig. 13 - Overview of the different power management methods (Source: Thomas Key, Brian Seal, Aminul Huque, "DER Active Power Management," 22nd Wind & Solar Integration Workshop | Copenhagen, Denmark | 26 – 28 September 2023, vol. 2023, 2023)

According to the specific use case, different active power management methods can be implemented.
The figure illustrates the wide range of active power management methods and provides a classification according to their use case and principle, autonomous and DERMS based.

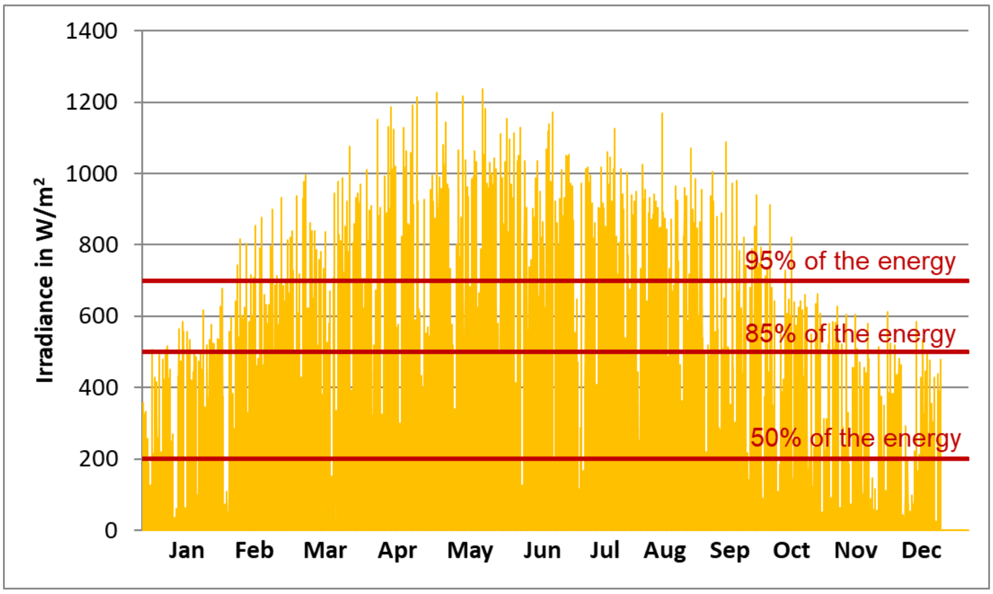


Fig. 14 - Hierarchy of measures to limit curtailment losses

From an energy and environmental perspective, energy curtailment should be limited. Depending on the level of PV penetration and the local situation, different measures can help to limit the amount of curtailed energy. The figure illustrates different measures at different PV penetration scenarios.

TASK 14 HIGHLIGHT

REACTIVE POWER MANAGEMENT WITH DISTRIBUTED ENERGY RESOURCES

Editors: Abdullah Altayara, Denis Mende (Fraunhofer Institute for Energy Economics and Energy System Technology IEE)
Contributors: C. Bucher (Fachhochschule Bern), Y. Ogasawara, E. Omine (New Energy and Industrial Technology Development Organization NEDO), Y. Ueda (Tokyo University of Science), R. Bründlinger (Austrian Institute of Technology, AIT), G. Adinolfi, G. Graditi (Italian National Agency for New Technologies, Energy and Sus-tainable Economic Development, ENEA), H. Wang, D. S. Stock (Fraunhofer IEE), M. Kraiczy (formerly Fraunhofer IEE) G. Heilscher (TH Ulm)

Reactive Power Management

Task 14 Webpage

KEY MESSAGE

Exploring Solar PV as a potential source for reactive power services can significantly improve efficiency and reliability of power systems with high shares of Renewable Energies.

OBJECTIVE

Reactive power management is an essential aspect in achieving optimal grid performance with high shares of RES and PV. Various new methodologies are being developed considering difference scenarios and highlighting the necessity for adaptability in response to evolving energy landscapes.

METHODOLOGY

This report investigates status and potential of reactive power management in three steps: At first, grid codes and frameworks shaping the requirements to provide reactive power are analyzed with respect to their applicability in power systems with increasing integration of renewable energy sources. Secondly, reactive power control support potential is discussed through different research case studies. At last, research examples, including use cases from three different IEA PVPS Task 14 countries highlight these applications using photovoltaics and other renewables.

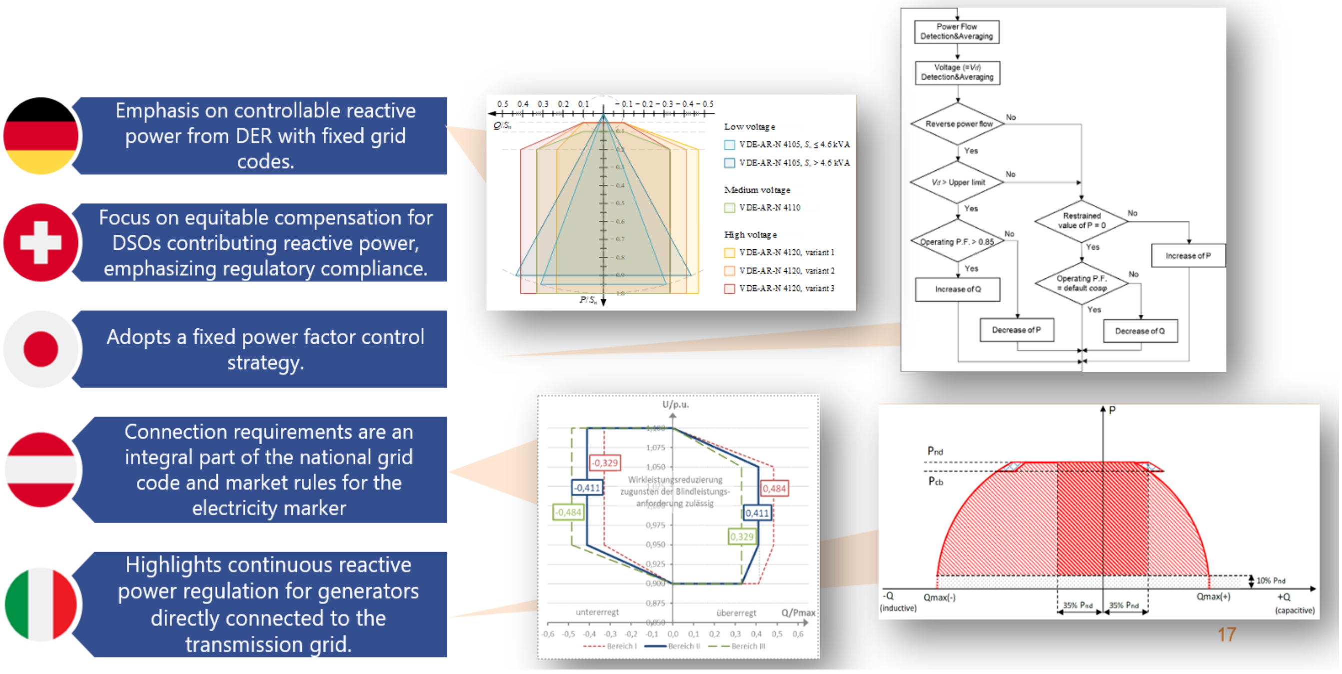


Fig. 15 - Overview of regulatory frameworks in five Task 14 countries

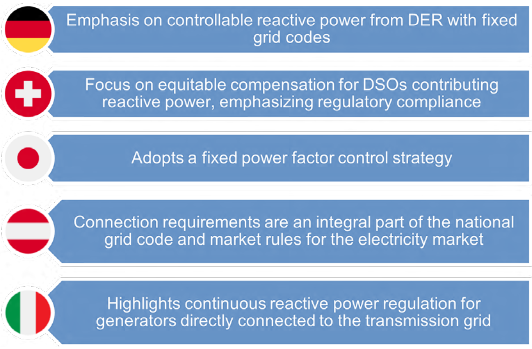


Fig. 16 - Overview of regulatory frameworks in five Task 14 countries

Grid codes and regulatory frameworks shape the requirements for connected distributed resources, including reactive power control. The report examines how these regulations influence the operation of power systems with increasing share of renewable energy sources and highlights differences, gaps and best practices.

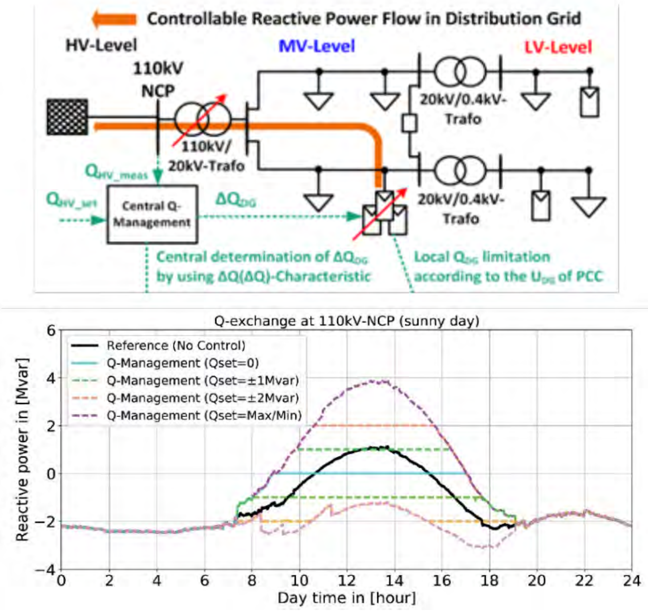


Fig. 17 - Concept of the three pillars of reactive power procurement, proposed by the German Federal Network Agency

Non-discrimination: All market participants must have equal access.

Market-based pricing: Price of reactive power in the market determined by supply and demand.

Transparency: The market will be transparent so that market participants can make informed decisions about their procurement of reactive power.

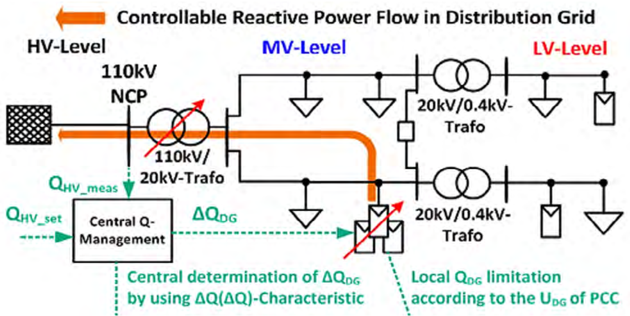


Fig. 19 - Application-oriented reactive power management approach Source: Wang, H.: 'Application-Oriented Reactive Power Management in German Distribution Systems Using Distributed Energy Resources' (Universität Kassel, 2022)

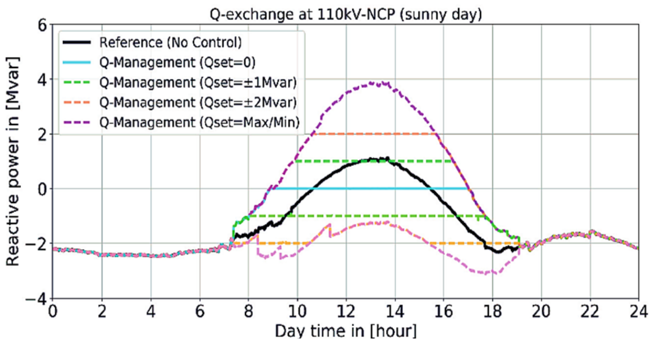


Fig. 20 - Application-oriented reactive power management approach Source: Wang, H.: 'Application-Oriented Reactive Power Management in German Distribution Systems Using Distributed Energy Resources' (Universität Kassel, 2022)

Application oriented reactive power management approach demonstrated in German grids allowing Distribution System Operators to control the exchange of reactive power at the grid interfaces and support local voltage stability without requiring complex information and communication technology infrastructure.

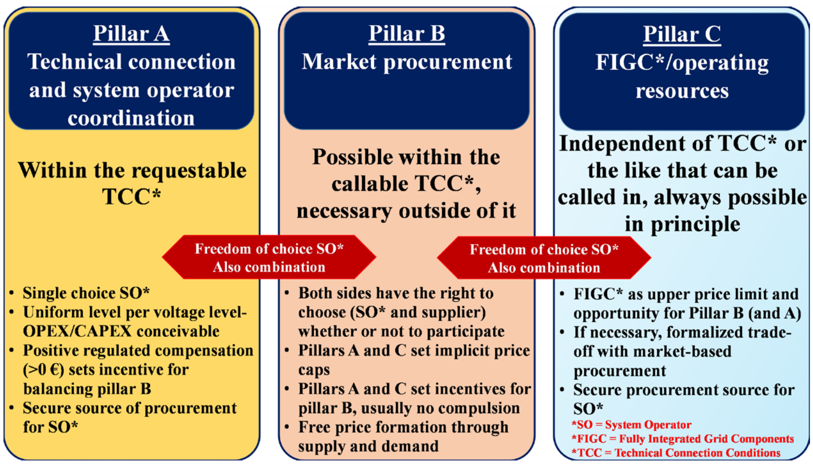


Fig. 18 - Concept of the three pillars of reactive power procurement, proposed by the German Federal Network Agency

TASK 15

ENABLING FRAMEWORK FOR THE DEVELOPMENT OF BIPV

Task Managers:

Mr Francesco FRONTINI
Swiss BiPV Competence Center, Uni Applied Science & Arts of Southern Switzerland (SUPSI), Switzerland

Ms Helen Rose WILSON
Fraunhofer Institute for Solar Energy Systems, Germany

Fig. 21 - IEA-PVPS Task 15 experts' Meeting in Stockholm, Sweden, with about 25 experts in person and 20 participating online. The group visited the Comfort Hotel Solna, which features a fully integrated photovoltaic façade designed by a Swedish Task 15 participant, White Arkitekter.

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 aimed at creating an enabling framework and accelerating 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 construction materials and provides new opportunities for architects and planners.

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

2023 KEY ACCOMPLISHMENTS

In 2023, more than 50 experts focused on preparing two new reports, organizing the concluding activities of Task 15, Phase 2 and preparing the new Work Plan for Task 15, Phase 3.

Key accomplishments of 2023 included: Technological Innovation System (TIS) Analysis for BIPV

A new report titled "Guide for Technological Innovation System (TIS) Analysis for Building-Integrated Photovoltaics (BIPV)" was published. This guidebook describes some common standards for analysis and serves as the foundation for a broader investigation of the topic involving different countries. The synthesis of TIS results from several countries was initiated, with preliminary results of the structural analysis presented at the EU PVSEC in Lisbon in September 2023.

Cross-sectional analysis: Learning from existing BIPV installations

A multidimensional evaluation methodology for BIPV projects has been developed, tested, refined and applied. It builds upon the previously reported classification of BIPV installations and a set of performance indicators (PI) categorized in four categories: (i) energy-relevant, (ii) economic, (iii) environmental and (iv) visual impact, with 5-7 PIs per category. A numerical basis for rating the PIs in the first three categories has been established. Developing a new methodology for visual assessment was necessary; after initial testing, it was re-designed and subsequently tested live on a BIPV building with all experts at the Task meeting in Stockholm. After gaining some experience by applying the PI-based evaluation matrix to eight completed BIPV installations (two BIPV roofs, four BIPV facades, two BIPV external devices), the methodology underwent further refinement. Detailed evaluations were conducted on two significantly different cases: an architectural lighthouse project with façade-integrated PV and a social housing estate with roof-integrated PV. The multidimensional approach successfully summarizes the performance of a BIPV installation in a comprehensive but differentiated manner, allowing decision-makers the flexibility to prioritize different performance categories based on the specific context of their BIPV application. The results were presented at the EU PVSEC 2023, and a peer-reviewed paper has been published in Energy and Buildings in the Special Issue on Photovoltaics in the Built Environment. Highlights of the work were also published in the PV Magazine in January 2024.

BIPV Guidelines: A guidebook and technical presentations providing a complete pathway from BIPV design to installation, maintenance and safety

A major milestone was reached with the submission of the full text and figures of the BIPV Guidebook to the publisher, Taylor & Francis. A total of 20 Task 15 experts have contributed to the book, which is structured into six chapters and contains 176 figures. Publication is foreseen in the second half of 2024.

Digitalization for BIPV: Using digitalization opportunities to enhance the accessibility, reliability and affordability of BIPV

Intensive work on a digital BIM-based process for BIPV and digital product data models resulted in a report which was published on the IEA-PVPS website in May 2024.

Pre-normative international research on BIPV characterization methods

Work on different aspects of fire safety resulted in the publication of a PVPS report and a scientific paper. The report titled "Fire safety of BIPV: International mapping of accredited and R&D facilities in the context of codes and standards 2023", summarizes information provided on over 40 fire-testing facilities in 20 countries. It provides background information through brief overviews of internationally applicable fire-safety standards, national building codes, and regulations related to fire safety of BIPV modules and systems. This report served as the basis for an article in the July issue of PV Magazine. Furthermore, Task 15 experts' experience on the fire safety requirements for BIPV in their respective countries were used for an international comparison, published as a peer-reviewed scientific paper.

OUTLOOK FOR 2024

In the first months of 2024, the remaining reports of phase 3 of Task 15 will be completed and published:

- Alongside national reports, a synthesis of the TIS analysis in several countries will be published.
- A technical BIPV guidebook for professionals will be released.
- Two publications on BIPV and digitalization will be issued, comparing real data with simulation analysis and the competitiveness of BIPV in different regions and cities.
- Three reports on pre-normative activities regarding BIPV characterization will be produced, covering progress in SHGC determination of BIPV, safety and reliability of BIPV, and standardized procedures to quantify the annual electricity yield of installed BIPV systems.

Coordination with standardization bodies will continue.

With the ambition to further support the market implementation of BIPV as a significant player in the energy transition, a new workplan has been approved, and the new activities commenced in 2024.

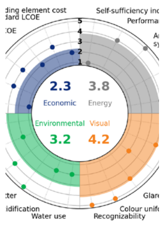
The new phase will focus on the roles of BIPV in the energy and building markets, better characterization, and assessment of multifunctional PV components (with a focus on fire safety, glare, SHGC, colored modules and shading resilience of BIPV), BIM-based simulation and digital information models for BIPV. Experts will also monitor and assess new BIPV products, projects, and demonstrations to report about innovation trends and reliability of BIPV. Finally, phase 3 of Task 15 will establish new approaches to improve collaboration between different stakeholders in the BIPV value chain to identify new training models and opportunities.

All Task 15's PVPS Publications are available here.

TASK 15 HIGHLIGHT

MULTI-DIMENSIONAL EVALUATION OF BIPV INSTALLATIONS: ASSESSING PERFORMANCE AS BUILDING COMPONENTS AND ELECTRICITY GENERATORS

Subtask Leader: Gabriele C. Eder, OFI (Austria)



Evaluation of BIPV installations

Task 15 Webpage

KEY MESSAGE

IEA-PVPS Task 15's multi-dimensional assessment methodology for BIPV systems represents a significant step forward. Through continuous learning cycles and real-world testing, the challenges posed by data availability, visual assessments, and evaluation of disparate projects have been addressed.

OBJECTIVE

The main goal of this work is to be able to assess the quality and efficiency of BIPV systems through a set of performance indicators (called PIs) established in four categories: Economic, Energy-relevant, Environmental, and Optical/Visual Appearance. This multi-dimensional evaluation tool is designed for architects, developers, and other stakeholders involved in BIPV projects.

METHODOLOGY

Following a systematic, step-by-step process, this methodology addresses economic, energy-relevant, environmental, and optical/visual performance, providing a differentiated tool to compare and optimize BIPV installations.
The research work identified various challenges and limitations, particularly in the context of pioneering and pilot building-integrated photovoltaic (BIPV) projects, which often used newly developed, immature or early-stage technologies at the time of their construction.

With the aim of assessing the overall performance of BIPV systems, a series of performance indicators (PIs) were created and classified into four categories: economic, energy-relevant, environmental and optical/visual. In the next step, a numerical rating system was created for each PI. The measured or calculated values were assigned a number between 1 and 5 (with 5 being the best rating).

A semi-quantitative approach was developed for the assessment of the visual appearance PIs, as they are not based on easily quantifiable numerical values. A simple rating system was developed for each of the chosen PIs, with guidelines for rating them in a range from 1 to 5. Results showcase the tool's efficacy in providing a comprehensive understanding of BIPV installations, including visual performance.

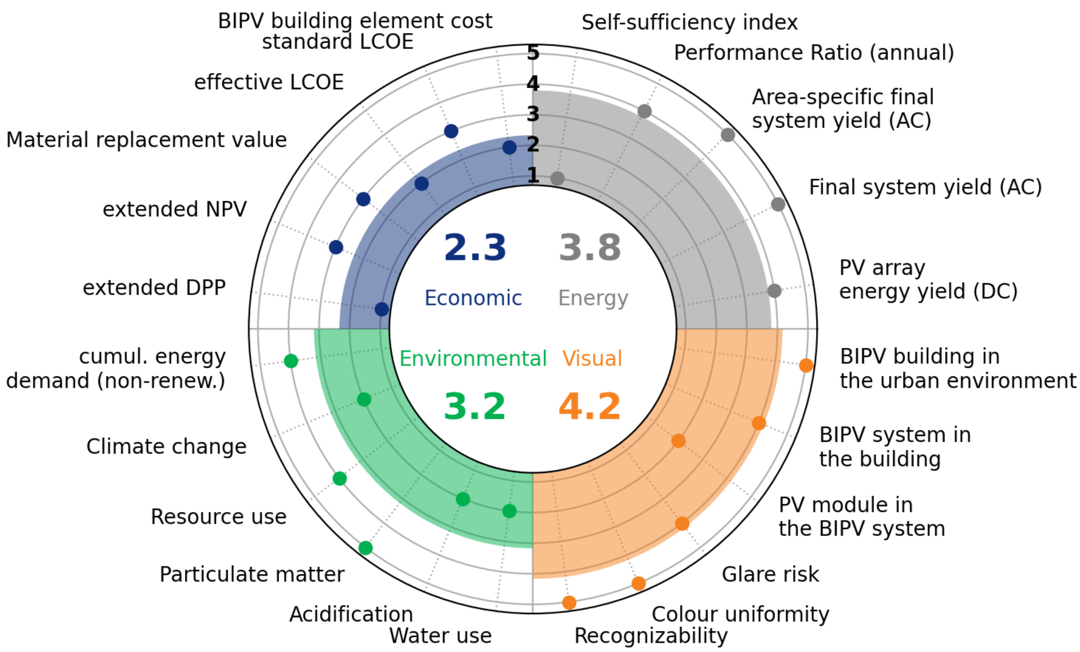


Fig. 22 - Visualized performance evaluation results in the described four categories indicating the numerical values of all evaluated PIs (arbitrary example).

Table 2: Guidelines for rating of colour uniformity and glare risk PIs.

Colour uniformity	Points		Glare risk	Points
Base rating	3		Base rating	3
Hue and/or saturation change within single module/element	-1		Satinated or highly structured glass (no specular reflections visible)	+1
Hue change between single modules/elements	-1		Flat glass (specular reflections highly visible)	-1
Saturation/lightness change over entire façade	-1		Facing only low traffic areas	+1
Colour-matched to surrounding materials (or no others)	+1		Facing high traffic areas	-1
Homogeneous colour over entire façade	+1		Small, unconnected areas (module areas < $2m^2$ AND < 25% coverage)	+1
Final rating:	**1 - 5**		**Final rating**	**1 - 5**

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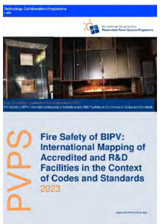
Gabriele C. Eder, Helen Rose Wilson, Francesco Frontini, Pierluigi Bonomo, Markus Babin, Sune Thorsteinsson, Jennifer Adami, Laura Maturi, Rebecca Jing Yang, Nilmini Weerasinghe, Nuria Martin-Chivelet, Simon Boddaert, Rolf Frischknecht, Multi-dimensional evaluation of BIPV installations: Development of a tool to assess the performance as building component and electricity generator, Energy and Buildings, Volume 312, 2024, 114207, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2024.114207.

TASK 15 HIGHLIGHT

FIRE SAFETY OF BIPV: INTERNATIONAL MAPPING OF ACCREDITED AND R&D FACILITIES IN THE CONTEXT OF CODES AND STANDARDS 2023

Editors: V. Shabunko and P. Kovács. Main Authors: S. Boddaert, P. Bonomo, G. Eder, R. Fjellgaard Mikalsen, H. Ishii, J-T. Kim, Y. Ko, P. Kovács, T. Li, X. Olano, F. Parolini, D. Qi, V. Shabunko, L. Slooff, R. Stølen, D. Valencia, S. Villa, H. R. Wilson, R. Yang, Y. Zang. Contributing Authors: K. Berger, T. Makris, G. Manzini, E. Roman, J.M. Vega de Seoane, D. Tan



Fire Safety of BIPV

Task 15 Webpage

KEY MESSAGE

This report presents an overview of testing laboratories, research teams, standards and regulations in twenty countries around the world which address the fire safety of construction products.

OBJECTIVE

In addition to providing a useful reference for BIPV module manufacturers looking for fire-safety testing facilities, the overview is a useful basis for further development of internationally harmonized test methods assessing the fire safety of BIPV products and systems.

METHODOLOGY

A survey was made of the experience and potential that accredited and R&D fire-safety test facilities can offer to test BIPV modules and systems. The survey was based on a questionnaire that was formulated jointly within Task 15 and then distributed and collected by national experts within their respective countries.

Fig. 23 - Reaction to fire test according to method SP Fire 105 on a BIPV façade system. (Source: RISE Fire Research).

Large-scale façade tests are essential to evaluate how complete BIPV façade systems react if they are exposed to flames. They provide information on fire development in the façade which cannot be predicted solely on the basis of small-flame ignitability tests of individual BIPV modules.

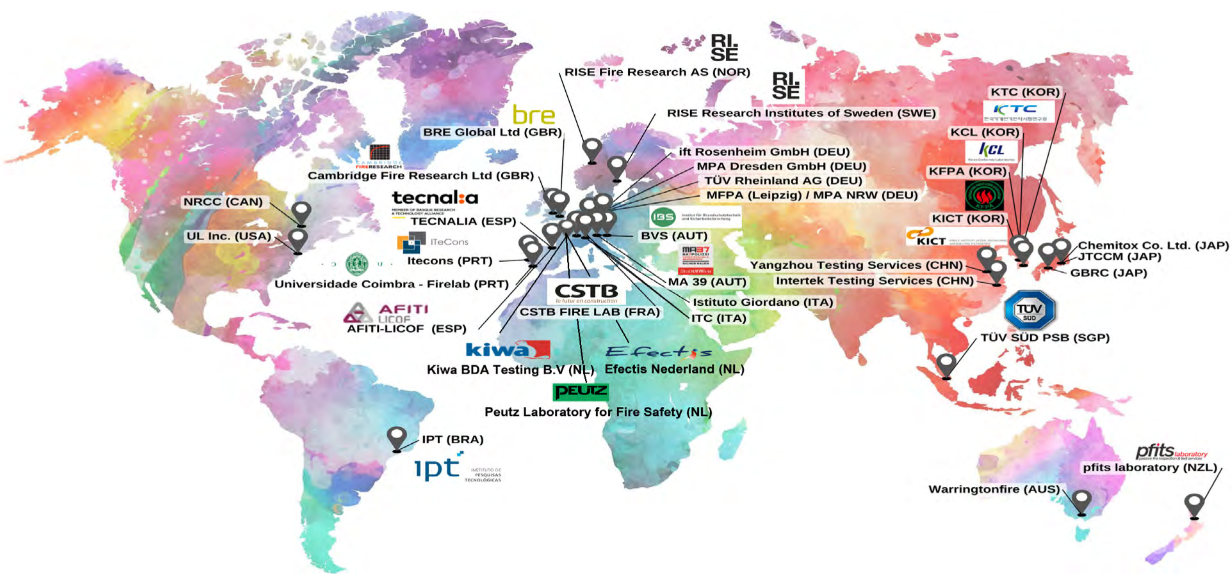


Fig. 24 - Fire-safety testing facilities for building components can be found in most member countries of IEA-PVPS.

The mapped fire-safety testing facilities are equipped to test building components and can be approached to assess BIPV installations and modules.

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. 25 - Mind the gap. Measurements without gaps are rare or even inevitable and gap-filling therefore an important topic. A new report includes a benchmark of different methods to fill gaps in global radiation time series.

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) and with Wind Task 51. 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 ground measurements, satellite retrievals and Numerical Weather Prediction
- Define best practices for data fusion of ground, satellite and model data (re-analysis) to produce improved datasets
- 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

2023 KEY ACCOMPLISHMENTS

Report: Benchmark of long-term radiation data

The work on the benchmark for solar radiation data led by CSP Services (Anne Forstinger) has been published in spring 2023. The ongoing work on benchmarking showed, that a report separate of the solar resource handbook is useful.

Report: Benchmark of GHI Gap-Filling methods

The report on GHI GAP-Filling method - written by Mines Paristech (Philippe Blanc, FRA) – has been published 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 intra-hour/intra-day probabilistic forecasting

The work for the benchmark has started in 2021 and is ongoing. It was decided to write a scientific paper instead of a Task report. The draft paper was ready for internal review by the end of 2023. The work is led by Philippe Lauret of Univ. La Reunion. FRA. It will be published in the first half of 2024.

Report & paper: Firm PV Power

In January 2023 the report about different firm power generation studies was published as a PVPS report (Perez et al., 2023). 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.

A paper about the same topic but with a stronger focus on the conclusions and outlook has been published in September 2023 (Remund et al., 2023).

Solar Resource Handbook – 4th Edition

Throughout 2023 a team lead by 10 main authors and 32 additional co-authors have been working on the update of the Handbook, which is the main result of the three year's phases of the Task 16. A internally reviewed draft version is ready by end of January 2024. It will be edited by a team at NREL. Publication in NREL and IEA format is foreseen for May – June 2024.

OUTLOOK FOR 2024

In spring 2024 the 4th edition of the Solar Resource Handbook will be published in IEA and NREL format. It will be disseminated with workshops and webinars.
Additionally, a paper about a benchmark of probabilistic forecasting will be finalized.

The spring Task meeting will be held in Roskilde (DNK) together with IEA Wind Task 51, which is about forecasting of wind energy. Separate and common Task meetings are planned as well as a public 1.5 days workshop about minute scale forecasting of wind and solar.The second Task meeting will be organized at NREL in Golden, CO, USA in October 2024.Different workshops are planned – e.g. at the EU PVSEC 2024.

REFERENCES

Remund, J., Perez, R., Perez, M., Pierro, M. and Yang, D. (2023), Firm Photovoltaic Power Generation – Overview and Economic Outlook. Sol. RRL. Accepted Author Manuscript. https://doi.org/10.100 solr.202300497

All Task 16's PVPS Publications are available here.

TASK 16 HIGHLIGHT

FIRM PHOTOVOLTAIC POWER GENERATION: OVERVIEW AND ECONOMIC OUTLOOK

Editors/contributors: Jan Remund, Meteotest AG, Switzerland, Richard Perez, SUNY, USA, Marc Perez, Clean Power Research, USA Marco Pierro, EURAC, Italy, Dazhi Yang, Univ. Harbin, China

Firm Power generation

Task 16 Webpage

KEY MESSAGE

Overbuilding and dynamic curtailment 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 based on the in-depth knowledge of their spatio-temporal variability and availability. The objective is to determine the lowest overall costs, the optimal shares of renewables, storage and energy curtailed.

METHODOLOGY

The optimum between storage and curtailment is calculated. The focus of the work in 2023 was to add more regions (e.g. Australia) and starting to analyze the conclusions: how can optimal curtailment shares be achieved? What regulations regarding the grid, investments and market must be changed?

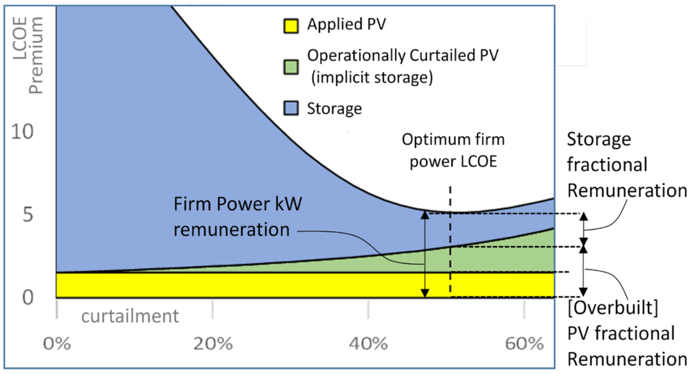


Fig. 26 - Firm Power remuneration
Example of a possible firm power remuneration system in the simplified case of PV/real/implicit storage configuration

Fig. 27 - Fast change to firm power remuneration lowers costs

Future (2040) cost of 100% VRE power generation in Michigan as a function of the onset of firm power enabling market rules. The current remuneration based on energy leads to high costs; it should be changed to capacity. Curtailed energy (flexibility) must be rewarded. The earlier the change the lower the costs.

REFERENCES

Rey-Costa, E., Elliston, B., Green, D., & Abramowitz, G. (2023). Firming 100% renewable power: Costs and opportunities in Australia's National Electricity Market. Renewable Energy, 219. https://doi.org/10.1016/j.renene.2023.119416

TASK 17

PV AND TRANSPORT

Task Managers:

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Mizuho Research & Technologies, Japan

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University of Technology of Compiègne, France

INTRODUCTION

With the widespread electrification of transportation, PV electricity and other renewable energy sources are crucial to leveraging EV adoption for even more significant CO2 emissions reductions. Options for low-carbon charging of electric vehicles include using the existing grid network with PV or other sustainable electricity sources, charging from a dedicated charging point with local PV electricity generation, or charging directly and independently with on-board PV (PV-powered vehicle: VIPV).

To help reduce the CO2 emissions of the transport sector and to enhance PV market expansions, Task 17 aims to clarify the potential for utilizing PV in transportation and to propose ways to proceed towards realizing these concepts. Task 17's scope includes various PV-powered vehicles such as passenger cars, light commercial vehicles, heavy-duty vehicles, and other types of vehicles, as well as PV applications for electric systems and infrastructures. This includes charging infrastructure with PV (PV-powered charging station: PVCS), battery, and other power management systems.

➢ Read about the objectives and structure of Task 17 in the Annex

2023 KEY ACCOMPLISHMENTS

PV-powered passenger cars – Technical requirements for VIPV

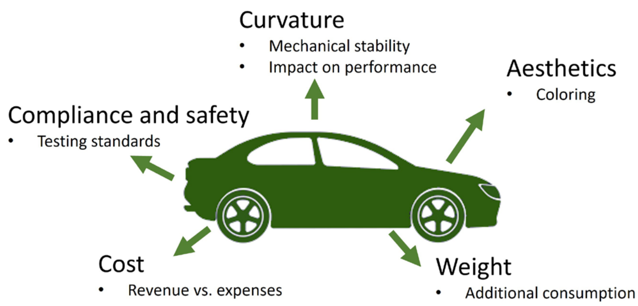

Fig. 28 - Main categories of the technical considerations for VIPV

The work within Activity 1.2 involves partners from Germany, France, Switzerland, the Netherlands, and Japan, with Germany taking the lead. This activity aims to explore technical considerations for applying VIPV in passenger cars by defining various categories. The main categories under investigation include curvature, aesthetics, weight, cost, compliance, and safety. In June 2023, work commenced on a report which is now nearly complete. This document dedicates each chapter to one of the technical considerations' main categories. In the curvature chapter, the focus is on investigating mechanical stability as a function of the spherical radius of curvature and the total cell's area, as well as the impact of curvature on solar module performance. The aesthetics chapter provides an overview of existing coloring techniques and discusses their applicability to VIPV, along with homogeneity and reproducibility. The weight analysis chapter debates whether the additional energy consumption due to the extra weight of the VIPV system is offset by the power generated by different PV technologies. The cost consideration chapter examines the potential economic benefits by analyzing the impact of various input parameters, such as irradiance, on output metrics like net present value. The final chapter addresses compliance and safety, summarizing automotive and PV testing standards with a focus on VIPV application for passenger cars.

Overall, the document includes (i) the current state of the art, (ii) proposed methodologies, (iii) example showcases, (iv) guidance for different stakeholders, and is slated for publication in 2024.

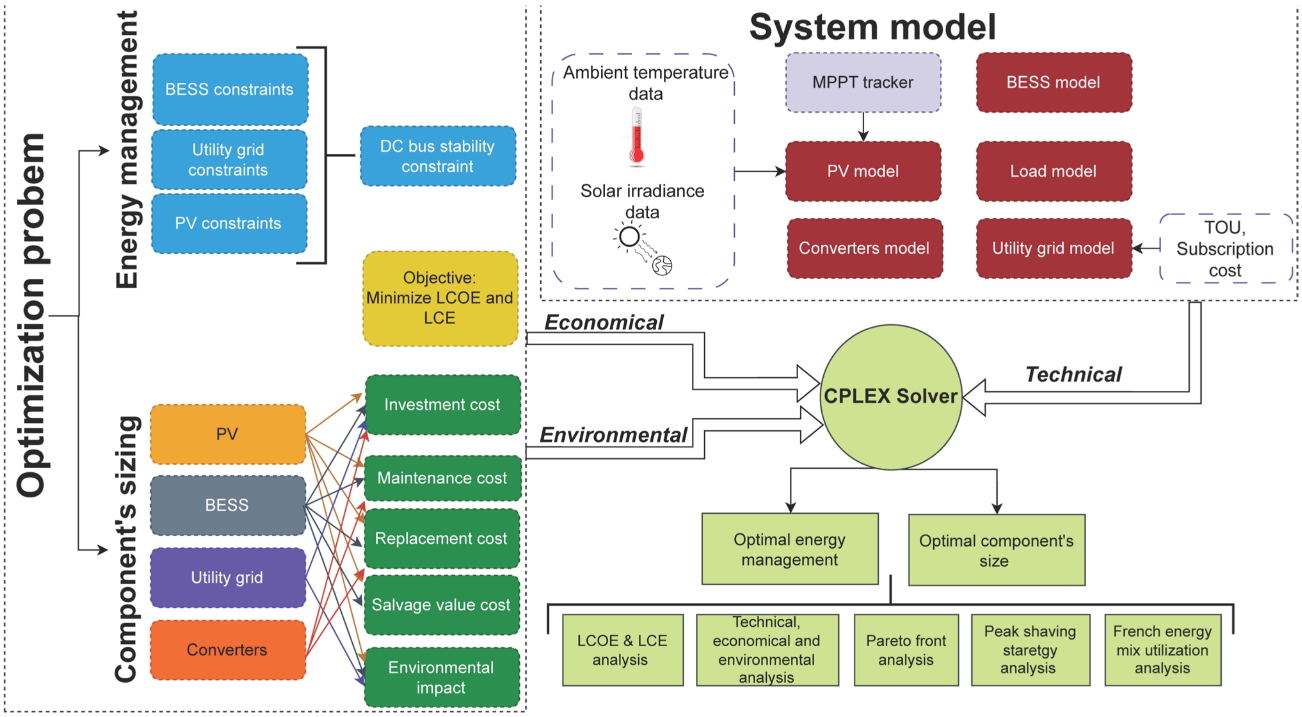

Fig. 29 - General framework of the PV-powered charging station multi-objective joint optimization algorithm (technical-economic-environmental co-optimization), https://doi.org/10.1016/j.renene.2024.120186

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

In 2023, the main results and findings were disseminated through publications in international journals and presentations at various conferences. Highlights from these results include:

- The application of a straightforward charging strategy, such as Mean Power, at Charging Point Operator (CPO) facilities for EV workplace charging significantly reduces the required size of the PV plant by nearly half compared to the traditional Plug and Charge mode. Moreover, the implementation of Solar Smart Charging could potentially decrease the size of the PV plant by nearly threefold.
  - ➢ This methodology was applied to a PV-Powered Electric Vehicle Charging Station (PVCS) at an industrial research complex in southern France, utilizing data from over 32,000 charging transactions over six years, involving 350 EV users and 80 charging points. The analysis compared three charging strategies: Mean Power, Plug and Charge, and Solar Smart Charging, aiming to maximize the self-production rate.
- An energy management optimization algorithm for PVCS, developed using mixed-integer linear programming, efficiently minimizes the total energy cost for EV users participating in Vehicle-to-Grid (V2G) services.
  - ➢ The optimization method not only meets the EV user demands but also enhances V2G service benefits, showing significant cost savings over the baseline scenario without optimization.
- Studies on PVCS for electric buses have outlined the characterization of current recharge and impact analysis, the required PVCS design, and the potential PV contribution. Modeling of electric bus operation and charging processes reveals the charging's impact on bus service quality by assessing delays and the local PV production's potential contribution.
  - ➢ Simulations indicate how charger placement affects bus battery capacity, peak power demand, and PV self-consumption ratio. Direct PV energy usage for bus charging remains low across scenarios, with insufficiency in winter but potential adequacy in summer with additional stationary storage.
- The optimal sizing of PVCS, determined through a technical-economic-environmental co-optimization, identifies the ideal PVCS capacity combined with an energy management algorithm, aiming to minimize the

levelized cost of energy (LCOE) while considering technical and economic factors.

- ➢ The simulation results shown that the off-grid PVCS requires higher resource capacity to fully supply the EVs while the overall cost is obtained 33% lower in on-grid PVCS case.

OUTLOOK FOR 2024

From the perspectives of 'Curvature,' 'Aesthetics,' 'Weight,' 'Cost,' and 'Compliance and Safety,' the technical requirements for PV-powered passenger vehicles are meticulously considered. Recently, the installation of PV onto heavy-duty vehicles like trucks is also expected to enter the market. Various aspects of PV-powered heavy-duty vehicles are discussed and analyzed.
The expected benefits and approaches covering both PV-powered vehicles and transport infrastructures include the resilience of PV-powered vehicles and charging stations, along with proposed business models for 'PV and Transport'.
Several studies will be conducted, including:

- Business models derived from energy and economic simulations in a PV-powered business park with integrated Vehicle-to-Grid (V2G) capabilities;
- PV-powered battery swapping stations along motorways;
- Energy management for an EV solar charging hub.

Based on the results and outcomes from all Subtasks and Activities, a roadmap or future scenario for both PV-powered vehicles and PV-powered infrastructures will be discussed. This will also include the potential global contribution and benefits.

All Task 17's PVPS Publications are available here.

TASK 18

OFF-GRID AND EDGE-OF-GRID PHOTOVOLTAIC SYSTEMS

Task Managers:
Mr Christopher MARTELL, Global Sustainable Energy Solutions, Australia
Mr Michael MÜLLER, OFRES, Germany

INTRODUCTION

The objective of Task 18 is to identify technical issues and barriers that affect the planning, financing, design, construction, operations, and maintenance of off-grid and edge-of-grid systems. This task focuses especially on challenges that are common across nations, markets, and system scales. It aims to provide solutions, tools, guidelines, and technical reports for free dissemination to those who might benefit from them.
Within the context of off-grid and edge-of-grid photovoltaic systems, the central discussion points include:

- Innovation: Enhancing systems to benefit from general innovations driven by other industries, enabling the installation and operation of systems with higher performance.:
- Reliability: Ensuring systems can generate and distribute energy to meet the demands of those connected with a high degree of confidence.
- Resiliency: Developing systems capable of withstanding or quickly recovering from natural disasters, deliberate attacks, or accidents.
- Security: Creating sustainably affordable systems that provide an uninterrupted energy supply, adequately meeting associated demands.

➢ Read about the objectives and structure of Task 18 in the Annex

2023 KEY ACCOMPLISHMENTS

Task 18 has also focused on evaluating software tools for standalone microgrid design and optimization. Various publicly available software tools that support microgrid design, optimization, and analysis have been analyzed.

The resulting report assists engineers, designers, and planners in selecting the appropriate software tools according to their requirements, including a special comparison between HOMER Pro and iHOGA PRO+.

Investigations into innovations stemming from lithium-ion batteries were conducted. PV off-grid best practice case studies have been selected for description in the report. Initial results indicate that, although lithium-ion battery systems can be significantly more expensive than lead-acid batteries, they may result in similar lifetime costs if financial conditions justify the higher investment. Digitalization in PV off-grid systems was another focus area.

A classification of digital technologies along the value chain of off-grid PV projects was completed. The degree of innovation and progress of each technology was investigated to understand trends and progress at each stage of the value chain.

Sustainable training schemes have been a part of the 2023 work. An inventory of existing training programs for maintenance in Tanzania was conducted, with a special focus on the target groups, their educational background, and their roles in the organization and implementation of maintenance. The distribution of roles varies significantly based on the system's institutionalization (ownership model and maintenance model), which can be completely private, state-organized, cooperative, non-commercial through a non-governmental organization (NGO), or in mixed forms.

Meeting Highlights 2023

- 02/2023 German kick-off meeting, Berlin, Germany
- 04/2023 F2F Task18 Meeting in Palma de Mallorca, Spain
- 0/2023 F2F Task18 Meeting in Adelaide, Australia Regular online meetings

OUTLOOK FOR 2024

The focus of work continues with the described work packages and shall result in a publication of 4 reports within 2024.

- Evaluation of Software Tools for Standalone Microgrid Design and Optimisation
- Lithium-Ion batteries in PV off-grid systems
- Digitalisation in design and management of PV off-grid systems
- Sustainable PV off-grid training schemes as a case study of Tanzania in Africa.

All Task 18's PVPS Publications are available here.

TASK 18 HIGHLIGHT

EVALUATION OF SOFTWARE TOOLS FOR STANDALONE MICROGRID DESIGN AND OPTIMIZATION

Task Managers: Gautam Rituraj (the Netherlands), Jorge Ortiz (Spain), Niccolo Ficarelli (Spain), Gautham Ram Chandra Mouli (the Netherlands), Paul Rodden (Australia), Christopher Martell (Australia), Xavier Vallve (Spain), Pavol Bauer (the Netherlands)

Evaluation of Software Tools

Task 18 Webpage

KEY MESSAGE

Selecting best performing standalone microgrid pre-design tools (between HOMER Pro and iHOGA PRO+) based on the criteria that apply to user's need.

OBJECTIVE

This report aims to evaluate (by defining criteria) publicly available software tools (whether freely accessible or paid) that facilitate the optimization to be done during the pre-design phase of standalone microgrids, and the creation of standalone microgrid case studies for comparison of these tools..

METHODOLOGY

1. Selection of software tools and definition of the criteria for comparison of these tools,

2. Case studies of standalone microgrids with measurements (and/or synthetic) data,

3. Simulations and analysis of results,

4. Evaluation of the software tools and recommendations.

Result Summary

1) HOMER PRO and iHOGA PRO+ are publicly available software tools for the microgrid optimization process during the microgrid pre-design phase.
2) 22 criteria (quantitative and qualitative) have been defined to help software users evaluate which software tool fits their needs better
3) Based on the quantitative criteria, it is found that the simulation results from both software tools are equivalent, both when simulation an existing microgrid with real measurement data and when simulating a new microgrid from scratch. However, based on the qualitative criteria, both software tools have some uniqueness in terms of their features.

TASK PARTICIPATION MATRIX

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

TM = Task Manager

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
AUSTRALIA	Australian Energy Market Operator (AEMO)				X				
	Australian PV Institute (APVI)	X							
	Ekistica			X					X
	Global Sustainable Energy Solutions (GSES)								TM
	IT Power Australia							X	
	Murdoch University			X					
	Royal Melbourne Institute of Technology (RMIT)					X			
	University of New South Wales (UNSW)	X	X		X		X	X	
	University of South Australia (UniSA)						X		

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
AUSTRIA	Austrian Institute of Technology GmbH (AIT)			X	TM	X			
	Austrian PV Technology Platform (TPPV)	X							
	Austrian Research Institute for Chemistry and Technology (OFI)			X		X			
	Polymer Competence Center Leoben GmbH (PCCL)			X					
	University of Applied Sciences Technikum Vienna					X			
	University of Applied Sciences Upper Austria (FH-OÖ)						X		
	Vienna University of Technology (TU Wien)					X			

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
BELGIUM	3E nv/sa			■					
	Becquerel Institute	TM							
	Energyville, IMEC			■					
	Energyville, KU Leuven			■		■			
	Lucisun					■			
	PV Cycle Association		■						
	Université Libre de Bruxelles (ULB)					■			
CANADA	Canadian Renewable Energy Association (CanREA)	■							
	Concordia University					■			
	National Research Council Canada					■			
	Natural Resources Canada - CanmetENERGY	■		■		■	■		
	University of Waterloo					■			
CHINA	Energy Intemet Research Institute, Tshinghua University							■	
	Institute of Electrical Engineering, Chinese Academy of Sciences	■	■	■	■	■			■
	Jinko Solar Co., Ltd.		■						
	LONGi Green Energy Technology Co., Ltd.	■				■			
	Public Meteorological Service Center, China Meteorological Administration						■		
	Trinasolar Co., Ltd.					■			
DENMARK	Danish Meteorlogical Institute (DMI)						■		
	European Energy A/S			■					
	Kenergy	■			■				
	Solar City Denmark			■		■			
	Technical University of Denmark (DTU)			■		■	■		
EUROPEAN UNION	European Commission Directorate-General for Research & Innovation Joint Research Centre	■			■				
FINLAND	Aalto University School of Science					■			
	Lappeenranta University of Technology	■							
	Turku University of Applied Sciences			■					

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
FRANCE	Laboratory for Innovation in Technology for Energy and New materials (CEA-LITEN)								
	Ecole Polytechnique à Palaiseau								
	Electricité de France (EDF R&D)								
	EnerBIM								
	Energy Network & Renewable Energies Department (ADEME)								
	Laboratoire PIMENT, University of Reunion								
	Mines ParisTech								
	Planair France SAS								
	SAP Labs France								
	Scientific and Technical Centre for Building (CSTB)								
	SOREN (PV Cycle France)								
	TotalEnergies		TM						
	University of Technology of Compiègne							TM	

TM = Task Manager

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
GERMANY	Africa GreenTec								■
	Asantys								■
	Ecolog Institute								■
	Forschungszentrum Jülich GmbH, Projektträger Jülich (ESE)	■						■	
	Fraunhofer Centre for Silicon Photovoltaics (CSP)			TM					
	Fraunhofer IBP		■						
	Fraunhofer IEE				■				
	Fraunhofer Institute for Solar Energy Systems (ISE)			■		TM	■		■
	German Aerospace Center (DLR)						■		
	Institute for Solar Energy Research GmbH (ISFH)			■					
	OFRES								TM
	Reiner Lemoine Institute								■
	Rolls Royce Solutions								■
	Technische Hochschule Ulm (THU)				TM				
	Univers GmbH			■					
ISRAEL	Arava EC&T			■					
	Israeli Public Utility Authority (PUA)	■							
	Office of the Chief Scientist, The Ministry of Energy	■							
ITALY	Elettricità Futura	■							
	European Academy Bozen/Bolzano (EURAC)			■		■	■		
	Gestore dei Servizi Energetici (GSE S.p.A.)	■		■		■			
	i-em						■		
	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)		■		■	■			
	Ricerca Sistema Energetico (RSE S.p.A.)	■	■	■			■		
	Sapienza University of Rome			■					
	University of Naples Federico II					■			
	University of Rome II - Tor Vergata						■		

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
JAPAN	Lixil					■			
	Mizuho Research & Technologies, Ltd.		■					TM	
	National Institute of Advanced Industrial Science and Technology (AIST)			■		■			
	New Energy and Industrial Technology Development Organization (NEDO)		■		■				
	Photovoltaic Power Generation Technology Research Association (PVTEC)					■			
	RTS Corporation	TM							
	Tokyo University of Science				■				
	University of Miyazaki							■	
	Waseda University							■	
KOREA	Kentech	■							
	Kongju National University					■			
MALAYSIA	Sarawak Energy Berhad								■
	Sustainable Energy Development Authority (SEDA)	■							
MOROCCO	IRESEN	■							■
NORWAY	Institute for Energy Technology (IFE)			■		■	■		
	Norwegian University of Science and Technology (NTNU)					■			
	Norwegian Water Resources and Energy Directorate (NVE)	■							
	RISE Fire Research AS					■			
PORTUGAL	Directorate-General for Energy and Geology (DGEG)	■							
	University of Lisbon Instituto Dom Luiz (IDL)							■	
SERIS	Solar Energy Research Institute of Singapore (SERIS)			■	■	■			
SOLAR POWER EUROPE	Solar Power Europe	■	■	■					

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
SOUTH AFRICA	Council for Scientific and Industrial Research (CSIR)								
	South African National Energy Development Institute (SANEDI)								
SPAIN	Centre for Research on Energy, Environment and Technology (CIEMAT)								
	Escola Superior de Comerc Internacional (ESCi), Oxford Brookes University								
	Mactech								
	National Renewable Energy Centre of Spain (CENER)								
	Public University of Navarra (UPNA)								
	Tecnalia								
	Trama Tecno Ambiental								
	Union Española Fotovoltaica (UNEF)								
	University of Alcala								
	University of Almeria								
	University of Jaen								
	University of La Laguna								
	University of Las Palmas de Gran Canaria								
	University of Malaga								
	University of Murcia								
	University of Sevilla								

TM = Task Manager

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
SWEDEN	Becquerel Institute Sweden	■							
	CheckWatt AB			■					
	IVL Swedish Environmental Research Institute		■						
	Mälardalen University			■					
	Research Institutes of Sweden (RI.SE)			■		■			
	Soltech Energy					■			
	Swedish Meteorological and Hydrological Institute (SMHI)						■		
	University Uppsala						■		
	White Arkitekter					■			
SWITZERLAND	Bern University of Applied Sciences				■				
	Dr. Schüpbach&Muntwyler GmbH							■	
	Institut für Solartechnik (SPF)						TM		
	Kromatix SA					■			
	Planair SA	■			■				
	Swiss Center for Electronics and Microtechnology (CSEM)							■	
	Treeze Ltd.		■						
	University of Applied Sciences and Arts of Southern Switzerland (SUPSI)			■		TM			
	Viridén + Partner					■			
	Zurich University of Applied Sciences (ZHAW)		■	■					
THAILAND	Department of Alternative Energy Development and Efficiency	■							
	King Mongkut University of Technology Thonbury, CES Solar Cells Testing Center (CSSC)			■					

TM = Task Manager

COUNTRY	ENTITIES	1	12	13	14	15	16	17	18
THE NETHERLANDS	bear-ID					■			
	Delft University of Technology		■						■
	Netherlands Enterprise Agency RVO	■							■
	Netherlands Organisation for Applied Scientific Research (TNO)		■			■		■	
	SmartGreenScans		■						
	Utrecht University			■			■		
TURKIYE	Middle East Technical University	■							
UNITED STATES OF AMERICA	Case Western Reserve University (SDLE)			TM					
	Clean Power Research (CPR)						■		
	Electric Power Research Institute (EPRI)		■		■				
	First Solar		■						
	National Aeronautics and Space Administration (NASA)						■		
	National Renewable Energy Laboratory (NREL)	■	TM	■			TM		■
	Sandia National Laboratory (SNL)			■					
	SmartGreenScans						■		
	Solar Consulting Services						■		
	State Universitiy of New York, Albany (SUNY Albany)						■		
	Univers Inc.			■					
	University of Oregon						■		
	US Department of Energy	■							

TM = Task Manager

AUSTRALIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors:
Renate Egan

Fig. 30 - PVPS Task Experts and Executive Committee Delegates at the Whole-of-Programme Meeting hosted by University of Adelaide, Mawson Lakes campus.

NATIONAL PV POLICY PROGRAMME

With solar power increasingly competitive in Australia, National Programmes that support deployment are drawing to a close, being replaced by initiatives that promote 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 has been met, with the installation of close to 9 GW of solar capacity exceeding 100 kWp. The program is now closed and will not incentivize future investment, yet interest in large-scale solar remains consistent.

Support for small-scale systems (up to 100 kWp) will continue until the end of 2030, with an uncapped Small-scale Renewable Energy Scheme (SRES) based on certificates (STCs) for their estimated generation until 2030. This means that STCs for small systems act as an upfront capital cost reduction. The value of the STCs decreases every year toward 2030.

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

National Programmes in support of solar PV are also complemented by state-based schemes that seek to attract new investment in clean energy projects. Examples include Renewable Energy Zones (REZs) that aim to combine utility-scale solar with wind, storage, and high-voltage transmission to deliver energy to load centers. By coordinating investment, connection, and location with respect to load, multiple generators, and storage, the REZ can capitalize 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 2023, research was funded by the Australian Renewable Energy Agency (ARENA), the Australian Research Council, and Cooperative Research Centres. ARENA is the largest funder of photovoltaics research in Australia.

The Australian Centre for Advanced Photovoltaics (ACAP), funded by ARENA, started its second term in 2023 to coordinate solar PV research nationally. ACAP is hosted at UNSW, and stage two will run to 2030, supported by $45 million AUD in ARENA funds and over $10 million in cash from partners.

ARENA also funded a host of new research initiatives in 2023, with close to $40 million AUD over eight years, under an Ultra Low-Cost Solar program aiming to drive the levelized cost of electricity from large-scale solar down from the current $50/MWhr to below $20/MWhr.

In addition, the federal government, under its education ministry, supported an initiative in research acceleration in the area of Recycling and Clean Energy (TRACE) with a program stream on solar technologies. The program has an ambitious goal to move rapidly and establish an innovation ecosystem to get research solutions to market faster.

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.

In 2023, Australia hosted the PVPS Whole-of-Programme meeting, including the PVPS Exco meeting and all Tasks. This was the first such large meeting in a decade, with the last one held in Kyoto in 2014. With over 100 delegates participating in meetings and a stakeholder workshop, the meeting was held in Adelaide to coincide with the end of the World Solar Car Challenge.

INDUSTRY & MARKET DEVELOPMENT

Australia had another down year with 3.77GW of solar installed in total, with most of the decline in utility scale solar, which is down to 972MW from a high in 2021 of 1.7GW (with 2022 recording 1.38GW). Residential, C&I solar remains strong with 2.77GW installed after 2.82GW last year, following a peak in 2021 of 3.28GW. Total installed solar capacity is now approximately 34.2GW.

We continued to observe a decline in solar costs, with the average price per watt (after incentives) dropping to $1.05 by December 2023, down from $1.10 in the previous year.

Rooftop solar accounted for an annual average share of total electricity demand generation of around 12%, while large-scale solar projects contributed over 6% for a combined total of 18% of electricity needs being met by solar throughout 2023. On the final day of 2023, Australia celebrated unprecedented achievements, with rooftop PV in Victoria and South Australia meeting the entire state demand at certain times.

The Australian storage market remained strong in 2023, with the Clean Energy Regulator now tracking and reporting battery installations. Over 23,829 new batteries were recorded as installed with small scale solar systems in 2023. Australia has now seen 90,160 batteries installed since 2014.The industry reports significantly higher numbers, reflecting a lack of systematic reporting to the Clean Energy Regulator.

The Australian market is favourably viewed by overseas battery/inverter manufacturers due to its high electricity prices, low feed-in tariffs, excellent solar resource, and large uptake of residential PV. There are also a large number of large-scale battery deployments being called for, as excess solar in the middle of the day results in curtailment, and evening peaks challenge grid capacity.

The total output for the 2022-2023 summer's rooftop solar was 8,046GWh, up 19.5 % on the same period the previous year.

2024 is expected to see stability in residential rooftop solar and continued growth in commercial and industrial installations. The economic fundamentals for residential and commercial PV are outstanding. Australia's high electricity prices and inexpensive PV systems mean payback can commonly be achieved in 3-5 years; a situation that looks set to continue in 2024.

There are increasing calls for large scale, firmed solar and wind projects and PPAs from large energy users, including mining and minerals processing companies, motivated by the low cost of energy from solar that could lead to a turnaround in the decline of utility scale solar installations.

Over 100 PVPS leadership and experts met in Adelaide for a once in a decade Whole of Programme PVPS ExCo and All Tasks meeting.

AUSTRIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 31 - Sonnenkraft-Campus in St.Veit/Glan, Austria – PV-Facade with certified Kromatix Solar Glas - Photo credit: Sonnenkraft.

NATIONAL PV POLICY PROGRAMME

As a member of the European Union, Austria fully supports the European climate and energy targets. At the national level, significant steps have already been taken towards climate neutrality by 2040. Central to this is the Renewable Energy Expansion Act (EAG), which has implemented a fundamentally modernized and market-oriented subsidy system for green electricity plants, thereby creating a stable long-term investment climate. In 2023, around 600 million EUR was made available for PV expansion via the EAG and the Climate Fund. From 2024, a reduction in VAT to zero per cent on systems up to 35 kWp will make the process much easier and will replace the support scheme, which was introduced in 2003 with the first eco-electricity law. From October 2022, a gradually increasing CO_2 price was introduced for fossil-based CO_2 emissions not covered by EU emissions trading. At the same time, households are reimbursed via the so-called “climate bonus,” which is a redistribution of revenue from CO_2 taxation. In addition, the BMK’s financial resources for the transformation of the energy and transport system were massively increased, and new instruments were created (e.g., transformation in industry). Nevertheless, almost two-thirds of the energy used in Austria currently still comes from fossil fuels. This proportion is set to be reduced to zero by 2040. Renewable electricity, in particular, will make a significant contribution to this. Electricity applications will become standard in the mobility and heating sectors.

The expansion of photovoltaics is one of the most important measures for converting the entire energy system to 100% renewable energy sources. This is associated with greater independence, environmentally friendly and low-risk energy provision, an affordable energy supply, and greater domestic value creation. The official target is currently set at 100% renewable electricity by 2030 (nationally balanced), in which PV is expected to increase by an additional 11TWh compared to 2020. Further targets are set in the draft of the Integrated Austrian Grid Infrastructure Plan, with 41TWh of PV by 2040.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation, and Technology, in conjunction with the Austrian climate and energy fund, offers a broad program of research and innovation support in the field of renewable energy and energy efficiency. PV systems are an integral part of many subsidized projects. Technological PV research was significantly more important in the 2023 annual energy research program than in previous years. The Austrian PV-Technology platform, which was initially supported by the same ministry, 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 the latest scientific results to the industry through innovation workshops, trainee programs, and conferences, joint national and international research projects, and other similar activities are part of the work program, in addition to the needed awareness raising, as well as aiming at further improving the framework conditions for manufacturing, research, and innovation in Austria for the relevant decision-makers.

The “Austrian Innovation Award for Integrated PV” is organized by the PV platform on a biannual basis. The target of “PV Integration” covers all kinds of integration of PV into the building, mobility, and agricultural sectors. In 2023, the fourth PV innovation award was launched.

Public spending on research, development, and demonstration projects in the energy sector amounted to 214.4 million EUR in 2022, of which about 9 million EUR went to Photovoltaic research.

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 program. Most Austrian producers in the photovoltaic sector are struggling to compete internationally. Research and innovation will increasingly play an important role.

INDUSTRY & MARKET DEVELOPMENT

The year 2023 was characterized by significant domestic market growth. Above all, rooftop photovoltaic systems for private, commercial, and industrial applications, as well as an increasing number of standard ground-mounted systems and agricultural photovoltaic systems, were increasingly implemented. This led to a doubling of the market figures in 2023 compared to 2022 and resulted in photovoltaic growth ofover 2.5 gigawatts in Austria, leading to about 10% of the domestic electricity demand.

In addition to standard applications, the commissioning of the largest floating photovoltaic system in Central Europe, along with many building-integrated photovoltaic systems and other integration solutions in the mobility sector, is also worth mentioning.

The Federal Association Photovoltaic Austria (PV-Austria) serves as 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 sectors and the political and public sectors. Its focus lies in 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 about the PV industry to the broader public, and organizes conferences, workshops, and industry meetings.

By the end of 2023, the association had 465 companies and individuals involved in the PV and storage industries as its members.

Doubling the market figures for 2022 in 2023 and resulting in photovoltaic growth of over 2.5 gigawatts in Austria, leading to about 10% of the domestic electricity demand.

BELGIUM

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 32 - Opening of the Soltech factory with the solar PV facade picture of a coal mine worker in the background

NATIONAL PV POLICY PROGRAMME

As Belgium is a federal state the responsibilities for energy policy are divided among the three regions (Flanders, Wallonia, Brussels) and the federal Government which is responsible for the renewable energy developments at the Belgian part of the North Sea.

During 2023 the Belgian governments wrote an updated National Climate Action Plan, in which the Flanders enhanced its solar PV target for 2030 from 6,7 GWp to 8,9 GWp. Wallonia stated a goal of producing 5100 GWh of solar PV electricity by 2030, which is comparable to 5 GWp at the end of 2030. The Federal Government aims for 1 GWp of floating solar in 2030. The Brussels Government didn't state an explicit target with regard to solar PV. All in all the combined targets yield to about 15 GWp.

Most specific measures are mentioned by the Flemish Government with regard to solar PV on large roofs: Big electricity consumers (more than 1 GWh of annual electricity consumption for the private sector and more than 250 MWh annual electricity consumption for public organizations) are obliged to install at least 10% of their roof area with solar panels, with at least 0,125 kWp per square meter horizontal roof area.

The subsidy of € 750 per system for residential customers in Flanders will not be halved to € 375 per 1 January 2024, as originally planned, but will be phased out completely as it is not deemed necessary anymore.

Given the cost decline of solar PV and the current market dynamics (already almost 10 GWp was installed by the end of 2023 and the annual installed capacity was 1.8 GWp in 2023) the overall target of 15 GWp by 2030 will be easily met. The assumption of the 2021 annual report that Belgium could reach 20 GWp to 22 GWp in 2030 can still be confirmed.

RESEARCH, DEVELOPMENT & DEMONSTRATION

R&D efforts are widespread over the value chain, from developing new cell architectures at imec/EnergyVille to power electronics, Agri-PV, floating solar, integration of PV in Concentrated Solar Power installations, and vehicle integration studies, this all at several universities and research centers.

Imec/EnergyVille reached an efficiency in a demonstrator set-up of a tandem cell (perovskite-CIGS) with an efficiency of 27,7%. This was done in the PERCISTAND project. Also perovskite-silicon tandem cell technology is in development. More and more emphasis of research is going to circularity issues, including LCA studies, focus on recycling of existing end-of-life panels a well as developing low-carbon footprint solar cells and modules, with very limited or no use of scarce materials, such as indium, bismuth or silver.

INDUSTRY & MARKET DEVELOPMENT

There are just a few, niche-market, solar module producers in Belgium. BelgaSolar (called EvoCells until recently) opened a 30 MWp production facility, aiming at consumers that value Belgian-made high-quality solar panels. Another example is Soltech, which targets the special use market of solar PV integrated in facades, glass, street furniture and stepping stones for instance. Their factory at a former coal mine site in Genk was officially opened in 2023 and shows a (solar PV) picture of a coal mine worker on their own façade.

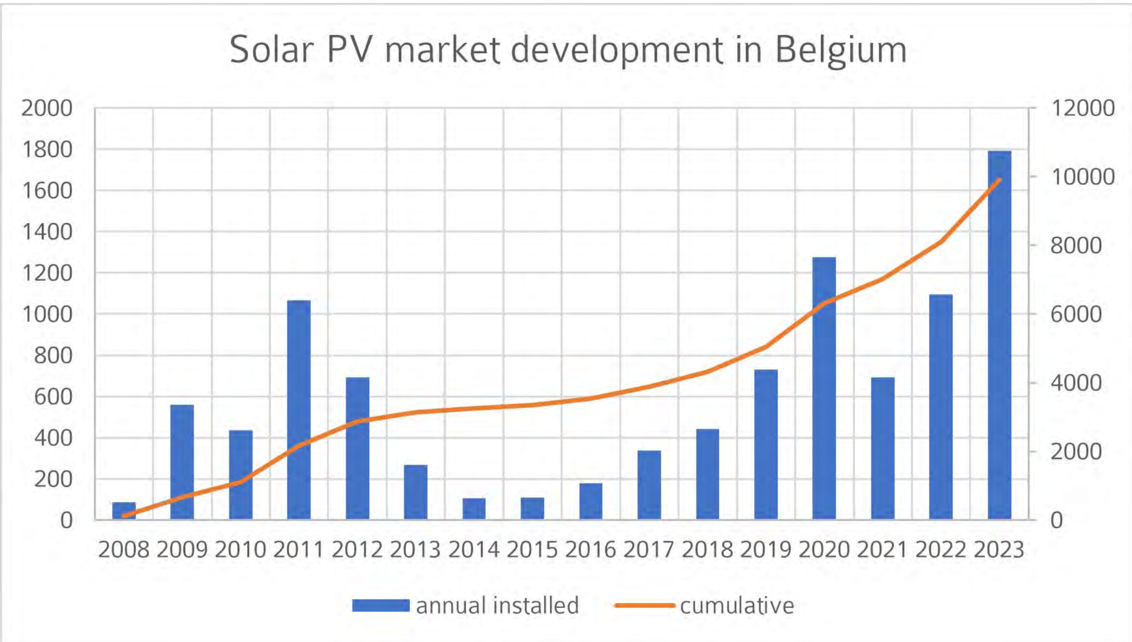

Fig. 33 - Solar PV Power in Belgium, both annual installed (blue bars) and cumulative installed (orange line). Data from Energy Commune

Since 2021 the market is growing again. Over the last decades we have seen a volatile market development, mainly because of policy changes in Flanders (which has the lion share of the market in Belgium). The effect of the sudden abolition of net metering can be seen in the almost halving of the market size in 2021. Also, the growth in 2023 is partly driven by the phasing out of the subsidies for residential systems per 1 january 2024. The high electricity prices in 2022 and 2023 stimulated demand as well. Today, no real subsidies are needed anymore in the residential sector due to the low cost of solar PV panels.

ELIA, the transmission system operator (TSO), measured a contribution of 9,7% of electricity by solar PV (or 7,2 TWh) in the electricity mix, up from 7,3% (or 6.4 TWh) in 2022.

CANADA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 34 - The North Klondike grid-tied PV system supplies power to the city of Whitehorse, in the Yukon Territory, and generates approximately 1.6 GWh of electricity annually. Photo credit: Solvest Inc. (Andrew Serack Photography)

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. However, there are no specific capacity installation targets for PV set by the federal, provincial, or territorial governments. As of December 31, 2022, Canada's PV sector reached approximately 6.45 GW_{DC} of installed capacity, representing a 12% increase (701 MW_{DC}) over the previous year. These data and other information on PV policy, prices, and industry trends are reported in Canada's annual National Survey Report[1] (NSR) provided to the International Energy Agency.

At the national level, PV is eligible for several federal support programs including the $1.56 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. There are also tax incentives for Canadian industry including, more recently, the Clean Technology Manufacturing Tax Credit which refunds 30% of costs for PV machinery and equipment. At the household level, the Canada Greener Homes Grant provides rebates of $1 000 per kW for a maximum system size of 5 kW, and the Canada Greener Homes Loan provides interest-free financing for green retrofits. Provinces and territories also implement their own local support policies such as capital subsidies, self-consumption, net metering, and Property Assessed Clean Energy programs whereby PV costs are repaid through property taxes.

1. In reference to Canada's NSR report for 2021 and all years prior, AC data were converted to and reported in DC using an AC/DC ratio of 0.85. Beginning in 2022, all data were reported in AC and the coefficient was changed to 0.67 to better reflect utility-scale system performance. The same coefficient is applied for both centralized and decentralized systems. Where DC figures in 2022 are compared to previous years, the 0.67 conversion has been retroactively applied. A shift from DC was undertaken because a growing number of provinces and territories report PV power generation in AC. However, DC data are used, for example, in the calculation of PV industry economic value and full-time jobs estimates.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Fundamental materials research into PV cell or module technology is conducted primarily through university and industry research groups, while research, 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 on the performance, durability, and costs of PV systems and components as well as their integration into buildings and electricity grids. CanmetENERGY in Varennes also studies PV system applications in remote Arctic communities in Nunavut, Yukon (Figure 1), 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.

Aside from the installation of standard ground-mounted and rooftop PV systems, there is also growing interest in agrivoltaics among Canadian PV installers, project developers, and farmers. More work is needed to promote research, develop case studies for different crops and PV configurations, implement policy mechanisms, and support farmers interested in renewable energy. Agrivoltaics Canada, a farmer-led not-for-profit advocacy group, was recently incorporated to help realize these goals in partnership with several academic institutions such as the University of Western Ontario.

INDUSTRY & MARKET DEVELOPMENT

Approximately 70% of Canada's cumulative 6.45 GW_{DC} PV capacity is connected to the low/medium voltage distribution grid and the remaining 30% to the high-voltage transmission grid. The economic value of the Canadian PV industry in 2022 was approximately CAD 1.81 billion. The combined number of full-time manufacturing, installation, distribution, and research employment in this sector was estimated to be approximately 13 000 jobs. This estimate, outlined in Canada's latest NSR, is highly conservative since it does not include PV system design and engineering, sales and marketing, project development and management, or legal/financial services and administration which collectively constitute a significant share of jobs. Examples of several large PV manufacturers in the Canadian market include Canadian Solar, Heliene, Stace and Silfab. Turnkey prices in CAD per Watt ($/W), as reported in the NSR, are divided into rooftop (building-added PV) and ground-mounted systems. For small rooftop PV systems from 1 to 10 kW, prices were around 2.07 to 2.71 CAD/W. Commercial roof-mounted PV from 100 to 250 kW varied between 2.22 to 2.50 CAD/W. Small ground-mounted centralized arrays between 10 to 50 MW in size were approximated by a lower price of around 1.31 CAD/W, but it was not possible to obtain data on an upper price boundary for this configuration at the time of writing.

Canada's Clean Technology Manufacturing Tax Credit covers 30% of the costs for new machinery and equipment used to manufacture low carbon technologies or to extract minerals and other resources used in their fabrication. This option is available to eligible property that was acquired and became available for use on or after November 21, 2023.

CHINA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 35 - The 19th Asian Games 100% green power supply [Source:The 19th Asian Games Official Website]

NATIONAL PV POLICY PROGRAMME

In 2023, guided by the goal of "carbon peak and carbon neutrality", China introduced nearly 200 energy-related policies. These policies aimed to optimise the development of the energy industry by guiding the scale of installed capacity, continuously strengthening the guidance of industry norms, enhancing the industry's overall planning, formulating industry standards, providing financial subsidies and policy incentives, and promoting the advancement of industrial technology. In 2023, the new installed PV capacity in China is 216.88GW(AC), an increase of 148.1% year-on-year. The Centralised PV base exceeded distributed PV base, with a new installation of 120.59GW(AC), an increase of 232.2% year-on-year.

On March 28, China issued a notice on supporting the development of the PV power generation industry and regulating land management. It requires that the development plan of PV power generation industry should be well connected with the spatial planning of land. It encourages the development of PV power generation industry by utilising unused land and existing construction land. Under the premise of strict ecological protection, it encourages the siting and construction of large PV bases in the Gobi desert regions.

On June 13, the Notice on the Pilot Work of Evaluating the Carrying Capacity and Enhancement Measures of Distributed PV Access to the Grid was issued. Requirements for rational arrangement of distributed PV filing scale and construction time, to guide enterprises and residents to do a good job in the development and construction of distributed PV systems.

On August 17, six national ministries and commissions issued the "Guiding Opinions on Promoting the Recycling of Decommissioned Wind Power and PV Equipment", which for the first time puts forward targeted opinions on the establishment of a sound PV recycling industry development in the form of a guiding document.

On August 3, the State issued the Notice on Doing a Good Job on the Full Coverage of Renewable Energy Green Power Certificates to Promote Renewable Energy Electricity Consumption, requesting to standardise the issuance of green certificates and issue green certificates for all the electricity produced by renewable energy power generation projects that have been built up in the country, such as wind power, solar power , conventional hydropower, biomass power , geothermal power and ocean power , so as to achieve full coverage of the issuance of green certificates.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The innovation of technology improved quickly in 2023. Scale production of p-type monocrystalline cells with PERC technology, reached an average conversion efficiency of 23.4%. N-type products have already made their mark in the market, with average conversion efficiencies of 25% for TOPCon cells and 25.2% for HJT cells.

LONGi Green Energy set a world record for silicon-perovskite tandem cells efficiency of 33.9% and for silicon solar cell efficiency of 27.09% in November and December 2023, respectively.

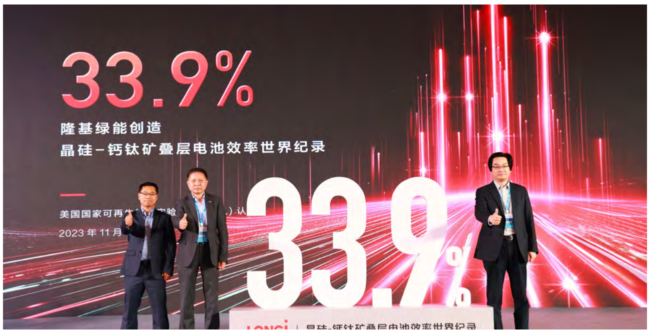

Fig. 36 - LONGi Green Energy set a world record for silicon-perovskite tandem cells efficiency of 33.9% [Source: LONGI]

The wafer thickness continued to decrease, with p-type monocrystalline wafers dropping to 150μm, n-type TOPCon monocrystalline wafers dropping to 125μm, and n-type HJT monocrystalline wafers dropping to 120μm.

The newly commissioned mass production lines are mainly n-type cell production lines, accounting for about 26.5%, of which the n-type TOPCon cell market accounted for about 23.0%, the HJT cell for about 2.6%, and the XBC cell for about 0.9%.
The market share for bifacial modules has now increased to 67.0% up from 40% in 2022.

By the end of 2023, the cumulative installed capacity of new energy storage projects in operation nationwide has reached 31.39 million kW, with an average energy storage time of about 2.1 hours. The new installed capacity is about 22.6 million kW, an increase of more than 260% from the end of 2022, nearly 10 times the installed capacity at the end of the "13th Five-Year Plan". Lithium-ion cell energy storage has increased to nearly 99%. It is expected that in 2025, the annual new installation of new energy storage in China will exceed 31GW and is expected to reach 35GW.
There are also many outstanding projects in PV applications.

In September 2023, the 19th Asian Games (Hangzhou) opened with the implementation of a dual-track mechanism of green power trading and green certificate purchasing, realising 100% green power supply for competition venues for the first time in the history of the Asian Games. Hangzhou Asian Games green power trading total electricity amounted to 621 million kWh, equivalent to reducing the use of about 76 300 tons of standard coal. Green power used in the Asian Games venues, both from outside the province of PV and wind power generation, but also from the distributed PV, offshore wind power and other green energy in Zhejiang Province.

LONGi and CENTER INT supplied a total of 3.88 MW of building-integrated photovoltaics (BIPV) products (LONGi Roof & LONGi Park) for the permanent venue in Boao Town,which was connected to the grid on March 15, 2023.

Fig. 37 - The Permanent Venue in Boao Town [Source: LONGI]

With installation of 523.1MW Astronergy PV modules, the first phase of the world's largest hydro-solar hybrid power plant - Kela solar power plant, also the world's highest power station of its kind, started power generation in China on June 25.

Fig. 38 - Kela Solar Power Plant [Source: Astronergy]

INDUSTRY & MARKET DEVELOPMENT

In 2023, the country's cumulative installed power generation capacity was about 2.92 billion kW, up 13.9% year-on-year. Among them, the installed capacity of solar power generation was about 610 million kW, a year-on-year increase of 55.2%; and the installed capacity of wind power was about 440 million kW, a year-on-year increase of 20.7%.

In 2023, China's new installed PV capacity was 216.88GW(AC), an increase of 148.1% year-on-year. Among them, most of China's utility PV projects were connected to the grid by the end of 2023, the second batch of base projects have started more than half of the work, and the third batch of base projects have completed nearly a quarter of the preliminary work. The new installed capacity of centralised PV power was 120.59GW(AC), up 232.2% year-on-year. Distributed PV power stations installed 96.29GW, up 88.4% year-on-year. The utilisation rate of PV power generation was 98%, down 0.3 percentage points year-on-year.

By the end of 2023, China's installed capacity of renewable energy power generation had exceeded 1.45 billion kW, accounting for more than 50% of the country's total installed power generation capacity, historically exceeding the installed capacity of thermal power, and the share of coal power installed capacity had dropped to below 40% for the first time.

Total renewable energy generation exceeded 3 trillion WkWh, accounting for about one third of the total electricity consumption of society, and per capita renewable energy generation reached 2 000 kWh.

On the manufacturing side, the output of all segments created new history, with growth rates above 64%. Among them, polysilicon production was 1.43 million tons, up 66.9%; wafer production was 622GW, up 67.5%; cell production was 545GW, up 64.9%; module production was 499GW, up 69.3%.

The market share of n-type cells increased rapidly, and the conversion efficiency of cells improved steadily, with the average conversion efficiencies of PERC, TOPCon and HJT reaching 23.4%, 25.0% and 25.2% respectively. The maximum power of modules reached over 750W, the market share of bifacial modules reached 67.0%, and the market demand for n-type products was strong. The market share of monocrystalline silicon wafers (p-type & n-type) exceeded 99%.

According to the forecast of China Photovoltaic Industry Association(CPIA) in Beijing, in February 28, 2024, the new PV installations in China in 2024 will reach 190-220GW(AC).
In 2023, the production volumes of polysilicon, silicon wafers, solar cells and modules in China increased significantly compared to 2022 (see Table 3).

Table 3: China

	Chinese PV industry production volume in 2022	Year on year increase from 2022
Polysilicon	1430 000 tons	66.90%
Silicon wafers	622 GW	67.50%
Solar cells	545 GW	64.90%
Solar modules	499 GW	69.30%

Source: China Photovoltaic Industry Association (CPIA) "2023 Photovoltaic Development Review and Outlook in 2024 Conference" in Beijing on 28 February 2024

The new installed PV capacity in China made a large leap in 2023 up to 216.88 GW (see Table 4).

Table 4: China

	Chinese PV capacity installed in 2023(AC) GW	Chinese PV capacity installed in 2023(DC) GW	Year on year increase from 2022
Total PV capacity	216.88	234.97	148.10%
Distributed capacity	96.29	96.29	88.4%
Centralized capacity	120.59	138.68	232.20%

Source: China Photovoltaic Industry Association (CPIA) "2023 Photovoltaic Development Review and Outlook in 2024 Conference" in Beijing on 28 February 2024

DENMARK

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 39 - 150 kWp PV system at Aarhus Harbor. Significant environmental initiatives beautifully integrated into the extensive roof surfaces of the innovative building "Karréerne" near Basin 7 in Aarhus. Green, living roofs benefiting insect life, biodiversity, and air quality. Photo: KlimaEnergi A/S

NATIONAL PV POLICY PROGRAMME

In 2022 the Danish Parliament decided that the country should implement a unified national PV program. However, due to a parliamentary election this decision was not realised. Finally, in 2023, it was decided that this national PV program should be developed and officially presented in the first quarter of 2024. This decision aligns with the political target of achieving a 70% reduction in carbon dioxide emissions by 2030, followed by reaching 100% in 2045. This ambitious goal was announced by the new government established after the national election November 2022. The latest forecast from the Danish Energy Agency expects PV to reach 7.5 GW by 2025 and more than 12 GW by 2030 and 18 GW by 2035. These figures are periodically revised.

Traditionally, the main potential for deployment of PV in Denmark has been identified as building-applied or integrated systems. However, there has been a growing trend towards ground-based centralised PV systems ranging from 50 to over 200 MW. These projects are typically based on commercial PPAs or providing power to the actual market price (Nordpool).

The total installed PV capacity in 2023 was 487.4 MWp compared to 1.754 MWp in 2022. The large drop is mostly affected by a 90% drop in the installed utility-scale projects due to new grid commission fees introduced in 2023. Additionally, longer municipality planning times and grid constraints are delaying the large scale PV plants. The reduction in installed capacity was already foreseen when the Danish Public Service obligation (PSO) funding grid connection cost was announced removed by the end of 2022. The residential sector grew by 40% in installed capacity from 61 MWp in 2022 to 84 MW in 2023. Both the commercial and industrial sectors showed 2 – 3 times growth in installed capacity from 2022 to 2023. All sectors are still driven by self-consumption from the PV plants which reduces the cost for electricity coming from the grid.

During 2020-2023 a number of R.D.D. projects has been supported mainly by the Danish Energy Agency's EUDP programme. Additionally, some technology-oriented support programmes targeted R&D in the green energy transaction have been initiated.

Net-metering for privately owned and institutional PV systems was established mid-1998 and still exists, however with consequent limitations and restrictions. In 2019, new requirements for generating plants to be connected in parallel with distribution networks (EN 50549-1) were implemented, along with national-specific requirements. The number of PV installations not applying for additional support but operating in the economic attractive "self-consumption mode", or based on selling electricity on the commercial market or through PPAs, is growing both in number and volume. Several commercial PV developers have activities in deploying PV across the EU, as well as internationally.

RESEARCH, DEVELOPMENT & DEMONSTRATION

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

The Energy Technology Development and Demonstration Programme (EUDP) under The Danish Energy Agency funds work by enterprises and universities on the demonstration of new green energy technologies. The program can support PV and every year different PV related projects are supported. The R&D program, as well as the ongoing and completed PV-related projects, can be found at the EUDP webpage.

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 digitalisation
8. Carbon capture, storage and use

ELFORSK - Danish Energy Association

ELFORSK supports projects that ensure a more efficient use of electricity at the end-users level. The projects cover 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.

INDUSTRY & MARKET DEVELOPMENT

The Danish PV Association established late 2008 with approximately 60 members, providing the emerging PV industry with a single voice and introducing ethical guidelines for its members. A few PV companies producing tailor-made modules such as windows-integrated PV cells can be found. 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. Several 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 domestic 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 of the members have activities inside and outside Denmark.

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

During 2023 the electricity market has almost normalised, with prices similar to those of the years before 2021. The increasing interest rates have raised financing costs, slowing down the growth of the market for residential systems slightly. However, the market for commercial and industrial systems is growing. Here, the customers place a significant focus on reducing their carbon footprint in their environmental reports, which they communicate to their customers.

The national green transition and the ambitious governmental target for CO2 reductions have the consequence that the forecast for electricity consumption in Denmark will double by 2030. This puts pressure on grid operators because connecting several GW of capacity for wind and solar parks and establishing thousands of charging systems for electric cars requires a lot of resources in terms of money and personal.

The electricity consumption in 2023 was 36.1 TWh, representing a growth of 2% compared to 2022. 84% of this consumption was covered by renewable energy sources, including biogas and sustainable biomass, among others. On a national level, the CO2 emissions per kWh used are now under 100 g.

Fig. 40 - Rema 1000's new headquarters and central warehouse is one of Denmark's largest roof-based PV systems with a capacity at 3.42 MWp covering a total area of 19,000 square meters. Phønix Tag Energi A/S supplied the PV system. Photo: Amatech

EUROPEAN COMMISSION

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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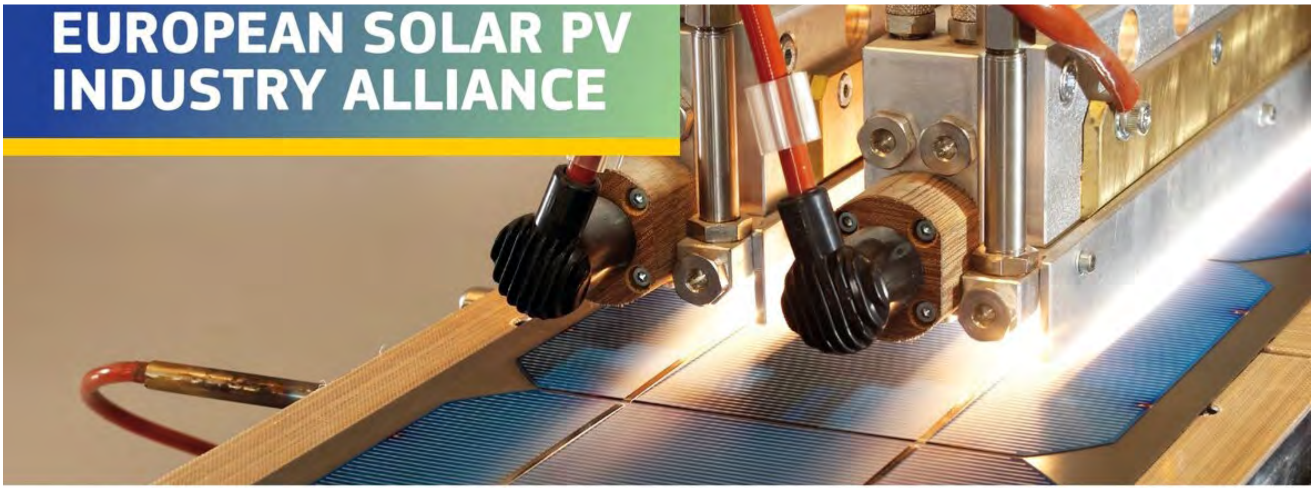

Fig. 41 - Photo courtesy of the European Solar PV Industry Alliance. More information: solaralliance.eu

NATIONAL PV POLICY PROGRAMME

During 2023, and as part of the Fit for 55 package, important legislative acts have been adopted concerning the deployment of renewable energy in the EU, including solar PV.

The EU Renewable Energy Directive (RED) was adopted in 2009 to achieve a minimum 20% share of renewable energy sources (RES) in EU final energy consumption by 2020. The RED was substantially revised in 2018 to meet the EU objective of a minimum 32% share of RES in final energy consumption by 2030. On July 14, 2021, the Commission adopted the 'fit for 55' package as part of the European Green Deal, which included a substantial revision of the RED. The co-legislators agreed to raise the share of renewables in the EU's overall energy consumption to 42.5% by 2030, with an additional 2.5% indicative top-up to potentially reach the overall share of 45%. Additionally, Parliament and Council agreed on accelerating the RES permit granting process and establish a series of sectoral targets (industry, transport, buildings, heating and cooling), some of which are binding, while others are only indicative (e.g. at least 5% of new renewable energy capacity to be of innovative renewable energy technology). The final act was signed on October 18, 2023. The revision of the Energy Efficiency Directive (EED) includes a targeted reduction of primary and final energy consumption of 11.7% at the EU level by 2030. According to the agreement, at least 3% of buildings owned by public administrations are to be renovated each year into near-zero energy or zero-emission buildings. The final act was signed on September 13, 2023. As part of the Fit for 55 package, the Commission adopted a legislative proposal to revise the Energy Performance of Buildings Directive (EPBD). An agreement between the Parliament and the Council was reached on December 7. It states that all new buildings should be zero-emission as of 2030, with new buildings occupied or owned by public sector being required to be zero-emission as of 2028. The agreement also envisages that Member States renovate the 16% worst performing non-residential buildings by 2030 and the worst performing 26% by 2033. The next step will be a formal endorsement of the agreement by the Parliament and the Council.

Following the rise in energy prices due to energy supply issues stemming from post-Covid recovery and Russia's aggression in Ukraine, the European Commission published its legislative proposal for an amending regulation to improve the EU electricity market design in March 2023. The provisional agreement between co-legislators foresees the use of Contracts for Difference (CfDs) in all investments in new electricity production from renewable and nuclear energy. The agreement also gives the Council the power to declare an electricity price crisis, reinforces the measures to protect energy-poor and vulnerable customers, and enables flexible use of the revenues generated by the state via two-way CfDs (e.g. to finance direct price support schemes or invest in reducing electricity costs for final consumers). The next step will be a formal endorsement of the agreement by the Parliament and the Council.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Horizon Europe - Work Programme 2023-2024 on Climate, Energy and Mobility under the destination Sustainable, Secure and Competitive Energy Supply, launched in 2023, includes the following topics in the field of Photovoltaics:

HORIZON-CL5-2023-D3-01-02: PV integration in buildings and in infrastructure aimed at:

- Demonstrating economic and sustainable integration of PV products in the built environment and infrastructure;
- Establishing enhanced collaborative innovation between PV companies and the (building) construction sector;
- Contributing to the Renovation Wave, the Mission on climate-neutral and Smart Cities and the New European Bauhaus initiative.

HORIZON-CL5-2023-D3-01-03: Floating PV Systems with the goal to:

- Expanding the potential application and minimising the environmental impact of Floating PV (FPV) technology for inland and offshore waters;
- Demonstrating significant improvements of FPV designs that reduce both CAPEX and OPEX and maximize energy output.

HORIZON-CL5-2023-D3-01-04: Solar Systems for Industrial Process Heat and Power aiming to:

- Demonstrate a system that, considering solar energy generation potential, topographical characteristics, land-use constraints, and system performance, generates solar medium-temperature heat and electricity in a modular, low environmental footprint, low cost and high-efficiency hybrid PV and ST design.

HORIZON-CL5-2023-D3-02-11: Advanced concepts for crystalline Silicon technology with the aim of:

- Developing architectures approaching the theoretical efficiency limit of c-Si cells and providing direction for even higher mass-production industrial cell performance.

HORIZON-CL5-2023-D3-02-12: Large Area Perovskite solar cells and modules with the objectives to:

- Increase the lifetime, efficiency and minimise the environmental impact of Perovskite PV.
- Enlarge the integration and application possibilities of PV technology with novel perovskite device architectures.
- Increase the potential for industrial production and commercialisation of perovskite PV, creating a competitive technological know-how for the European PV industrial base.

HORIZON-CL5-2023-D3-02-13: Operation, Performance and Maintenance of PV Systems expected to:

- Increase PV system performance, reliability, security and flexibility under various topology and operating conditions with enhanced digitalization.
- Increase utility-friendly integration of PV generation into the European energy system at high-penetration levels and the profitability of PV systems.

From these topics, 14 projects resulted with a total EC contribution of EUR ~81 million.

INDUSTRY & MARKET DEVELOPMENT

Under the European Green Deal and the REPowerEU plan, solar power is a building block of the EU's transition to cleaner energy. The EU solar generation capacity keeps increasing and reached, according to SolarPower Europe, an estimated 259.99 GW in 2023. The EU has long been a front-runner in the roll-out of solar energy. EU capacity additions in 2023 totalled 56 GW, representing a 40% increase over the additions seen in 2022 and a new record number for the third year running.

Table 5: The EU solar generation capacity keeps increasing and reached, according to SolarPower Europe, an estimated 259.99 GW in 2023.

Key facts on solar capacity		
164.19 GW	**204.09 GW**	**259.99 GW**
2021	2022	2023
The EU solar generation capacity keeps increasing and reached, according to SolarPower Europe, an estimated 259.99 GW in 2023		

However, in 2023, less than 2% of Europe's demand for solar panels could be met with European-produced solar panels and more than 90 % of PV installed in the EU was imported from China. To meet Europe's renewable energy objectives and avoid replacing one dependency for another the European Solar PV Industry Alliance was launched by the European Commission in December 2022. It aims to accelerate solar PV deployment in the EU by scaling-up to 30 GW of annual solar PV manufacturing capacity in Europe by 2025, facilitating investment, de-risking sector acceleration, and supporting Europe's decarbonisation targets.

Faced with massive support packages adopted by other third countries, the Commission presented in February 2023 a Green Deal industrial plan for the net-zero age. The plan sets out a European approach to boost the EU's net-zero industry. The Commission announced in this plan that it would present a Net-Zero Industry Act. The proposed regulation would establish the framework of measures for innovating and scaling up the manufacturing capacity of net-zero technologies in the EU, to support the EU's 2030 target and the Union's 2050 climate neutrality target. A provisional agreement on the Net-Zero Industry Act (NZIA) foresees measures aimed at ensuring that by 2030, the manufacturing capacity in the EU of strategic net-zero technologies approaches or reaches at least 40% of the EU's annual deployment needs. These strategic technologies include solar photovoltaics. The NZIA aims to ease conditions for investing in green technologies, by simplifying permit-granting procedures and supporting strategic projects. It also proposes to enhance the skills of the European workforce in these sectors and to create a platform to coordinate EU action in this area. The provisional agreement now needs to be endorsed and formally adopted by both institutions.

In addition, a Temporary Crisis and Transition Framework (TCTF), adopted in March 2023, permits flexible investment support schemes for production of strategic net-zero technologies. The Innovation Fund has so far granted support to new investments in solar manufacturing projects totalling approximately EUR 400 million over two years. And finally, the political agreement on the creation of a new Strategic Technologies for Europe Platform (STEP) will help to better channel the existing EU funds towards critical investments aimed at supporting the development or manufacturing of critical technologies, including clean technologies such as solar PV.

FINLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 42 - Solarigo Systems Oy built Finland's largest solar power park (13 MWp) as part of the Juurakko hybrid park in Kalajoki in 2022-2023. (Photo: Solarigo Systems Oy)

NATIONAL PV POLICY PROGRAMME

Finland has the objective to become a carbon-neutral society by 2035 and advancing towards carbon negativity. The Government, led by Prime Minister Petteri Orpo, will prepare a new national Climate and Energy Strategy during 2024-2025. In the Programme of Prime Minister Petteri Orpo's Government (20 June 2023), a goal for Finland to become a leader in clean energy and a positive climate handprint is highlighted.

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 the direct and indirect electrification of energy use with carbon-free electricity. The goal is to double the production of carbon-free electricity production (nuclear, wind, PV). Finland aims to become a key player in the hydrogen economy in Europe. Forest-based carbon sinks have an important role in achieving the carbon-neutrality target. Additionally, Finland aims to lead the way in the capture and utilisation of biogenic carbon dioxide (technological carbon sinks). 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 PV power generation in Finland. Previously, 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 increased during the last few years.

To support PV installations, the Ministry of Economic Affairs and Employment and Business Finland can grant investment subsidies to renewable energy projects. Energy aid may be granted to projects that promote new technology and its commercial utilization. The support is intended only for companies, communities, and public organizations, and it is provisioned based on applications. The need for and level of aid are assessed on a case-by-case basis. In 2023, a total of 14.85 million EUR energy investment aid was granted for two PV plants by the Ministry of Economic Affairs and Employment under Finland's Recovery and Resilience Plan. 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, amounting up to 40% of the total labour cost, including taxes, resulting up to about 10-15% of the total PV system cost.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In Finland, there are no specific budget lines, allocations, or programs for solar energy R,D&D, but PV is funded as part of open energy programs.

The research and development work at universities and research institutes is mainly funded by the Research Council of Finland and Business Finland, which also finance company-driven development and demonstration projects, and the European Union funding programs.

Research and development topics related to PV range from material science to PV systems, grid integration and solar economy. Research and development activities are distributed across various universities and research institutes: Aalto University, Lappeenranta-Lahti University of Technology and Tampere University, Metropolia, Satakunta and Turku Universities of Applied Science, as well as VTT Technical Research Centre of Finland.

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 2022, the installed off-grid PV capacity was estimated to be approximately 22 MW.

Currently, 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. In the end of 2023, the installed grid-connected PV capacity was estimated to be approximately 1000 MW. In 2023, PV represented 0.8% of the total electricity production in Finland.

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. The largest PV plant in Finland began operating 2023 in Kalajoki. This 13 MWp PV plant is part of the Juurakko hybrid PV and wind power park in Kalajoki. In recent years, several companies have announced their plans for multi-megawatt scale PV plants, even up to a scale of hundreds of MW. If all the current investment plans are realised, a total capacity of large-scale PV plants could increase to over 9 500 MW by 2030.

Business interest is currently particularly focused on implementing plants in areas where it is difficult to find other uses for the land, such as decommissioned peatlands. Integrating power storage in PV plants is often considered beneficial for balancing variable PV production. Additionally, there is increasing interest in combining PV production with wind power production to balance the variation in power production and improve the cost effectiveness of projects by using a common infrastructure.

If all the current investment plans are realised in Finland, a total capacity of large-scale PV plants could increase to over 9 500 MW by 2030.

FRANCE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 43 - The 2023 law for the acceleration of renewables included measures on value sharing with local citizens to increase benefits for local communities. (Image credit: Yann Villaret/ Solaris)

NATIONAL PV POLICY PROGRAMME

The current 10-year Energy Programme Decree (PPE), published in 2020, targets 3 GW to 5 GW of new capacity per year, aiming to reach 20 GW by 2023 and 35 GW to 44 GW by 2028. Consultations for the next revision began in mid-2022 for what was meant to be a mid-2023 publication of a structural Energy and Climate Law with an updated PPE. Ministerial announcements pushed this publication back to late 2023, then 2024. The draft French Energy-Climate Strategy, published in September suggests doubling the rhythm of PV development (5.5 GW_{AC} to 7 GW_{AC}/year) to reach 75 GW in 2035. However, in December, a draft Energy Sovereignty Bill was presented, deleting specific targets for renewables, including solar in the Energy Code.

In March, the 2023 Law on Accelerating Renewable Energies was adopted. It contains provisions to simplify and facilitate permitting, transcribing the December 2022 EU decision on overriding public interest for solar projects. This allows simplified assessment for environmental permits and creates renewable energy acceleration zones. Additionally it fixes shorter delays for permitting procedures and permits solar installations on previously unavailable land along trainlines, canals and motorways. It mandates solar installations on car parks and other buildings. The law also includes articles on "sharing" added value with local communities, defining agrivoltaic projects, modifications on local authority participation in RES projects, a new framework for PPA's. Measures to accelerate grid connections include queue jumping provisions, reformed provisions for regional capacity schemas, and incentives to share pre-project information between project developers and grid managers.

It received mixed support from the solar industry; after a long period of consultation, some provisions were considered potential barriers rather than enablers.
The unprecedented high wholesale costs of electricity in 2022

were not repeated in 2023, and prices stabilised between 60 and 90 €/MWh (still above 2020/2021 prices). The concurrent drop in price of commodities such as steel, as well as modules, meant that PV remained competitive over 2023.

An estimated 2 360 million euros are expected to be returned to the state from both the Contract for Difference mechanism and feed-in-tariff, through the obligated buyer – a significant windfall revenue for the state used to help finance capped electricity prices for consumers. Contributing to this, fiscal measures increased taxes on revenue from PV electricity sold directly on the electricity market in 2023 (90% for sales made at over 100 €/MW). This windfall did much to improve the acceptability of solar over 2023, with a positive impact on residential uptake and an increased visibility in the media.

RESEARCH, DEVELOPMENT & DEMONSTRATION

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

The National Energy Research Strategy serves as a focal point for various organizations, including the National Alliance for the Coordination of Research for Energy (ANCRE), which comprises 16 research organizations and competitive clusters, coordinating national energy research efforts. Additionally, the National Association for Technology Research, a public-private network, produced the 2023 report "Game Changers for the Energy Transition 2030-2050". This report includes specific recommendations for PV research, such as focusing on upstream research, tandem and perovskites, new supports for integrated PV (e.g. buildings, vehicles), digital twins, eco-conception and materials re-use.

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

IPVF works on perovskite, silicon tandem modules, III-V materials, and other technologies, with a clear goal of industrial transfer. In 2023, it included a partnership with Holosolis, a future GW scale manufacturer working towards 2T perovskite on cSI tandem, and several projects developing perovskite technologies. INES works with industrial partners on a wide range of subjects, including fundamental research on silicon and cell technologies, as well as applied research on module technologies. Recent work includes low-carbon-modules (demonstrator at 317 kg/ CO2/ kWp in January), low silver cells, record efficiencies for tandem perovskite/silicon cells (gaining 2% up to 28.4% in December), heterojunction silicon cells, flexible perovskite modules, and solar (TOPCon, HJT) for space applications. Several innovations are carried by spin-off-companies, such as ultra-light modules.

The principal state agencies financing research are : The National Research Agency (ANR), which funds projects through topic-specific and generic calls, as well as tax credits for internal company research; The French Agency for Ecological Transition (ADEME), which conducts its own calls for R&D on renewable energies and supports PhD students. It serves as the French liaison for the IEA PVPS, SOLAR-ERA.net and M-ERA.net pan-European network.

Table 6: 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	
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**	101.24 EUR/MWh	82.42 EUR/MWh	8.31 EUR/ MWh	80.38 EUR/MWh	60.1 EUR/MWh	84.84 EUR/ MWh

* Call for Tender is not limited to photovoltaics systems; other RES technologies are eligible as well.:
**Winning candidates tendered in 2021 (innovative), 2022 (Self Consumption) or 2023, depending on the tender

INDUSTRY & MARKET DEVELOPMENT

The main market segments in France include 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 1 MW up. Floating systems have become mainstream although volumes remain low, whilst many agrivoltaics projects are in development or in the early phases of production but remain somewhat experimental.

The number of systems installed in 2023 was more than double that of 2022 at 215 000. Roughly 2/3 of new capacity is pure injection, the remaining 1/3 with some form of self-consumption. Capacity with no injection has increased threefold since 2021, reaching over 60% of new 2023 capacity (110 MW) in commercial and industrial systems, a direct consequence of increased electricity prices. While partial self-consumption has increased at a similar pace, 80% of new partial self-consumption capacity is still in the residential segment, taking advantage of feed-in-tariffs and investment bonuses. Storage has picked up again, with nearly all installations in the residential segment, matching volumes seen in 2018 and 2019, with roughly 2 500 systems installed after a low of just 820 systems in 2021.

Overall grid-connected volumes grew by an unprecedented estimated 3.8 GW_{DC} (2.8 GW_{DC} in 2022, 3.7 GW_{DC} in 2021). The 100kWp to 250kWp segment grew from around 40 MWp per quarter in 2022 to nearly 300 MWp in Q3 2023 (or roughly 25% of the annual market), as a backlog of projects was connected after the combined impacts of revisions to Feed-in-Tariffs and reduced module prices. This brought the share of systems connected to the medium-voltage grid (over 250kWp) down to historical lows, hitting just 31% of the Q3 market and less than 40% overall. The total installed capacity topped 24 GW_{DC} (20 GW_{AC}), just meeting the 2023 PPE targets, once thought to be too conservative by industry actors.

New grid connection requests remained steady, with nearly 8 GW_{AC} of new projects in 2023 (compared to approx. 8 GW in 2022, 4 GW in 2021). The stock of projects with ongoing grid requests remains high, over 26 GW_{DC} (22 GW_{AC}), of which roughly two thirds are industrial or utility scale and over 5.5 GW_{AC} have signed preliminary contracts. Since the first PPE2 Call for Tenders in Q4 2021, 7.4 GW have been called, but only 4.4 GW have been awarded, due to chronically undersubscribed calls. The most notable exception is the Q4 2023 ground-mounted Call with over 1.5 GW awarded. Historically, the lead time for these systems from grid connection request (planning permits received) to grid connection is between 2 and 2.5 years. Considering this, 2024 should see at least 2 GW_{DC} of these systems commissioned. However, these volumes are well under the volumes in the grid connection queue, indicating strong and continued development of systems outside of subsidy frameworks.
Estimates for 2024 are in the range 4,5 GW_{DC} to 5.5 GW_{DC}, up on 2023 volumes with a considerable stock of projects in the grid connection queue, low modules prices and increased labour available.

Table 7: Feed in tariffs for 4th quarter 2023

Power of PV installation (kW)	Feed in tariff no self-consumption (Ta,b,c)	Feed in tariff for partial self-consumption and bonus (Pa,b)	Bonus for certified building integration products (Pint) : expired 09/10/2023
≤3 kW	173.5 EUR/MWh	130 EUR/MWh (+0.37 EUR/W installed)	0.133 EUR/W installed
3 kW to 9 kW	147.4 EUR/MWh	130 EUR/MWh (+0.28 EUR/W installed)	
9 kW to 36 kW	138.2 EUR/MWh	78 EUR/MWh (+0.20 EUR/W installed)	
36 kW to 100 kW	120.2 EUR/MWh	78 EUR/MWh (+0.10 EUR/W installed)	
	120.8 EUR/MWh	120.8 EUR/MWh	"< 250 kW : 0.128 EUR/W installed < 500 kW : 0.125 EUR/W installed "

GERMANY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 44 - Dual land use for agriculture and photovoltaics (© Forschungszentrum Jülich / Sascha Kreklau)

NATIONAL PV POLICY PROGRAMME

Germany is one of the leaders in the transition to renewable energies, with photovoltaics (PV) playing a pivotal role on the road to sustainable energy. Recent developments in PV in Germany underscore both technological advancements and policy shifts that are shaping the nation's renewable energy landscape. The solar package, which was approved by the cabinet on 16.08.2023 (but not by parliament!), marks a further key step towards achieving the ambitious PV expansion targets by 2030 and implements key elements of the photovoltaic strategy, presented by the German Federal Ministry for Economic Affairs and Climate Protection (BMWK) in May 2023.

By 2035, the electricity supply should be almost climate-neutral, i.e. almost completely powered by renewable energies and green hydrogen. The German government has therefore decided to increase the share of renewable energies in Germany's (gross) electricity consumption to over 80% in 2030. To achieve this, the Renewable Energy Sources Act (EEG) aims for 215 gigawatts of installed photovoltaic (PV) capacity in 2030. This requires the annual expansion of photovoltaics to increase to up to 22 gigawatts within just a few years. With the installed capacity doubling to over 14 GW in 2023 (see Fig. 1), Germany is well on the way to achieving this goal. This is reflected in the record participation in the Federal Network Agency's last tender for ground-mounted PV systems. The tender volume of 1,6 GW was oversubscribed almost three and a half times and the average award value determined was a low 5 cents/kWh.

This strong expansion also makes sense because photovoltaics is one of the cheapest energy sources and is therefore one of the most important power generation sources of the future.

Furthermore, the BMWK wants to initiate funding to strengthen the domestic solar industry, which seeks to establish or expand production capacities in Germany. In the run-up to the planned funding along the entire value chain of photovoltaic production, the Ministry has launched an expression of interest procedure as a first step. The process is still ongoing.

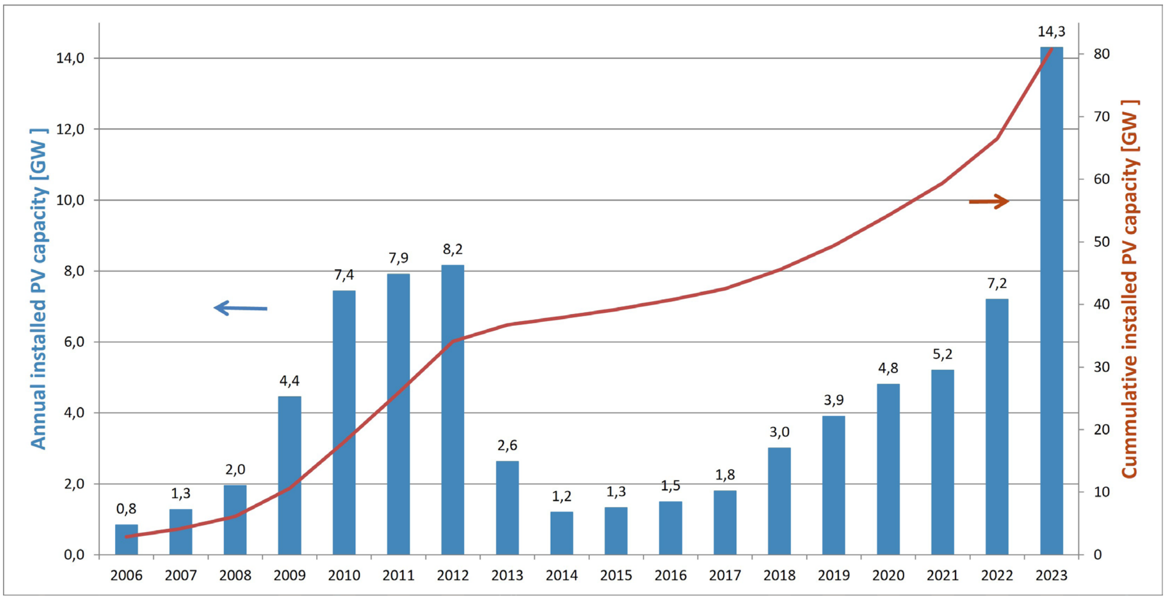

Fig. 45 - Development of annual PV installations and cumulated installed capacity

RESEARCH, DEVELOPMENT & DEMONSTRATION

Energy research funding has been supported for years by specific energy research programs (see the programs and Fig.45 for granted PV projects under the 6th and 7th Federal Energy Research Program - ERP).

In 2023, the Federal Ministry for Economic Affairs and Climate Protection has published the new 8th Energy Research Program for applied energy research entitled "Research missions for the energy transition". It outlines the objectives and priorities for research funding in the coming years. For the first time, the BMWK is pursuing a mission-oriented research and innovation policy. The focus is on cross-sector and cross-thematic project funding that is targeted at specific and ambitious goals. In this way, research results should contribute to accelerating the transformation of the energy system and be put into practice quickly.

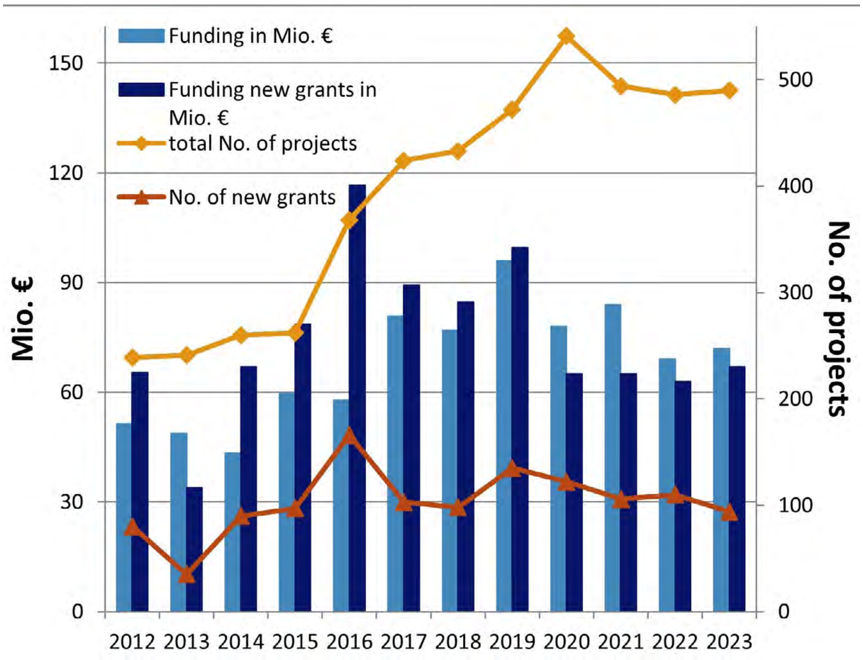

Fig. 46 - R&D support and quantity of PV projects funded by BMWK in the 6th and 7th ERP

The five missions of the BMWK's energy research program are

- Mission Energy System 2045: Research for a resilient and efficient energy system
- Mission heat transition 2045: Research for a climate-neutral heating and cooling supply
- Mission electricity transition 2045: Research for the conversion of the electricity supply to renewable energies
- Hydrogen mission 2030: research for a sustainable hydrogen economy
- Mission Transfer: rapid transfer of research results into practice

In 2023, the focus areas of R&D projects for PV included technology developments for high efficient solar cells and modules, silicon-perovskite tandem solar cells, and issues of reliability and sustainable operation of photovoltaic systems

Fig. 47 - Dual land use for agriculture and photovoltaics (© Forschungszentrum Jülich / Sascha Kreklau)

INDUSTRY & MARKET DEVELOPMENT

The market of photovoltaic systems in Germany has been steadily growing over the last ten years, with the cumulative installed capacity reaching 81 GW in 2023, experiencing a boost of 14 GW in that year alone. For the first time, in 2023 more than half of Germany's electricity was generated from renewable energies such as solar and wind power. This is also reflected in the number of people working in this area. Employment in the energy transition is significantly increasing. In 2022, the employment level in renewable energies was 387 700 people, with the solar energy sector accounting for 22% of this figure. Compared to the previous year, employment in 2022 increased by 14.9% or 50 400 additional employees. This made 2022 the year with the highest level of employment since 2012 and the largest annual increase since 2006. Due to the very high expansion this year, significantly higher employment figures can be expected for 2023. Nevertheless, the market environment remains very challenging, especially for German photovoltaic manufacturers, due to strong competition, particularly from Asia.

For the first time, in 2023 more than half of Germany's electricity was generated from renewable energies such as solar and wind power.

ISRAEL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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NATIONAL PV POLICY PROGRAMME

In 2023, Israel increased its total renewable energy (RE) capacity by approximately 860 MW, reaching a total of ~5,500 MW. By year-end, Israel achieved 12% RE electricity generation, calculated by the potential of the installed capacity at year's end and its average hourly production. Two-thirds of Israel's PV capacity comes from decentralized rooftop and water reservoir sites.

In 2022, the General Assembly of the Electricity Authority allowed the entrance of additional 2.5 GW of RE into the grid.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Chief Scientist Office (CSO) at the Ministry of Energy supports research and development (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 2023, the Office of the Chief Scientist invested over 20 million USD in energy-related R&D projects. Winning projects include waste to energy by gasification, AgroPV, green hydrogen, energy efficiency, and various applications for dual use.

INDUSTRY & MARKET DEVELOPMENT

In 2023, the price of electricity increased by 16% to 0.4598 ILS, excluding VAT, per KWh, still one of the lowest in the developed world.

Table 8: Israel Electricity prices between 2016 to 2023 in ILS cents (PUA report)

2017	2018	2019	2020	2021	2022	2023
47.26	46.19	47.16	44.84	43.30	45.98	53.4

In 2022 the Israeli PUA published a fix tariff of 0.245 ILS/ KWh for 100-300KW 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. 815MW were accepted at a tariff of ILS 0.1705 (0.053$) per KWh
Israel had approved a national outline plan for over 130 AgroPV sites, which are expected to be built in the last quarter of 2023.

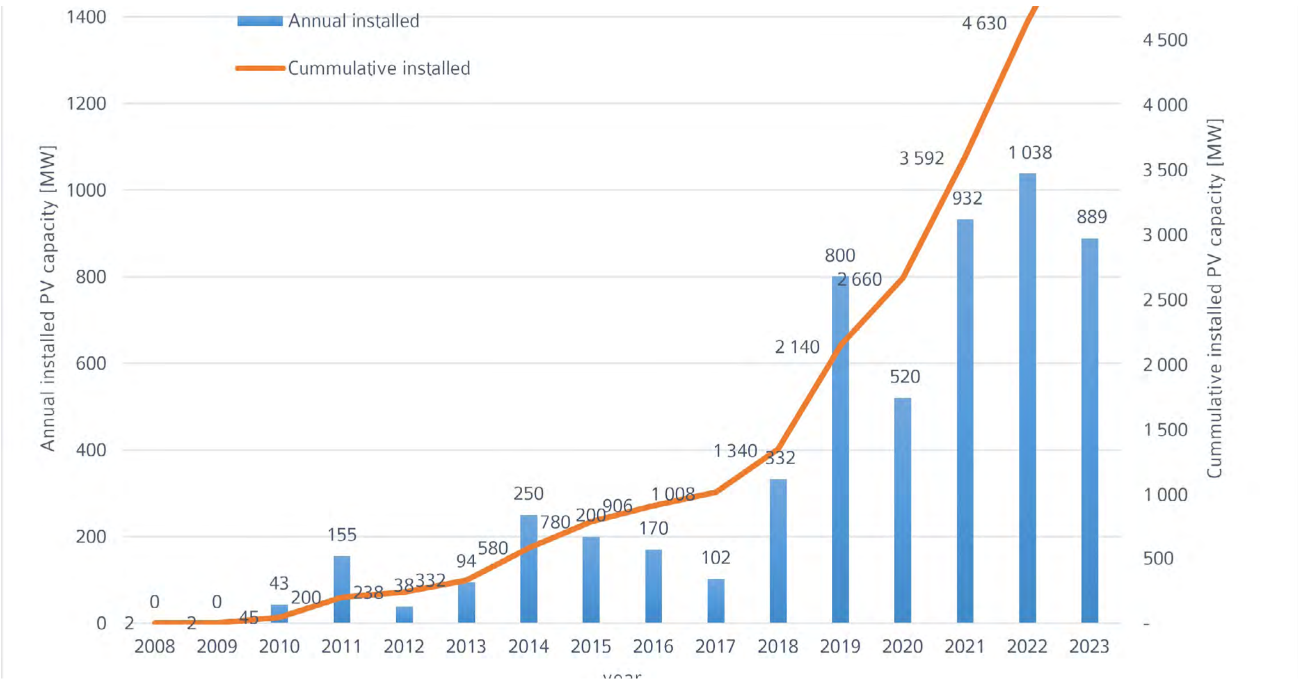

Fig. 48 - Development of grid connected PV capacity in Israel through 2023

ITALY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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This work has been financed by the Research Fund for the Italian Electrical System under the Three-Year Research Plan 2022-2024, funded by the Ministry of the Environment and Energy Security (MASE).

Fig. 49 - Innovative integrated solutions of agrivoltaic plant with assembly of modules elevated from the ground, Borgo Virgilio, nominal power 2,15 MW (Photo courtesy of RemTec)

NATIONAL PV POLICY PROGRAMME

The Integrated National Plan for Energy and Climate (PNIEC), bolstered by several initiatives of the National Recovery and Resilience Plan (PNRR), paves the way for energy decarbonization in Italy and was updated in 2023. The update increases the 2030 targets in line with the Fit for 55% goals and the REPowerEU perspectives. The main 2030 target (a 30% RES energy share in gross final energy consumption) necessitates new PV installations reaching 80 GW of cumulative PV installation and an annual production of 100 TWh. The trend in PV installations appears to align with the required evolution of photovoltaic installations, but despite the costs being suitable for installing PV plants at market parity, obtaining permits for installation remains challenging. In 2023, Italy added 5.23 GW of PV capacity, reaching a total of 30.3 GW (+21% compared to 2022) (see fig.50).

Below are some key measures to support PV installations:

a) Economic support

- The tax relief mechanism for installing residential systems (up to 20 kWdc), reimbursing 50% of the photovoltaic installation costs; this is noted as an even more advantageous measure.
- A feed-in tariff mechanism, established by Ministerial Decree, supports "mature" RES.
- A premium tariff for shared and self-consumed energy in Renewable Energy Communities (CER), enhanced by a recent decree that increased the single plant power limit to 1 MW and expanded the perimeter to primary electric stations.
- A PNRR investment promotes PV installation on agricultural infrastructure roofs for Agrivoltaics and floating PV on water basins.
- PNRR investment of 2.5 billion euros for Industrial Transformation, developing strategic supply chains in the transition towards a zero-emission economy (solar photovoltaic, wind, batteries, heat pumps, electrolysers, and technologies for the capture, storage, and use of CO_2), energy efficiency, and sustainability of production processes.

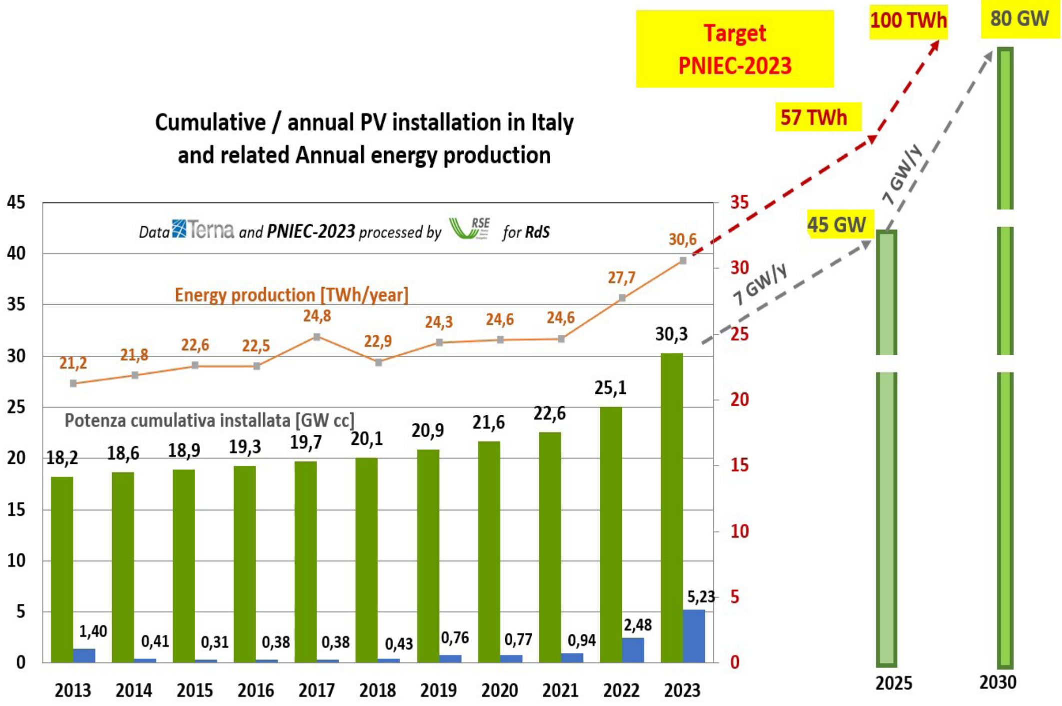

Fig. 50 - Cumulative and annual PV installations in Italy [GW_{DC}] and related Annual energy production [TWh] at 2023 (data source: TERNA)

b) Structural reforms for easier market penetration

- Simplification and rationalization of environmental regulations regarding permitting procedures.
- PV on roofs: no authorization required; only simplified communication to the grid operator is needed for power installations up to 200 kW.
- Designation of special areas suitable for PV installation by law (e.g., abandoned industrial areas, compromised and marginal areas, ceased quarries, and mines), while criteria for regional "suitable areas" for PV installations are being defined in discussions between the Government and the Regions.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The advancement of new photovoltaic (PV) technologies and the exploration of integrated, innovative PV solutions are crucial for achieving Italy's national goals outlined in the PNIEC and the PNRR. These efforts aim to create competitive growth opportunities for the national industry and enhance the benefits for electricity system users through savings and environmental sustainability. Research in the PV sector prioritizes increasing module efficiency and reducing the land needed for installations, aiming for impactful results in the short to medium term.

One key objective is developing competitive domestic supply chains for Renewable Energy Sources (RES), especially PV, to lessen reliance on imported technologies and boost innovation in fields like photovoltaics, electrolysers, and batteries. The Research Fund for the Italian Electrical System (RdS), supported by the Ministry of the Environment and Energy Security (MASE) and the PNRR, significantly backs research and development in new PV technologies, involving various research institutes and PV operators.

Fig. 51 - Visit of the President of the Italian Republic, Sergio Mattarella, and the President of the Federal Republic of Germany, Frank-Walter Steinmeier, to the 3SUN Gigafactory in Catania, which will soon be the largest new generation solar module factory in Europe (22.09.2023) (data source Presidenza della Repubblica Italiana Quirinale).

ENEA, a public research entity, focuses on high-efficiency solar cells, module eco-design, PV system digitalization, and promoting "Sustainable Agrivoltaics." RSE, a private energy system research company, explores multi-junction solar cells, thin film deposition on Si-cells, advanced PV plant operations and maintenance (O&M) strategies, and Life Cycle Assessment (LCA) of innovative PV technologies. Other key research organizations include CNR and EURAC Research, working on low-cost thin film processes and improving PV plant performance, respectively, alongside contributions from university labs and PV operators covering the entire PV value chain.

Additionally, Italy hosts the ReteIFV "National Photovoltaic Network for Research, Development, and Innovation," fostering collaboration in photovoltaic project initiatives and research infrastructure nationwide, supporting the research and innovation activities mentioned.

INDUSTRY & MARKET DEVELOPMENT

An interesting sign of the photovoltaic market's excellent recovery in Italy comes from the installation numbers registered in 2023. According to preliminary data provided by TERNA and GSE, a cumulative value of 30.3 GW was reached in Italy (+21% compared to 2022), adding 5.23 GW of PV capacity in the year (see fig. 1). The energy produced by PV in 2023 amounted to 30.6 TWh, of which approximately a quarter was self-consumed, representing 10% of the total electricity demand. Regarding size, 4.4 GW of PV plants are decentralized, while 0.9 GW are centralized/industrial scale.

GSE data also reveals that the growth observed in recent years concerns all sizes of photovoltaic plants, and for those larger than 1 MW, mainly located on the ground, there was a notable recovery in the last quarter of 2023. On the fronts of economic support and structural reforms, the government has made further efforts to promote the photovoltaic objectives indicated above.

The leading regions for photovoltaics are in northern Italy (even if the solar potential is lower) while southern Italy, although growing, remains significantly behind except for Sicily, which gains fifth place in the ranking of regions with the greatest power and production. It can also be observed a growing diffusion of storage systems associated with PV plants: at the end of 2023, there were a total of around 536,000 (+100% compared to 2022), mainly concentrated in the residential sector.

Among the initiatives of Italian photovoltaic producers, it is worth mentioning both that of FuturaSun, for the creation of a line of 1 GW/year high-efficiency modules in the Veneto region, and that of EGP for the creation of a line of HJT cells and 3 GW/year modules in the Catania plant (Figure 2), whose start-up is expected by June 2024. The topic of Agrivoltaics is attracting great interest from agricultural and photovoltaic operators, with a significant amount of GW in the permitting process. Agrivoltaic systems (Figure 3) allow for combined use of land for energy production and agriculture, thus reducing land use and landscape preservation concerns. In November 2002, the Italian Association for Sustainable Agrivoltaics (AIAS) was launched (chaired by ENEA) and now accounts for about 100 members from different sectors (energy, technology, agriculture, research). Several guidelines (at national and regional levels) and technical specifications have been published, with the aim of making a clear distinction between ground-mounted PV and agrivoltaics, and eventually easing the permitting process:

- UNI/PdR 148:2023, Sistemi agrivoltaici - Integrazione di attività agricole e impianti fotovoltaici (03.08.2022)
- CEI PAS 82-93 ed. 2 (2024-01) Public Available Specification on Agrivoltaic systems from the CEI - Italian Electrotechnical Committee, which was attended by several photovoltaic and agricultural experts.
- Ministerial decree on agrivoltaics (13.02.2024), which include a definition of "advanced agrivoltaics".

The trend of photovoltaic installations in Italy seems to have reached the annual trend necessary to achieve the national objective of decarbonisation of the energy system. While agrivoltaics, energy communities and floating photovoltaics appear to be the most promising new applications, further efforts are needed to overcome the still difficulties in obtaining permits for PV installations..

JAPAN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 52 - PV system at Tokyo Big Sight in Koto Ward, Tokyo (T-Green® Multi Solar, building-integrated PV (BIPV) modules, see-through type and solid type, jointly developed by TAISEI and KANEKA) PV power generation capacity: 0.68 kW ©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 Countermeasures by the Ministry of the Environment (MoE), the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), and the Ministry of Agriculture, Forestry and Fisheries (MAFF), among others, have started their initiatives. These four ministries have promoted the expansion of PV introduction through laws, systems, measures, regulatory reforms, and budgets under their jurisdictions. Additionally, the government has placed these initiatives under the Basic Policy for the Realization of GX. The Basic Policy consists of the following:

1.) thorough promotion of energy conservation;
2.) making renewable energy a main power source;
3.) utilization of nuclear power; and
4.) addressing 11 other important issues.

Regarding making renewable energy a main power source, the sure accomplishment of the renewable energy power source ratio of 36 to 38% in FY 2030 is targeted based on the Sixth Strategic Energy Plan, with close cooperation among the related ministries, agencies, and organizations. As an immediate response, Japan will not only expand PV installations in public facilities, residences, factories, warehouses, airports, railways, etc., but also promote PV introduction led by local communities while utilizing the Global Warming Countermeasures Act. In addition to the introduction under the Feed-in Premium (FIP) program, the expansion of introduction models that do not rely on the FIP program will also be promoted. On a mid- to long-term basis, as grid improvement and responses to output fluctuations accelerate, measures toward the next decade were presented, such as improving the grid nationwide, securing dispatching ability with stationary storage batteries, improving the technological self-sufficiency rate by mass-producing next-generation solar cells (perovskites, etc.) on a GW scale, ensuring business disciplines for PV installations in harmony with local communities, maximizing the use of existing PV systems, and systematically responding to the mass disposal of PV modules in the future. Further, the government has developed the Basic Policy for the Realization of GX into the GX Promotion Strategy and formulated the 13 TJPY GX Investment Strategy that includes perovskite solar cells and storage batteries using GX Economy Transition Bonds. Based on the GX Decarbonization Power Supply Act, METI has been promoting the improvement of the dissemination environment through the creation of new rules to ensure harmony with the local community (stricter approval, holding briefings, the establishment of an order for the return of the renewable energy surcharge, recycling, making PV a long-term stable power supply, etc.), establishing a new FIT price for the expansion of rooftop installations, and introducing a package to reduce output curtailment. With the aim of prioritizing and maximizing the introduction of renewable energy, MoE has continued to take the initiative in introducing PV in public buildings by national and local governments, introducing community-friendly PV power generation led by municipalities through positive zoning, supporting the introduction of self-consumption type PV systems by private businesses, and creating Decarbonization Leading Areas based on the local decarbonization roadmap. MoE plans to establish 100 Decarbonization Leading Areas nationwide and selected 28 in FY 2023, the second year of the scheme, making the total reach 74 locations. In addition, the target PV installed capacity on government-owned land and facilities has been set at 114 MW by 2030. The PV installed capacity in 2023 (preliminary figure) is estimated to be 6.3 GW_{DC}. It is primarily introduced under the FIT and FIP programs, but it also includes PV systems for self-consumption via PPA with subsidies that are not covered by the FIT program, and the voluntary introduction that does not use the scheme or subsidies.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Regarding research, development, and demonstration activities for PV technology, commercialization efforts administered by METI are conducted by the New Energy and Industrial Technology Development Organization (NEDO), and fundamental R&D administered by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) are promoted mainly through the projects of the Japan Science and Technology Agency (JST) and the subsidy program for Grants-in-Aid for Scientific Research. NEDO is working on the research and technological development of film-type ultra-light solar cells, wall-mounted PV system technologies, and PV modules for mobility under the "Development of Technologies to Promote Photovoltaic Power Generation as a Primary Power Source" project (FY 2020-FY 2024). In 2023, Sharp achieved the world's highest conversion efficiency of 33.66% with a prototype of a practical-sized, lightweight, and flexible compound/silicon stacked PV module for vehicle mounting. The development of multi-junction solar cells also commenced in FY 2023, with two projects selected. NEDO updated its design and installation guidelines in 2023 to ensure the safety of PV systems for special types of installation, such as on slopes, Agro PV, and floating PV systems. It was also decided to conduct demonstration experiments to verify the safety ofbuilding-integrated PV (BIPV) systems. Initiatives to explore more effective ways to market PV-mounted vehicles began, selecting three projects for development. Other ongoing efforts include developing technologies for separation and material recycling of PV modules, identifying technological challenges, and conducting demonstration experiments to utilize PV power generation for dispatching capability to mitigate grid impacts, developing high-precision performance evaluation technologies for new types of solar cells, and creating solar radiation forecasting technologies to support next-generation O&M. As part of the government's Green Innovation Fund (GIF) project, NEDO is undertaking the Next-Generation Solar Cell Development Project, focusing on fundamental and commercialization technologies for film-type perovskite solar cells (PSC). This ten-year project, running from FY 2021 to FY 2030, aims to achieve a power generation cost of 14 Yen/kWh or lower under specific conditions by FY 2030. Sekisui Chemical, EneCoat Technologies, Panasonic, Ricoh, and others initiated or announced plans for demonstrative installations at infrastructure facilities and various buildings in cooperation with local governments and private users in 2023. Sekisui Chemical, in partnership with the Tokyo Metropolitan Government (TMG), began verifying film-type PSC at a wastewater treatment facility in May 2023. METI, NEDO, and MoE are carrying out demonstrations on PV utilization technology, with METI leading demonstration projects on power grid control, including PV and storage batteries. In 2023, four projects were chosen for renewable energy aggregation demonstration, involving about 46 companies, including electric companies and VPP operators. Demonstration projects for Net Zero Energy Building (ZEB) and Net Zero Energy House (ZEH) for detached houses are also underway.

INDUSTRY & MARKET DEVELOPMENT

While the majority of PV installations in Japan have been supported by the FIT program, installation independent of FIT is expanding through PPAs, driven by declining FIT purchase prices, the growing consumer demand for renewable energy, and rising electricity bills. Regarding residential PV systems, the provision of PPA services in collaboration with electric companies, among others, has progressed, alongside efforts to convert condominiums to ZEH in addition to newly built detached houses and rental houses. Daiwa House Industry will convert all condominiums it builds from FY 2024 onward to ZEH. In public and industrial applications, several new onsite PPA companies were established, and business alliances formed in the PPA business. iGRID SOLUTIONS and Tokyu Land established a new company, TLC VPP LLC, to engage in the onsite PPA business. Local governments' active participation in public solicitations for PPA projects has promoted their introduction to public facilities. Renewable energy procurement has been mainly promoted by RE100 member companies, etc. Offsite PPA has expanded alongside onsite PPA, while virtual PPA initiatives have progressed. Kansai Electric Power (KEPCO) will construct a PV power plant with a maximum capacity of 150 MW for offsite PPA, in collaboration with Daiwa Energy & Infrastructure, SMFL MIRAI Partners, and Eco Style. Tokyo Metro signed a virtual PPA with Mitsubishi HC Capital Energy. Murata Manufacturing concluded a 60-MW scale virtual PPA with RENOVA. The use of the self-wheeling system has also expanded; Mizuho Bank, Mizuho Securities, Mizuho Leasing, AEON MALL, Eco Style, and Sai No Sakaki are collaborating to build new low-voltage PV power plants of 55 MW at about 650 locations to supply electricity to AEON MALL stores. The FIP program, which started in April 2022, is also being utilized. JAPAN BENEX started operation of an approximately 4-MW FIP PV power plant on a leased rooftop of a logistics facility in Tsukuba City, Ibaraki Prefecture.

According to PV module shipment statistics released by the Japan Photovoltaic Energy Association (JPEA), total shipments of PV modules from January to September 2023 were 4,144 MW, of which imports accounted for 93% with 3,835 MW. Foreign manufacturers are presumed to have maintained the highest ranks in shipment volume as in the previous year. In anticipation of future market expansion, the PV module recycling business by Japanese companies has progressed. Shinryo will deploy recycling facilities for PV modules across Japan.

In the area of inverters as Balance of System (BOS), NICHICON will launch a compact and advanced PV inverter that can be linked to storage batteries and V2H systems. In the storage battery-related business, the introduction of large storage battery systems and new entries into the grid-scale storage battery business have advanced. GS Yuasa delivered a lithium-ion storage battery system with a capacity of 4.2 MWh to Kawara Town, Fukuoka Prefecture, as part of a joint project with NTT Anode Energy, etc. JFE Engineering jointly invested in and established J&S Energy Storage LLC with S.D.L. and JFE Shoji to enter the grid-scale storage battery business.

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KOREA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 53 - PV on vehicle loading area at Hyundai Motors, Ulsan, Korea.

NATIONAL PV POLICY PROGRAMME

Korea has consistently raised its renewable energy targets in recent years. The first significant step was the increase of the renewable energy target from 7% to 20% by 2030 under the Implementation Plan for Renewable Energy 3020, released in 2017. The 3rd Energy Master Plan, released in 2019, further introduced a target of 30-35% renewable energy by 2040, and the 9th Basic Plan for Electricity Supply and Demand, released in 2020, further increased the share of renewable energy to 42% by 2034. However, the energy policy of the government that took office in May 2022 deviates from the previous government's trend. The new government's energy policy aims to build a feasible and reasonable energy mix, including increasing the share of nuclear power to more than 30% by 2030, assuming all nuclear power plants currently under and pending construction are fully operational. Based on reasonable and realistic supply conditions, the government will set targets for the penetration of renewable energy and determine the optimal proportions of different power generation sources, such as solar and offshore wind, resulting in a significant reduction in the share of renewable energy.

The current government has lowered the Renewable Portfolio Standard (RPS) targets from 14.5% in 2023, 17% in 2024, 20.5% in 2025, and 25% in 2026 and beyond to 13% in 2023 and 13.5% in 2024. The 25% RPS target has been delayed beyond 2030 as the renewable energy penetration targets have been revised downwards in the 10th Basic Plan for Electricity Supply and Demand. This plan has set a renewable energy generation target of 21.6% in 2030, which is 8.6% lower than the National Greenhouse Gas Reduction Target confirmed in 2021. While the target for renewable energy generation has been reduced, the target for nuclear power generation has been increased from 25.0% to 32.8% in 2030. This trend is expected to be more concretely reflected in the 11th Basic Plan for Electricity Supply and Demand, expected to be finalized in 2024, with plans to increase the share of nuclear power, including plans to build new nuclear power plants. In this context, the outlook for renewable energy is even more negative. The current government has drastically cut the 2024 budget for renewable energy. The budget for renewable energy support items from the power industry infrastructure fund was reduced by 42.3%, the budget for support for renewable energy deployment was reduced by 35.4%, the budget for Feed-in Tariff (FiT) was reduced by 65.1%, and the budget for financial support for renewable energy was reduced by 27.5%.

The main PV distribution programs in Korea are as follows:

- Subsidy for Residential Installation: Launched in 2004, this program continues the existing 100,000 rooftop PV system installation program. It focuses on various resources, including PV, solar thermal, geothermal, and small wind. Both single-family and multi-family homes are eligible, covering 60% of the cost for single-family homes and 100% for public multi-family rental housing. The maximum PV capacity allowed is 3 kW.
- Subsidy for Building Installation: The government supports part of the cost (varying by building type) for installing PV systems (200 kW or less) on commercial buildings. Additionally, up to 80% of the initial cost for installing new and renewable energy (NRE) systems is covered following the demonstration of new technologies, to ensure market entry of newly developed technologies. BIPV systems are prioritized for subsidy assessments.
- Subsidy for NRE Infrastructure Expansion: Aimed at promoting NRE use in the public sector and creating an NRE market, this program supports the installation of NRE systems in local government buildings (including social welfare facilities), covering up to 50% of project costs for PV systems on buildings, facilities, and social welfare facilities owned or managed by local governments. For BIPV, up to 70% of installation costs are covered.
- Subsidy for Hybrid Installation: This program promotes NRE dissemination in underserved and vulnerable areas, such as islands, remote off-grid areas, and long-term rental housing districts. Emphasizing local adaptability and the optimal integration of various NRE resources and cross-local mix, local authorities or NRE producer and utility consortia can apply. The government supports up to 50% of the total project cost, and up to 70% for BIPV systems.
- Public Building Mandate Program: By law, new public buildings with a gross floor area of 1,000 square meters or more must use at least 32% (by 2023) to 40% (by 2030) of their total expected energy consumption from newly installed NRE systems.

Korean-type FiT: Introduced in 2018 to enhance the bankability of small-scale distributed PV systems, this temporary subsidy (for 5 years from 2018-2022) offers a fixed contract price (for up to 20 years) for systems smaller than 100 kW through a tender, with the price being the sum of SMP and REC. This program was terminated in July 2023.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Fundamental materials research into PV cell or moduDue to changes in government policy and a downturn in the domestic solar industry, solar R&D budgets have significantly shrunk, and this trend is expected to continue in the coming years. Korea has established and is operating a solar cell/module development platform that companies can use in 2023, which can also be utilized to develop next-generation solar devices such as perovskite/Si tandem cells.

INDUSTRY & MARKET DEVELOPMENT

OCI is the only company in Korea producing polysilicon, with a total capacity of 39,700 tons, including 35,000 tons in Malaysia. OCI ceased producing solar polysilicon in Korea in 2020 and now only produces 4,700 tons of polysilicon for semiconductors at its Korean plant. All polysilicon for solar is produced in Malaysia. All domestic ingot and wafer production has been suspended due to the offshoring of these production areas. Hanwha Solutions has a production capacity of 4,500 MW of c-Si solar cells and 2,900 MW of modules. Hyundai Energy Solution has a production capacity of 650 MW of c-Si solar cells and 1,400 MW of modules. Korean companies are seeking technological advantages in premium solar cells and modules through various technological approaches, including n-type mono wafers, PERC (Passivated Emitter and Rear Contact) process, half-cell technology, and bifacial modules. They are also developing perovskite-silicon tandem solar cells.

Korea's annual solar installations have significantly increased 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, annual installations have declined from 2020 onwards, with 3.92 GW in 2021, 3.28 GW in 2022, and an estimated 3.31 GW in 2023. This decline is related to the government's nuclear-centric energy policy, tightening regulations, and shrinking budgets for solar power, and is expected to continue in the coming years.

Fig. 54 - 5.8MW Floating PV system at Jecheon-si, Chungcheongbuk-do, Korea

MALAYSIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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1 SEDA Malaysia

NATIONAL PV POLICY PROGRAMME

Solar PV installation was first introduced in Malaysia through the pioneering Solar PV Rural Electrification Programme in 1982, installing solar PV in approximately 100 homes in remote villages across the country. The largest electricity utility in the country launched the first grid-connected PV system in 2000. This was followed by SURIA 1000, a 5-year programme from 2006 to 2010. Successful bidders received subsidies for installing solar PV systems in their homes. Notably, SURIA 1000 created opportunities for the public and industry to directly participate in solar-related initiatives.

Under the Eighth Malaysia Plan (2001-2005), the Small Renewable Energy Power (SREP) Programme was introduced, along with the Biomass Power Generation and Cogen Full Scale Model Demonstration (BIOGEN) Project, utilizing oil palm-based by-products for small-scale electricity generation. The Ninth Malaysia Plan (2006-2010) saw further progress, with the development of rooftop solar becoming prominent through the Malaysia Building Integrated Photovoltaic (MBIPV) Project. The MBIPV project focused on policy development for grid-connected PV systems, market and incentive measures, and capacity-building programs for rooftop solar.
The programs and projects under the 8th and 9th plans led to the subsequent development of the National RE Policy and Action Plan (NREPAP) in 2010, aiming to establish a policy guide for RE development in Malaysia. In 2016, the Large Scale Solar (LSS) program was introduced, with a total capacity awarded of 370.89 MW.

As part of the third-party access assessment, the Corporate Green Power Programme (CGPP) was introduced in 2022, enabling business entities to purchase green electricity from solar power producers via a virtual grid.

To date, the National Energy Transition Roadmap (NETR) is pivotal in accelerating Malaysia's green and sustainable growth agenda, launched by the 10th Prime Minister of Malaysia in August 2023. Ten flagship catalyst projects of the NETR, covering six energy transition levers—energy efficiency (EE), renewable energy (RE), hydrogen, bioenergy, green mobility, and carbon capture, utilization, and storage (CCUS)—are expected to attract investments of more than RM25 billion, create 23,000 job opportunities, and reduce GHG emissions by more than 10,000 Gg CO_2eq per year.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In Malaysia, power generation accounts for approximately 30% of total GHG emissions. Consequently, most decarbonization strategies undertaken by countries focus on increasing renewable sources for power generation and improving energy efficiency. Solar PV power capacity, in particular, can be quickly scaled up, providing an effective means of mitigating carbon emissions from power generation.

The Malaysia Renewable Energy Roadmap (MyRER) aims to decarbonize the electricity supply sector by increasing RE installed capacity from 23% (8.5 GW) in 2020 to 31% (12.9 GW) by 2025, and 40% (18 GW) by 2035.

In 2022, Malaysia achieved a total cumulative capacity of 2,681 MW PV, with an increase of 420.58 MW in 2022. The breakdown of the installations is as follows:

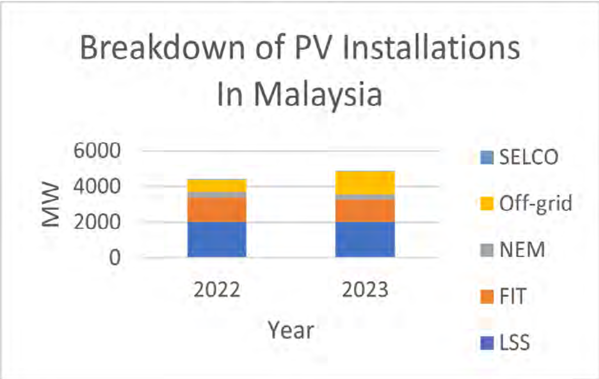

Table 9: 2023 based on projection by JPPPET Report 2022

MECHANISMS	2022	2023
LSS	1 361.2	1 249.8
FIT	322.4	288.1
NEM	697.4	1 292.0
OFF-GRID	38.3	4.5
SELCO	261.8	267.4
TOTAL	**2 681.2**	**3 101.8**

INDUSTRY & MARKET DEVELOPMENT

As technology costs for solar PV generation have decreased substantially in recent years, financing support focuses less on grants and tax exemptions, and more on improving access to finance. The decrease in RE cost for solar PV can be attributed to:

a) Competitive procurement of renewable power through auctions and quota systems to promote competition among project developers.
b) Economies of scale and technology innovation.

For solar PV, among the key challenges are:

a) Securing land for LSS.
b) Securing affordable debt financing for solar PV rooftop systems.
c) Capacity limits.
d) Limitation of the NEM scheme to assets on customers' own premises.
e) Lack of financial options from banks to support customers' appetite.
f) High cost of exploring new technology, i.e., battery energy storage systems (BESS).

The Government provides support by prioritizing green adoption by extending the Green Investment Tax Allowance (GITA) and Green Income Tax Exemption (GITE) until 2023. Additionally, the Income Tax Exemption (ITE) was prolonged for solar leasing companies to encourage participation in the Net Energy Metering Scheme (NEM) introduced by SEDA.

Under NETR's Responsible Transition (RT), it is projected that the potential investment opportunities for solar PV in Malaysia will increase from approximately 7GW in 2030 to 57GW in 2050, achieving the ambition of a 70% RE share of installed capacity by 2050, predominantly driven by solar PV installation. Three key initiatives have been introduced in NETR to promote solar, namely to establish solar parks for utility-scale solar, promote floating solar and agrivoltaics technology, as well as expanding the virtual aggregation model for rooftop solar.

Malaysia is committed to low-carbon development aimed at restructuring the economic landscape to a more sustainable one.

MOROCCO

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 55 - The Noor Midelt complex is set to host one of the world's largest capacities for renewable solar energy and storage, boasting a total installed capacity of approximately 1600 MW. © Antonio Garcia/Unsplashq<w

NATIONAL PV POLICY PROGRAMME

The solar photovoltaic (PV) market in Morocco is experiencing rapid expansion, in line with a global shift towards renewable energy sources. The country is on the brink of achieving a significant milestone with its approach to an annual installed capacity of 1 gigawatt (GW). This achievement underscores Morocco's dedication to sustainable development and highlights the success of its National PV Policy Programme.

Under the National PV Policy Programme, Morocco has launched several initiatives to boost solar energy adoption, supported by strong policy frameworks, public-private partnerships, and incentives for technological innovation and investment.

Public perception of solar energy in Morocco is highly positive, driven by growing environmental awareness and the economic advantages of renewable energy. This public support is crucial for the continued growth of the solar PV market.

Efforts to implement the programme have varied, from large solar farms to distributed generation projects that empower communities, enhancing the accessibility and affordability of solar PV technology and encouraging its broad adoption.

The outlook for Morocco's solar PV market is promising. The legal framework is being updated to open a new chapter for renewable energy in the country. Upcoming legislation aims to ease the provision of renewable energy to industries on the medium voltage (MV) network, which will likely accelerate the solar PV market's expansion and secure solar energy as a key element of Morocco's energy portfolio.

As Morocco progresses with these legislative updates, the National PV Policy Programme is also advancing, integrating feedback and adjusting to changing market conditions. This program exemplifies Morocco's commitment to a sustainable and thriving energy future. The anticipated growth in installed capacity and imminent legal changes further solidify Morocco's role as a leader in renewable energy within the region and as a committed player in the global move towards a greener economy.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Morocco has significantly invested in advancing its photovoltaic (PV) technology through a comprehensive research, development, and demonstration (RD&D) program. This initiative showcases a commitment to using the nation's vast solar resources for sustainable energy advancements, aiming to increase its renewable energy share to 52% by 2030.

The Noor solar initiatives and the development of advanced solar PV plus storage solutions highlight Morocco's efforts to integrate renewable sources into its energy grid, enhancing national energy security. The targeted R&D&I projects focus on:

- Integrating PV plants into the grid infrastructure.
- Leading technology development.
- Innovating in energy storage.
- Connecting various PV energy sources, including Floating PV, Agri-PV, and Power-to-X technologies, to form a comprehensive renewable energy ecosystem.

Morocco's strategy leverages its rich research infrastructure, including research centers, universities, and the innovation-driven private sector, to promote local technology development. This collaborative approach is vital to Morocco's renewable energy strategy through 2027. An example is the OCP Group's collaboration with the International Finance Corporation to establish 400MW PV plants, fostering local PV module production with a focus on emerging technologies and clean solutions suited to local conditions. This project also highlights innovative operation and maintenance strategies to improve efficiency and reduce the levelized cost of electricity (LCOE) for PV energy sources.

The Green Energy Park, a joint effort between IRESEN and UM6P, leads in PV research, developing hybrid PV cells, including initiatives like desert modules, the locally developed first HJT module, and an advanced Tandem HJT/Perovskite module. To enhance digital operation and maintenance (O&M) for PV installations, research teams have introduced Cloud-based monitoring and preventative maintenance systems, along with the Photovoltaic Soiling Monitoring System (PVSMS), aimed at revolutionizing soiling monitoring and speeding up cleaning operations for optimal PV facility efficiency and performance.

Additionally, this initiative aims to equip national economic stakeholders with advanced technical and technological knowledge, positioning Morocco to capitalize on the significant export potential of this growing economic sector. It also addresses research financing challenges by fostering an industrial and innovation-friendly environment within the country.

INDUSTRY & MARKET DEVELOPMENT

The Moroccan photovoltaic (PV) industry is entering a transformative phase, characterized by strategic growth and significant investments. The Office Chérifien des Phosphates (OCP), through its ENR Project – Vision 2027, is leading this transformation, aiming to generate 5GW of clean energy by 2027 and an ambitious 13GW by 2032. This vision includes the development of 200MW and 440MW PV plants in previously exploited mine areas, showcasing a commitment to sustainable practices and land repurposing.
A critical move toward these objectives is the €100 million finance agreement between the International Financing Corporation (IFC) and the OCP Group for a 400MW PV plant. This deal represents not just a financial commitment but also a catalyst for industry growth.

In Morocco, the PV manufacturing sector is adopting a strategy of horizontal integration, focusing on setting up assembly line manufacturing units to streamline production, reduce costs, and enhance module manufacturing efficiency.

Almaden Morocco, the only active producer in the local market, is leading by targeting utility-scale projects in partnership with GPM Holding, as well as residential and off-grid small-scale installations with their innovative Frameless PERC modules. With a current production capacity of about 300MW annually, they make a substantial contribution to national output.
Manufacturing trends are moving towards vertical integration within the local value chain, incorporating both cell and module production. Highlights include two major projects: a 1GW production line using TOPCon technology by a private entity and a 1.2GW production line of HJT technology within the OCP Group ecosystem. These initiatives not only strengthen Morocco's manufacturing capabilities but also elevate its standing in the global PV market.

The inauguration of Almaden FZ in Tangier marks another significant development in Morocco's PV landscape. With an annual capacity of 500 MWp and employing advanced glass-glass half-cell technology, this facility is poised to produce panels starting from 580W (G12), signaling a shift towards high-efficiency, high-output modules.

These collective efforts in the PV sector reflect Morocco's commitment to renewable energy and its pivotal role in the energy mix. The current state and trends of the PV industry underscore Morocco's potential to emerge as a leader in clean energy production and a center for solar technology innovation.

Morocco is nearing a significant milestone with an annual installed capacity of 1 GW.

NETHERLANDS

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 56 - Agro PV, strawberry crops and solar, source RVO

NATIONAL PV POLICY PROGRAMME

In 2023, the growth of solar PV on land in the Netherlands stabilized at 4.2 GW for the consecutive year, and both spatial and grid integration emerged as more urgent issues. The government announced several new policies to address this situation while continuing to strive for the ambitious goal of achieving 35 TWh of renewable energy by 2030. This goal approximately translates to a 55% CO_2 reduction and would pave the way for a new phase of electrification, including sectors not easily reached by solar and wind, ensuring the 2050 goals remain achievable.

While the innovation policy for the energy sector does not specify targets for particular technologies, 2023 saw the announcement of specific policies for solar to adapt to the pressing situation. These measures include a strong preference for deploying solar panels on available rooftops, the multifunctional use of land within the built environment, and utilizing federal land adjacent to highways, railways, dredging depots, etc. The involved ministries and regional governments have become more active in allocating scarce spaces, planning, and granting permits. Overall, nature reserves and agricultural lands are to be avoided. Additionally, the Minister of Economic Affairs & Climate announced plans to install 3GW of floating solar on the North Sea by around 2030, located in areas designated for offshore wind.
Grid congestion worsened in 2023, and new, large-scale solar parks must now demonstrate grid capacity before applying for the SDE++ scheme. Together with grid operators, additional measures are promoted to address this urgent situation, including power plant design, cable pooling, load shifting, passive and active curtailment, and increased use of storage facilities. Additional funds were released in 2023 by state-owned grid operators for grid reinforcement, although this will not resolve the existing backlog of solar projects that cannot be connected in the short term. For the future rollout of solar in the Netherlands, these new power lines are essential. More attention is also needed for the circularity of solar panels' design and lifespan and affordability for end-users.

Several support schemes are in place, but the tax (VAT) return scheme was discontinued early in 2023:

- SDE++ for solar systems larger than 15 kWp.
- Net metering for smaller, often residential systems.
- The postal code (tax reduction scheme) was adjusted to the SCE (subsidy cooperative energy).
- ISDE for SMEs up to €125/kWp.
- Cheap green loans in many municipalities, but only if signed up to a national fund.

While the phasing out of the net metering scheme was previously announced by the government, the public debate continues, focusing on different business cases for solar energy and ensuring a fair return on investment for all end users.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In 2023, the mission-oriented R&D program targets the following topics:

- Renewable Energy Production
- Energy Saving
- Flexibility of the Energy System
- Circular Economy
- Natural gas-free Neighborhoods and Buildings

Significant budgets were allocated in existing subsidy schemes for demonstration and pilot projects, aimed at accelerating market introduction, such as the Demonstratie Energie- en Klimaatinnovatie (DEI+) aanvragen| RVO.nl | Rijksdienst. In 2023, a more detailed plan was announced for a demonstration project for "offshore floating solar" with a substantial separate budget dedicated to ecological research.

Higher technology readiness levels (TRL) are managed in separate programs for fundamental research by national organizations NWO and STW. Research activities are spread across various universities and institutes like AMOLF, DIFFER, Solliance, and TNO (the national institute for applied research). A growing trend is observed in higher professional education (bachelor level) offering courses in solar technology and installation.

The "National Growth Fund" was initiated in 2021 with a budget of 20 billion euros up to 2025. In the first two calls, no projects on solar were granted, but a proposal on solar was approved in 2023. The program officially started on January 1, 2024, and the kickoff with all partners took place in February. The main topics covered are: Si HJT cell factory, Flexible solar foils, and Lightweight/integrated PV.

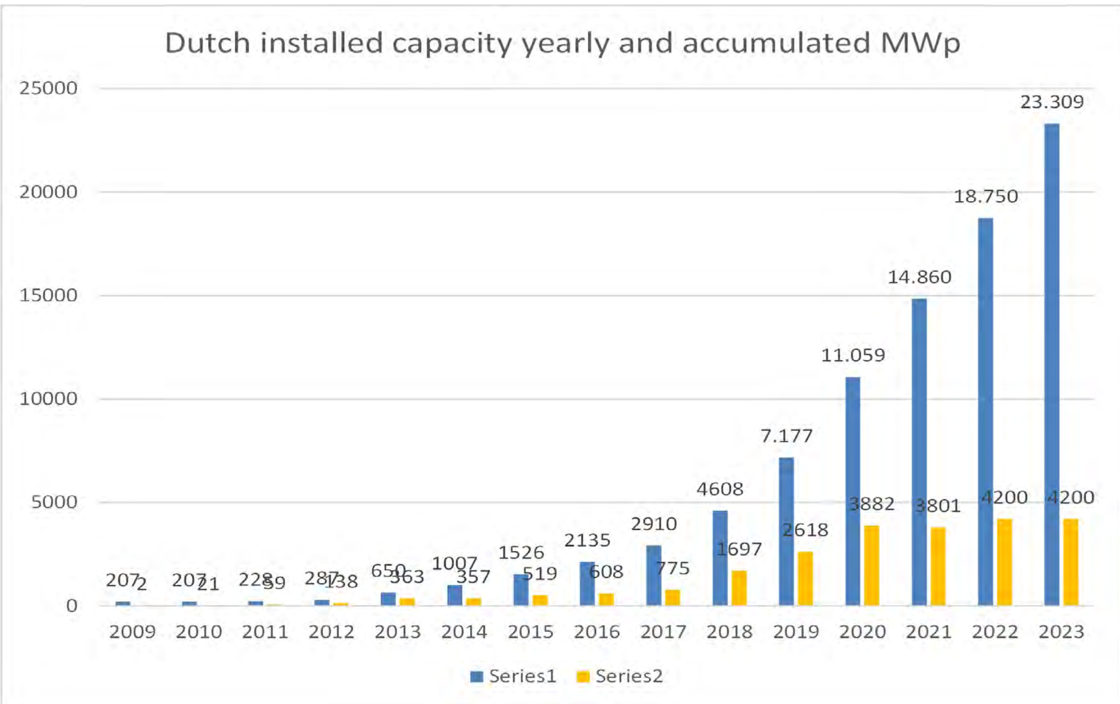

Fig. 57 - Source CBS, data estimated 2023

The Top consortium for Knowledge and Innovation (TKI) concerning solar, under the flag of Urban Energy, drives innovation through forming partnerships and matchmaking TKI Urban Energy | Topsector Energie.

INDUSTRY & MARKET DEVELOPMENT

In 2023 the Dutch solar market stabilized with an estimated level of 4.2 GWp installed capacity which is almost the same amount as in the previous year. This will lead to a total cumulative installed capacity of around 23.4 GWp in 2023. These figure are extrapolated from early figures over the first half of 2023 provided by the CBS and have yet to be confirmed. The official figures are provided and updated regularly by Central Bureau for Statistics (CBS) StatLine - Electricity balance sheet; supply and consumption (cbs.nl)

It shows a steady growth a year but not an acceleration of the solar market anymore. While grid congestion affect increasingly the business market, with over a 10% release of planned solar plants, the residential market seems more robust. However, close to 50% of house owners have now installed solar panels while the rental home fall behind with an estimated 20%. In the coming years the business case and markets have to change to keep up with the growth rates of the last few years. There are still areas and sector hard to reach like business parks, transport and heavy industry.

Over the summer whole sale prices fell from in the 30-35 euro cent range for mainstream solar panels to an average15 euro cent while also the supply chain recover the second half of 2023.

The National consortia, formed around integrated solar in the landscape, infrastructure, BIPV and floating Solar, play an important role in integrating solar PV into multifunctional applications on the scarce available surface in the Netherlands. Solar in combination with Wind is also becoming an integral part of so called "energy hubs" which have considerable storage capacities, matches more directly local demand and supply and deliver additional energy services to the grid operators.

The Dutch industry took a hit in 2023 with several bankruptcies and take over caused primarily by the low prices. However, still plans are underway in the National Growth Fund proposal Solar NL, to develop national production for niche markets and high efficiency panels.

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NORWAY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 58 - The world's northernmost ground mounted PV system at Isfjord Radio, Svalbard, 78° north. Source: Store Norske

NATIONAL PV POLICY PROGRAMME

Norway's programs in the energy sector aim to promote renewable energy and increase energy efficiency. Support for the implementation of PV is integrated into these programs.

Owners of small-scale PV installations can register as prosumers. Prosumers are exempt from grid usage fees, which are otherwise applied to electricity suppliers, as they already pay for the grid when drawing power from it. Surplus electricity can be fed into the grid at net electricity retail rates (i.e., excluding grid costs, taxes, and fees). If such installations exceed a limit of 100 kW electric power feed-in to the grid, excluding own consumption, grid connection fees will apply.

The public agency Enova SF subsidizes up to 32,500 NOK of the installation costs for grid-connected residential PV systems at a rate of 7,500 NOK per installation and 1,250 NOK per installed kW rated capacity up to 20 kW. This program also includes leisure homes with grid connections.

The government agency Innovation Norway supports investments in PV systems in the agricultural sector, requiring that the PV system be used for the commercial operation of the actual farm.
Previous rules for grid fees were unfavorable concerning collective self-consumption between separately metered installations in the same building, particularly affecting residential apartment buildings. From October 1st 2023, a new regulation allows PV plants up to 1,000 kW to share electricity generation between local customers under certain conditions, applicable within a building or a cluster of adjacent buildings at the same location as the PV plant.

In 2023, the Norwegian parliament announced the goal to reach a yearly electricity generation of 8 TWh from PV by 2030.

Solar power for a global market is one of the six priority areas in Energi21 - The Norwegian national strategy for Research, Development, and Commercialization of New climate-friendly energy Technology. From 2023, the PV industry is also a priority area in the Norwegian government's strategy for green industry (Grønt industriløft).

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 includes R&D projects on the silicon chain from feedstock to solar cells, novel solar cell concepts, novel applications, and 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), funded by RCN and Norwegian industry partners. Research activities cover silicon production, silicon ingots and wafers, solar cell and solar panel technologies, and the 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 Norway's university and research institute sector participating in the Research Center:

- Institute for Energy Technology (IFE) focuses on polysilicon production; design, production, and characterization of silicon solar cells; and the effects of material quality on solar cell performance.
- University of Oslo (UiO): The Centre for Materials Science and Nanotechnology (SMN) coordinates activities within materials science, micro-, and nanotechnology.
- Norwegian University of Science and Technology (NTNU) in Trondheim: Engages in materials science, micro-, and nanotechnology relevant for solar cells.
- SINTEF in Trondheim and Oslo focuses on silicon feedstock, refining, crystallization, sawing, and material characterization.
- Norwegian University of Life Sciences (NMBU) conducts fundamental studies of materials for PV applications and assesses PV performance in high-latitude environments.
- Agder University (UiA) researches silicon feedstock. It also has a Renewable Energy demonstration facility with PV systems, solar heat collectors, heat pumps, heat storage, and an electrolyzer for research on hybrid systems.

INDUSTRY & MARKET DEVELOPMENT

The Norwegian PV industry is segmented into "upstream" materials suppliers and companies engaged in the development of solar power projects. Downstream activities range from companies developing small and medium-sized PV equipment for deployment in Norway to companies specializing in planning, building, and operating large utility-scale PV plants internationally.

The three companies that have been producing solar grade silicon, ingots and wafers are REC Solar Norway, Norsun, and Norwegian Crystals. The products supplied by all three companies have had a low carbon footprint compared to the industry average. However, the operations of these companies have been severely impacted by competition and pricing challenges in Europe. In 2023, both REC Solar Norway and Norwegian Crystals ceased operations.

Scatec is a renewable power producer, with a significant portion of its operations dedicated to developing and operating PV power plants. Its current portfolio of PV power plants has a capacity of approximately 2.6 GW, located in Africa, Asia, South America, and Europe. Other companies like Equinor and Statkraft are also active in these markets.

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

Norway's electricity supply is predominantly hydropower (88%) and wind (10%). Although the Norwegian PV market is small on an international scale, it experienced very strong growth in 2023. A total of 300 MW of PV capacity was installed in 2023, which is approximately twice the volume installed in 2022. The total PV generation capacity also doubled from the previous year to approximately 600 MW, excluding off-grid installations.

In 2023, the Norwegian parliament announced the goal to reach a yearly electricity generation of 8 TWh from PV within 2030.

PORTUGAL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 59 - PV plant owned by Finerge with 9.6 MWp installed in Coruche, Portugal. Source: Voltalia

NATIONAL PV POLICY PROGRAMME

The main energy policy developments with impact on PV that took place in 2023, relate to the undergoing update of the National Energy and Climate Plan 2021-2030 (NECP). This update reflects a higher ambition of the government regarding decarbonization but also reindustrialization, both implying a large increase in the electricity demand.

According to the draft reviewed NECP delivered in July 2023, there are three main issues. First, advancing the target for 2026 to achieve an 80% renewable share at final consumption of electricity, and to reach close to 90% by 2030. Second, doubling the capacity for hydrogen production by electrolysis foreseen by the National Strategy for Hydrogen, that is, from 2.5 GW to 5 GW (output). Third, promoting new industries, such as data centres, batteries, and green ammonia in the short term, and green steel in the medium term. Besides these, other policies will also raise the electricity demand, such as promoting the electrification of residences and industrial processes, and larger stock shares of electric vehicles. Such a rise in demand is to be met mainly with wind and PV. The (draft) perspectives for PV are 20.4 GW in 2030 – from 3.9 GW at the end of 2023, thus a five-fold increase in capacity in just 6 years. Around 13.8 GW would be allocated to demand in the economic sectors, and approximately 6.6 GW for the production of renewable hydrogen and other renewable gases. This seems ambitious but consider that there are 20 GW of projects in the queue for access to the grid.

A consistent strategy of successive governments has been to let the existing feed-in tariffs reach the end of the supporting period, and instead conduct auctions for new capacity, seeking discounts on the market price of electricity. Some progress has been made on simplifying environmental licensing in 2023, but much remains to be done to provide a more favourable environment for investors. This could include a timeline for PV capacity auctions consistent with the revised NECP, as well as measures for further improving licensing speed (more staff, digitalization, single contact points). The ability of the grids to absorb renewable production is a current bottleneck in the public power system. The sharing of injection points (hybridization) is to be facilitated, and so are launching auctions for adding storage at congested points and lines (flexibility). Another issue of concern to be addressed in the next few years is the high proportion of imports. They continue to represent approximately 18% of the total supply, and this is hardly compatible with the 80% renewables target set for 2026, and clearly not with the approximately 90% target for 2030. Market reforms and more PV could help mitigate the problem. It is noted that while the public perception was initially neutral towards PV projects, as large power plants spread, concerns are now being raised and even taken to court about visual and ecological impacts. As part of an effort to reduce these concerns, auctions are being prepared for non-conventional surfaces, such as water reservoirs and road margins. Note that a change in Government due in early 2024 may lead to an adjustment of strategies and priorities.

RESEARCH, DEVELOPMENT & DEMONSTRATION

As regards academic research, the major universities all perform R&D on PV. The 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. The University of Porto (at FEUP) is working on Solar PV cells and modelling processes. The University of Aveiro is working on semiconductor physics, growth, and characterization of thin films for PV applications. The 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. The University of Lisbon is working on PV integration (buildings, vehicles, agrivoltaics), solar forecasting and critical materials (at FCUL); and on organic cells (at IST). University of Évora works on agrivoltaics, floating PV and energy communities. The 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. The National Laboratory of Energy and Geology is working on tetrahedrite-based materials, PV/T modules, and PV prosumers. The International Iberian Nanotechnology Laboratory 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, and advanced thin-film solar cells by the implementation of micro- and nanostructures

As regards private companies operating in Portugal, they mostly deal with issues further down the PV value chain. 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 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 (formerly Martifer Solar) and Open Renewables also perform R&D activities related to PV technologies. Plus, the major Portuguese utilities have their own R&D activities, either directly like GALP, or via branches, like EDP (EDP NEW) and REN (R&D Nester). They perform research on various technical aspects, especially storage and control and optimization of performance and operation.

Finally, the Directorate-General of Energy and Geology, in its support role for the government, conducts studies for public policies promoting PV, including national energy plans and roadmaps, proposes technical legislation, and helps in the design and implementation of specific measures, like auctions and Calls.

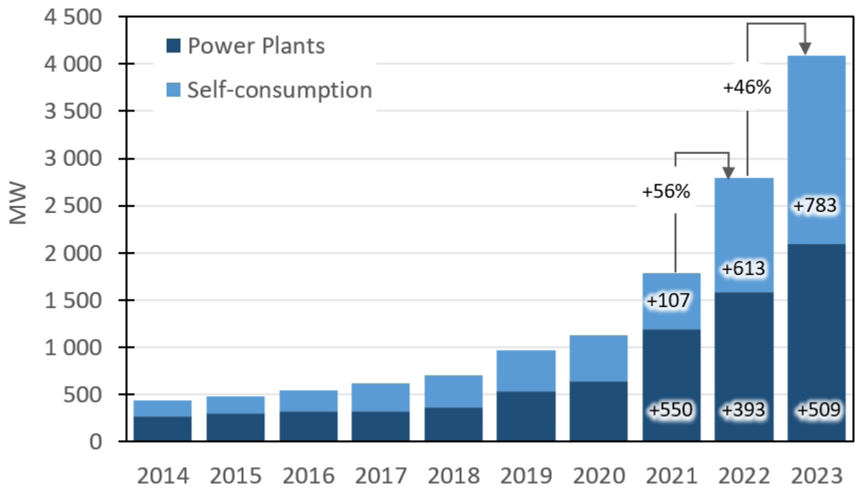

Fig. 60 - Installed PV capacity (DC) in Portugal, 2014-2023. (Data source: DGEG; NB. supersedes preliminary data communicated before).

INDUSTRY & MARKET DEVELOPMENT

Final electricity demand in the country rose from 51.9 GWh in 2022 to 52.4 GWh in 2023, a 0.8% annual increase, or 0.6% when corrected for temperature and holidays. This is only about a third of the typical annual rise (except for the pandemic years), for reasons that can only be clarified when more detailed statistical data becomes available.

As can be appreciated in Figure 60, the installed PV capacity rose from 2.8 GW in 2022 to 4.1 GW in 2023, a 46% growth. However, it was remarkable that the growth has been, again this year, much larger at decentralized systems (+783 MW; +65%) than at centralized power plants (+509 MW; +32%). By now large power plants represent 2.1 GW, but BIPV and other small dispersed systems – installed about 40% at services, 38% at industry and 22% at residences – already represent 2.0 GW and will quite probably outpace the former next year. As for the PV production, it rose again by approximately 56% year-on-year as can be appreciated in Fig. 61.

The role of PV in the centralized power supply and market is expected to continue growing, supported in particular by PV capacity auctioned in 2019 and 2022 that will come online. As regards decentralized PV systems, here also the strong growth recorded in 2022 and 2023 is expected to continue, and with larger shares of PV systems with batteries and of systems deployed at energy communities. This is supported by a multiplication of companies that offer technical solutions for self-consumption systems and in parallel, enticing financial conditions. This includes branches of the major energy utilities. Plus, in the context of the Recovery and Resilience Plan, the government provides incentives for buying residential PV systems, up to a limit of 85% of the cost, or 1000€ for systems with no batteries, and 3000€ for systems with batteries.

Even allowing a conservative estimate of 20% lower percentage increases in capacity than in 2023, around 1,500 MW would be installed in 2024 (ca.1 GW decentralized, and 0.5 GW centralized).

The electricity supply mix in 2023 - see Figure 62 - was influenced by a wetter than usual weather and by the growth of PV capacity. It was dominated by renewables with a record 37.1 GWh, i.e., a 63% share. Fossil sources (19%) and imports followed. While hydro (28%) and wind (22%) were still the major renewable electricity technologies, the penetration of PV continued to rise fast, from 5.9% in 2022 to 9.3% in 2023 (this includes self-consumption).

The electricity market price in the Integrated Iberian Electricity Market continued its declining trend, stabilizing towards the end of 2023, although some large swings in price were experienced. On an annual average, it dropped almost by half, from 168 €/MWh in 2022 to 88 €/MWh in 2023. In part, this decline was due to lower gas prices, but also to electricity imports.
Regarding industry, a production line for assembling flexible PV panels initiated activity at the end of the year. Its owner, LuxOEnergy, has a partnership with Austrian DAS Energy, and occupied the facilities of the former 'Moura Fábrica Solar' that closed in January 2019.

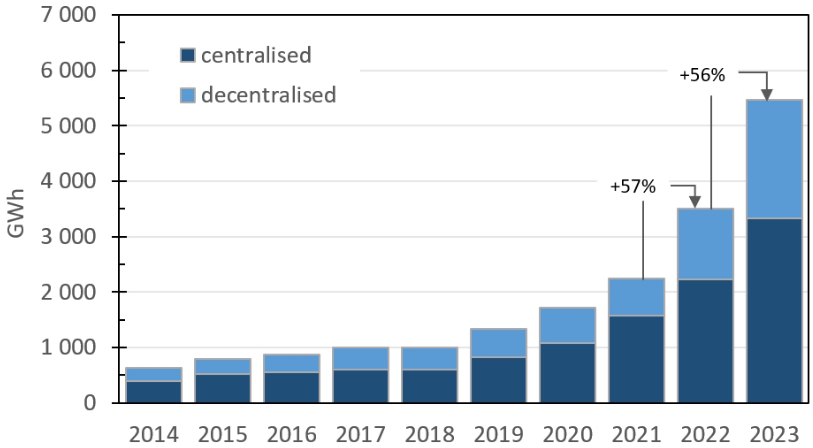

Fig. 62 - PV electricity production in Portugal, 2014-2023.

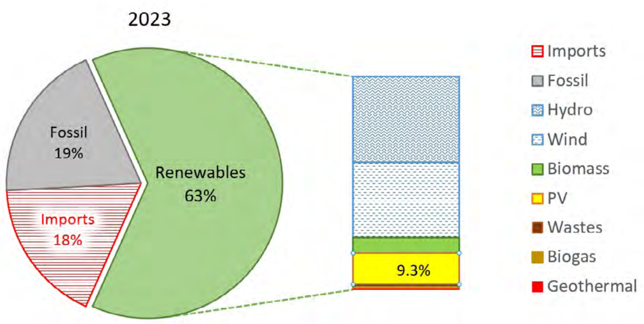

Fig. 61 - Electricity supply mix in Portugal, 2023.(Data sources: DGEG, plus statistical services from the Autonomous Regions of Madeira and Azores).

In 2023 the installed PV capacity rose to 4.1 GW, a 46% growth over last year. It was remarkable that this growth has been, again, much larger at decentralised systems (+65%) than at centralised power plants (+32%). But this pattern may not last when large PV plants associated with hydrogen production will start to come online.

SOLAR ENERGY RESEARCH INSTITUTE OF SINGAPORE (SERIS) LEADING APPLIED PV R&D INSTITUTE IN THE TROPICS

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors:
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Fig. 63 - Aerial view of the Yuhua Agritech Solar (YAS) Living Lab located on the rooftop of a residential carpark in Singapore. The YAS Living Lab has 10 test-bedding projects run by institutes, companies and community members to study the combination of solar panels and urban farming for the optimum balance between crop yield and renewable energy generation on the same area. The solar roof invented by SERIS features moveable louvers that allow to track the sun during the day and are also used for rainwater management and control of the microclimate around the plants. (Image credit: SERIS).

NATIONAL PV POLICY PROGRAMME

Singapore is actively participating in global efforts to promote the transition to clean and sustainable energies. Given its limited space as a city-state and few renewable energy options (lacking hydropower potential and experiencing low wind speeds), solar photovoltaics (PV) emerge as the most viable renewable energy resource. To support its goal of becoming a more sustainable city, the government introduced the Singapore Green Plan 2030 in 2021. 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 installed 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. The total installed PV capacity at the end of 2023 has surpassed 1 GWp. In addition, Singapore aims to collaborate with neighboring countries to import reliable low-carbon electricity competitively, with a target of 4 GW of total imports by 2035. This would cover a large share of Singapore's annual electricity demand, as the current system has a peak demand of approximately 7.5 GW.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Singapore The Singapore National Research Foundation (NRF) implements research programs and funding schemes directed at the industry, research institutes, universities, and polytechnics. The current Research, Innovation, and Enterprise (RIE) 2025 Plan allocates 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, addressing 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. Established 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. 64.

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).

Key achievements in 2023 include the official launch of the REC@NUS Corporate R&D Laboratory for Next Generation Photovoltaics (SGD77 million over 5 years for research, development and commercialisation of disruptive perovskite-silicon tandem solar cells; see Fig. 65), a new perovskite solar cell world record (24.35% on 1 cm2 area) and the establishment of SERIS' agrivoltaics testbed at the Yuhua Agritech Solar (YAS) Living Lab in Singapore (see Fig. 63).

INDUSTRY & MARKET DEVELOPMENT

Singapore hosts a significant 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). Prominent industry players in Singapore include REC Solar, which operates a GW-scale solar cell & module manufacturing plant, Maxeon Solar (formerly known as SunPower Corp.), which has an R&D Center, Sembcorp, which owns & operates several hundred MWp of solar assets (including a 60 MWp Floating Solar farm), and EDPR, which uses Singapore for its expansion plans in Asia (planned investment volume of $10 billion by 2030).

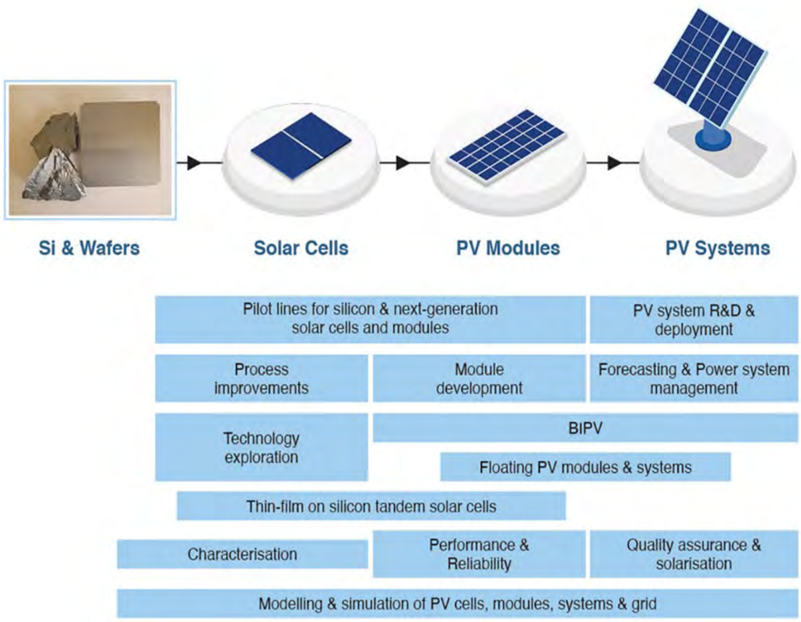

Fig. 64 - Overview of SERIS' RD&D activities in the areas of solar cells, PV modules and PV systems.

Fig. 65 - The official launch of the REC@NUS Corporate R&D Laboratory for Next Generation Photovoltaics at the National University of Singapore by Deputy Prime Minister HENG Swee Keat (third from left).

SERIS joined the IEA PVPS programme in 2022 as a sponsor member and is actively involved in Tasks 1, 13, 15 and 19, with the purpose of sharing its know-how with other experts and fulfilling its vision of contributing to global sustainable development.

SOLAR POWER EUROPE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 66 - © Natalia Radtke / Greenvolt

NATIONAL PV POLICY PROGRAMME

Solar PV keeps booming across Europe. We are announcing the third consecutive record of new PV installations, and uninterrupted growth since 2016. Taking any of this for granted, however, would be a grave mistake. We see several trends coming together that require decision-makers' attention. First, the market conditions for solar have been exceptional in the last years but these conditions are now changing, in particular due to the normalisation of energy prices and the current inflationary environment. Second, solar PV is hitting real system boundaries limiting further growth and integration, and thirdly, we are still confronted with heavy permitting delays despite years of legislative action on that front. While we celebrate another record year, we should not lose the perspective that solar PV is just doing the minimum of what is needed to keep the door open to a 1.5 C climate safe world and a Net Zero Europe well before 2050. As we enter a new cycle of political leadership in Brussels, following the June EPµ£ elections, we ask EU leaders to pay attention to the needs of the solar sector:!

1. Set a robust and predictable pipeline for solar towards 2030. NECPs should be updated and made coherent with the more ambitious Fit-for-55 renewable energy targets. This should be accompanied by faster and more predictable permitting in the framework of the Emergency Regulation on Permitting, and by prioritising the transposition and implementation of the revised Renewable Energy.

2. Maintain an investment-friendly environment for solar PV. The solar sector pledges to keep solar PV at record low LCOE (levelised cost of electricity), making it the cheapest energy source in the EU and the world. Inflation is, however, impacting the cost of capital of solar developers. While this does not affect the competitiveness of solar PV in the long-term, it is impacting and delaying solar project financing at the moment. Member States should integrate indexation in reflection of changing inflation rates in auctions design, and ensure that Contracts for Difference provide revenue stability to developers even in times of negative prices.

3. Bring grids and flexibility investments to the next level, especially on the distribution level. Most solar and renewables in the comingyears will be connected to lower-voltage grids, and this will particularly accelerate in given the agreed EU Solar Rooftop standard under the Energy Performance of Buildings Directive. This requires an EU action plan on grids and flexibility to reinforce the governance of the EU grids policy, looking beyond only cross-border energy projects and adopt new governance tools to better monitor decentralized infrastructure with clear performance-based KPIs, and investing smartly into the grid through efficient, participatory, and anticipatory planning.

4. Grow the pool of certified installers and skilled workforce. The solar sector currently employs 648,000 people in the EU. In order to reach the EU's 2030 solar deployment targets the number must at least double, from 650,000 today to well over 1.2 million by 2030. First, we must rehabilitate technical education and jobs. Second, we must cooperate on EU level to develop standardised training material for solar workers, especially for installers.

5. Scale-up solar module and inverter manufacturing capacity in the EU. For solar modules, supply chains are highly concentrated and dependent on one supplying country. Reshoring parts this chain is possible and necessary, and requires a robust and tailored industrial policy, based on financing incentives to build new factories and demand side incentives by setting up "resilience policies" in public procurement and auctions following the Net Zero Industry Act. For inverters, the EU supply chain is still very strong, but global competition is increasing. This, too, requires a robust and tailored approach, including by monitoring inverter uptake by system operators and regulators, and rewarding sustainability and cyber-security benefits of European inverters.

INDUSTRY & MARKET DEVELOPMENT

The year 2023 set another record for solar PV in the EU, with 55.9 GW installed across the 27 Member States, showing a 40% growth from 2022 and a doubling of the market in just two years. For the third year in a row the EU market broke its previous record in absolute terms, and for the third year in a row the market saw an annual growth rate of at least 40%. This sustained growth can be seen as a continuation of the market dynamics taking place in 2022, when Member States acknowledged solar power as an environmentally friendly, cost-effective, and unparalleled rapid solution to diminish their reliance on Russian fossil fuels. While the first months of 2023 were still under the full effects of the energy crisis, with elevated electricity price acting as a shock for citizens, businesses and policymakers, market conditions changed significantly in the course of the year.

According to our EU Market Outlook for Solar Power 2023-2027, published in December 2023, Germany took back the role of the largest solar market, installing 14.1 GW and surpassing Italy's 12-year-old record of 9.3 GW in 2012. Spain came second with 8.2 GW, while Italy entered the top 3 for the first time in a long while, installing 4.8 GW through the year. Market diversification is growing stronger, with 14 countries exceeding 1 GW of annual installations in 2023, up from 10 in 2022. The total EU solar PV fleet now amounts to 263 GW, up 27% from the 207 GW in 2022. Germany continues to be the largest contributor with 82 GW, trailed by Spain at 36 GW and Italy with 29.5 GW, while the Netherlands retains its top spot in installed PV capacity per capita, reaching 1,280 W/capita in 2023 and improving by over 250 W/capita in a single year.

Looking ahead over the next 4 years, our prospects continue to show double-digit growth every year, but considerably below the 40% annual increase experienced in recent years, due to changing market conditions. Over the course of 2023, prices have dropped significantly to record lows, driven by an increase in global production. While this is positive news for installations, the current conditions make for an extremely difficult business case for local manufacturers and have triggered trade discussions that could potentially impede solar deployment. As per our Medium Scenario, solar will continue its upward trajectory, reaching 62 GW in 2024, 73.8 GW in 2025, 84.2 GW in 2026 and 93.1 GW in 2027. Under our High Scenario, the market has the potential to surpass 100 GW as early as 2026. But much more relevant seems our Low Scenario this time, which is characterised by the recently emerged threat of trade defence measures and additional challenges, and hardly sees any growth compared to today's levels with 58.7 GW by 2027. This is below the average of around 70 GW that solar should deploy every year from now to 2030 to reach the REPowerEU goals.

Our solar National Energy and Climate Plans analysis has been updated, based on the new draft NECP published by EU Member States through the course of 2023. Upon the publication of our report, 22 Member States submitted a new draft NECP, while 5 updated plans were missing. The increase in national solar ambition has lifted the aggregate NECP target by 76% to 591 GW by 2030 – a strong upswing that is, however, still significantly below the 750 GW REPowerEU target. By contrast, we anticipate 902 GW of solar capacity deployed in our Medium Scenario projection to 2030.

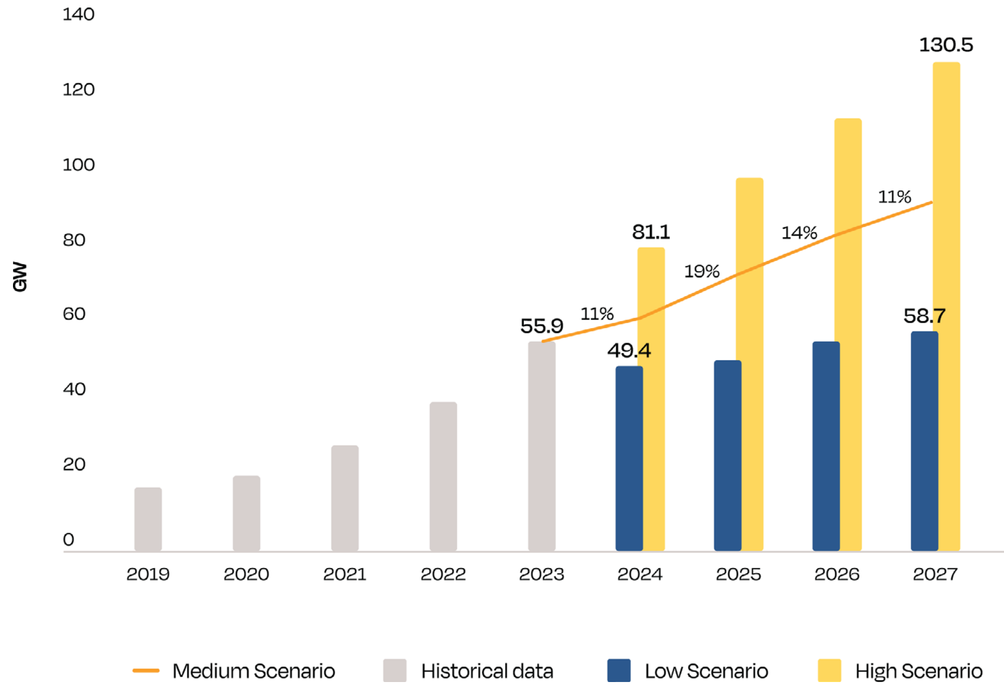

Fig. 67 - EU-27 annual solar PV market scenarios 2024-2027 © SolarPower Europe

SOUTH AFRICA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors:

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Fig. 68 - Residential PV installation during construction in Gauteng Province in South Africa © Dr. Karen Surridge, South African National Energy Development Institute (SANEDI)

NATIONAL PV POLICY PROGRAMME

South Africa's renewable energy and storage market has historically been focussed on utility-scale government-led procurement, through the Renewable Energy Independent Power Producer Procurement Program (REIPPPP). Since 2011, the REIPPPP, along with the Risk Mitigation Independent Power Producer Procurement Programme (RMIPPPP), has procured 11 590MW of renewable energy technologies and 415MW of battery storage capacity. This has supported many learnings (for policy and market development) as well as material cost reductions. However, the procurement of solar PV projects under Bid Window 5 (BW5) was hamstrung by the implementation of local content rules and unfortunately delays and changes to the procurement framework have also undermined policy certainty. As a result, market confidence in South Africa's utility-scale public procurement appears too low to underpin industrial, inclusive development on its own. Further public procurement is nevertheless on the cards, which could provide foundational anchor demand. A BW7 of 5 000MW was planned for procurement in 2023, followed by another 5 000MW procurement window (BW8). In line with the 2019 IRP, substantial generation capacity remains to be procured by the public sector, as the plan envisages to add 14 400MW of wind, 6 400MW of solar PV, 2 088MW of storage and at least 4 000MW of embedded generation over the 2022-2030 period.

Since 2021, regulatory reforms have enabled the private sector market, by first reducing (Aug 2021) and then removing (Dec 2022) licensing requirements for IPPs. Despite some persisting regulatory challenges, these policy changes have triggered development of renewable energy projects through the private sector. These are being complemented by a tax incentive scheme, first implemented in 2005 and enhanced in 2012, 2015 and 2023. In addition, fast-rising electricity prices, combined with rising carbon pricing domestically and border carbon taxes in export markets, have further strengthened the renewables business case.

Other streams of demand are progressively emerging e.g. Small Scale Embedded Generation (SSEG) has been increasingly enabled and, in some cases, incentivised, by municipalities. During 2020, 56 municipalities (out of 177 licensed municipal authorities) allowed SSEG, 31 having an approved SSEG tariff, and 44 with application processes in place. In 2023, National Treasury announced a tax incentive for households to invest in solar systems (and enhanced the existing incentive for businesses). A number of national departments, municipalities, provincial governments and state-owned entities have also embarked on their own procurement processes to ensure energy security.

Trends indicate a significant pipeline of both public and private sector-led renewable energy projects into the future. Additionally, new demand drivers from power-to-x applications, such as green hydrogen and NEVs, could further support the market. Regional demand from the African continent is also forecasted to drive South Africa's export market.
(Adapted from SAREM)
(further info on policy available here)

Fig. 69 - Roof-top PV system installation in Gauteng Province in South Africa © Dr. Karen Surridge, South African National Energy Development Institute (SANEDI)

RESEARCH, DEVELOPMENT & DEMONSTRATION

The research and development priorities for photovoltaics in South Africa are at present mainly focussed on battery energy storage systems (BESS), solar PV for self-consumption, and the integration of renewable power generation at grid scale. The country's solar energy market is expected to grow at a compound annual growth rate of approximately 30% from 2021 to 2026, driven by conducive climatic conditions such as higher solar irradiation and government policies supporting solar PV projects. The government's Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) has led to the procurement of 6.4GW of renewable energy capacity with more to come. The localisation potential of the South African PV industry is being explored, with recommendations to support local manufacturing and technology transfer. The South African Renewable Energy Masterplan (SAREM) aims to leverage the rising demand for renewable energy and storage technologies, particularly solar energy, wind energy, lithium-ion battery and vanadium-based battery technologies, to unlock industrial and inclusive development in the country.

The most promising areas of research and implementation for photovoltaics in South Africa includes community-level solar PV approaches, decentralised PV installations with storage and the integration of renewable energy technologies into low-income households. The country's high solar resource and current government support for renewable energy make it an ideal candidate for scalable solar power projects and the development of industrial value chains for associated technologies such as lithium-ion and vanadium-based battery technologies. The decreasing cost of solar panels and energy storage technology also contribute to the potential for growth in the solar power industry. The increasing demand for renewable energy, driven by a desire to reduce reliance on fossil fuels and address climate change challenges, presents opportunities for businesses and households to adopt solar power, further driving investment in the industry

INDUSTRY & MARKET DEVELOPMENT

South Africa is currently in an extremely electricity constrained environment due to a number of contending factors. As such there is a lot of pressure being placed on the economy in terms of the commercial and industrial sectors, but also in the residential sector. From industry and commerce to homeowners, are finding it increasingly frustrating and/or threatening to be without electricity for prolonged periods of time during load shedding and possible associated technical power outages.

However, South Africa is in the fortunate position of having a variety of energy resources available, including renewable energies. While wind energy, of which South Africa also has an excellent resource, is not necessarily an initial thought when considering an intervention, solar energy has become the go-to solution. It is against this backdrop, that a large uptake of PV technology across market sectors is being observed (see table below).

In the past the main driver for implementing technologies such as solar PV tended to be to reduce electricity costs, however due to electricity grid constraints, the uptake seems to have accelerated in an exponential manner simply to meet energy security requirements across the sectors. In most cases energy storage solution is also implemented in order to support energy security during periods when the solar resource may be limited or not available.

It is important to consider that there are two different approaches to providing electricity in South Africa viz. grid connected electricity and self-generation electricity. Apart from the exceptions listed above, most PV interventions not at grid scale are for self-consumption only and do not feedback into the national electricity grid, therefore any surplus energy is either stored or lost. This opens a large market segment potential for addressing electricity needs in self consumption and particularly in many micro/mini off grid scenarios, here the primary focus should be on ensuring that expectations for system performance are managed.

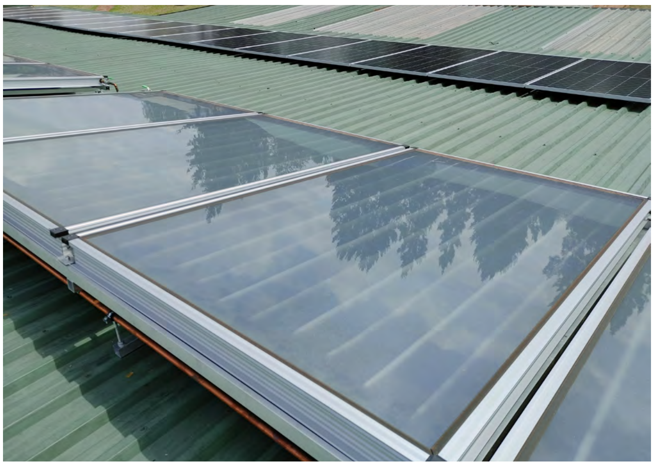

Fig. 70 - Solar Technology operating in symphony: Roof-top Solar Thermal and PV system installation in Gauteng Province in South Africa © Dr. Karen Surridge, South African National Energy Development Institute (SANEDI)

Table 10: System Installation Tracker SAPVIA (South African Photovoltaic Industry Association)

Market Segment	System Size	Total Capacity
Residential (SSEG)	0 - 30 kWp	620.89 MWp
Commercial and Industrial (C&I) - SSEG	30kWp - 1MWp	1247.63 MWp
C&I Large Scale and utility scale	1 - 50MWp	1925.53 MWp
Utility Scale	> 50MWp	1865.03 MWp
TOTAL		5659 MWp

In an electricity constrained environment, Energy Security has become paramount, such that it even in some cases trump's cost, This has created exponential market growth and demand in South Africa over the past year.

SPAIN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 71 - Utility-scale PV power plant. Courtesy of Solar Steel Gonvarri.

NATIONAL PV POLICY PROGRAMME

Spain has developed a Strategic Energy and Climate Framework with the goal of achieving climate neutrality by 2050. This framework consists of four main pillars: the Integrated National Energy and Climate Plan 2021-2030 (INECP), the Law 7/2021 addressing climate change and energy transition, the Long-Term Decarbonisation Strategy for 2050, and the Just Transition Strategy.

The INECP 2021-2030 is Spain's framework to uphold its commitments to global and European initiatives. The INECP tackles challenges and opportunities across five dimensions of the Energy Union: decarbonization, renewable energy, energy efficiency, energy security, the internal energy market, and research, innovation, and competitiveness. Currently undergoing revision, this draft plan seeks alignment with the new Fit for 55 and REPowerEU targets, proposing updates to various regulations, including the Renewable Energy and Energy Efficiency Directives, to establish more ambitious objectives. The preliminary proposal sets ambitious goals for solar energy, aiming for 76 GW of photovoltaic (PV) capacity by 2030, including 19 GW for distributed PV installations and 57 GW for utility-scale PV power plants. Additionally, the proposal targets 22 GW of storage capacity, expected to further boost sector growth and set a positive trajectory for PV development in the coming years.

During the summer of 2023, the Ministry of Ecological Transition and Demographic Challenge launched a public consultation on the draft revision of the National Energy and Climate Plan. Following this period of public input, efforts are underway to finalize the document. As required by the Governance Regulation, the completed plan is due for submission to the Commission by June 2024.

Furthermore, in 2023, a series of decrees and regulations related to photovoltaic (PV) energy and electricity market regulation were issued, covering various aspects such as:

- Royal Decree-Law 17/2022, of 20 September, adopting urgent measures in the field of energy.
- Order TED/741/2023, of 30 June, updating the remuneration parameters of the standard installations applicable to certain electricity production facilities.
- Order TED/189/2023, of 21 February, creating the Division of Electrical Energy Projects.
- Resolution of 23 February 2023, of the National Markets and Competition Commission.
- Draft Royal Decree to regulate the functioning of Energy Communities and Citizens' Communities.

Moreover, the government is actively developing a National Floating PV strategy alongside a Royal Decree aimed at establishing regulations for the installation of floating PV plants within the public hydraulic domain. This initiative involves amendments to the Public Hydraulic Domain Regulations. Currently, only the draft of these regulations is available for public access.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Ministry of Science, Innovation, and Universities of Spain oversees the implementation of policies related to scientific research, technological development, and innovation across various sectors. The strategic framework for research, development, and innovation is outlined in two key documents: the Spanish Strategy for Science, Technology, and Innovation 2021-2027 and the State Plans for scientific and technical research and innovation. Notably, the budgetary allocation for grants under the State Plans for the year 2023 exceeds 6 billion euros. The Annual Action Programme is the operational planning tool in which all the R&D&I actions are planned by the different agents which integrate the General State Administration in a specific year, in order to achieve the objectives of the Spanish Science, Technology and Innovation Strategy 2021-2027 and the State Plan for Scientific, Technical and Innovation Research 2021-2023.

Due to the COVID-19 health crisis, Spain is receiving EU funds to aid in economic recovery. The National Recovery, Transformation, and Resilience Plan, focuses on four primary areas of action: ecological transition, digital transformation, gender equality, and social and territorial cohesion. The priorities outlined in this plan closely align with the seven European Flagship Initiatives introduced by the Commission in the Annual Sustainable Growth Strategy 2021. These initiatives encompass various goals, including promoting electrification and renewable energy, facilitating the integration of renewable hydrogen, retrofitting buildings for energy efficiency, expanding electric vehicle charging infrastructure, enhancing 5G coverage in diverse regions, modernizing public administrations through digitalization, boosting energy efficiency in processors, advancing Big Data and cloud services, and improving digital skills and vocational training.

In 2023, several photovoltaic (PV) initiatives targeting self-consumption, storage, and energy communities secured funding from Next Gen funds. Furthermore, the Spanish Government issued the inaugural report on Ecological Transition within the Recovery, Transformation, and Resilience Plan. This report assesses the impact of these funds on ecological transition across three critical areas: biodiversity and ecosystems, climate change mitigation and energy, and initiatives to tackle pollution and enhance resource management.

Regarding projects funded last year by the State Research Agency, both the Public-Private and Strategic Lines calls featured several initiatives focused on the integration of photovoltaic (PV) systems into different substrates, along with numerous agrivoltaic projects. However, it's notable that no photovoltaic project received funding in the Transmission Call. Conversely, the industrial technological development centre (CDTI), institution dedicated to advancing the technological capabilities of Spanish companies, supported multiple projects in the operation and maintenance of photovoltaic (PV) power plants, as well as initiatives concerning floating PV. Additionally, one project focused on integrating concentrating PV technology into greenhouses was also granted.

INDUSTRY & MARKET DEVELOPMENT

Over the past few decades, Spain's photovoltaic (PV) industry has not only grown but also secured a prominent position throughout the PV value chain, encompassing manufacturing structures, trackers, and power electronics. The sector is home to numerous significant players involved in development, engineering, distribution, construction, and operation & maintenance. Regarding PV module manufacturing, several companies, including newcomers, produce PV modules and provide Building Integrated Photovoltaics (BIPV) solutions. Moreover, a prominent company specializes in manufacturing technological equipment for PV module production.

Spain's well-established PV industry, along with its associated components, has the potential to cultivate a strong techno-economic ecosystem, driving a sustainable, efficient, and profitable economy across Europe. Spain's abundant solar radiation and expansive landscapes make it an ideal location for PV plant installations. Achieving the production of affordable and efficient energy in Spain and Europe could greatly boost the competitiveness of both Spanish and European industries, significantly impacting the overall European economy.

Last year, the installed PV power capacity in Spain amounted to 7,652 MW (5,605 MW in utility scale, 2,020 MW in distributed PV, and 28 MW off-grid PV). Currently, Spain has 37,632 MW of accumulated capacity (29,286 MW of utility scale, 8,260 MW of distributed PV, and 86 MW off-grid PV). This data confirms the upward trend observed in recent years and may suggest the expected growth rate in the coming years. However, there has been a stagnation in distributed PV in 2023, compared to 2,507

MW in 2022, attributed to citizens' decreased perception of high energy prices and families' reduced purchasing power due to inflation and the depletion of aid provided under the Recovery Funds.

In 2023, renewable energy generation in Spain, as estimated by Red Eléctrica, accounted for approximately 50% of the national generation mix, marking a historical maximum of production, with PV generation contributing 28.7% of renewable energy generated, covering 14% of the national energy demand. Additionally, thanks to photovoltaic clean electricity generation, the emission of 3,812,840 tons of CO_2 was prevented in Spain. The average electricity price in Spain, at 87.43 €/MWh, was once again the lowest among the major economies of the European Union (Germany, France, Italy, Spain), which exceeded 101.82 €/MWh.

In 2023, the Ministry for Ecological Transition and the Demographic Challenge (MITECO) was expected to initiate a tender seeking bids for approximately 7 GW of renewable capacity. However, this auction was never launched, and it is anticipated that it may occur in the first quarter of 2024.

CENER | NATIONAL RENEWABLE ENERGY CENTRE

The well-established PV industry in Spain, coupled with its associated components, has the potential to cultivate a strong techno-economic ecosystem, driving a sustainable, efficient, and profitable economy across Europe.

SWEDEN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 72 - Residential house with PV roof tiles produced in Sweden by Midsummer. (Industry & Market Development)

NATIONAL PV POLICY PROGRAMME

Swedish energy policy strives to blend ecological sustainability with competitiveness and security of supply, grounded in EU legislation. Sweden's ambitious energy and climate goals include:

- Achieving net zero emissions by 2045, with at least 85% of the emission reductions occurring within Sweden.
- Ensuring electricity production is 100% fossil-free by 2040.
- Attaining an energy-efficiency target of 50% more efficient energy use compared to 2005 levels by 2030, measured in terms of energy relative to GDP.

The Swedish power system is segmented into four bidding areas (SE1–SE4) by the Swedish National Transmission System Operator (Svenska Kraftnät) to manage electricity supply-demand imbalances. These areas help identify where grid expansion is needed and where increasing electricity production can meet consumption demands, thereby minimizing the need for long-distance electricity transport.

Sweden and Norway jointly operate a technology-neutral, market-based support system for renewable electricity production known as "the electricity certificate system." This scheme has significantly propelled renewable energy deployment over the past decade. The 2030 target of 46.4 TWh of new renewable electricity production was achieved by 2021. The scheme ceased accepting new applications at the end of 2021.

Since 2021, a tax deduction for individuals installing green technology allows for a 20% deduction on labor and material costs for PV installations, capped at 50,000 SEK per year. For batteries intended for storing self-produced electricity and charging equipment for electric vehicles, the deduction is 50%.

Introduced in 2015, a new tax credit scheme for small-scale renewable electricity production grants PV system owners with a main fuse ≤ 100 A a feed-in premium as a tax credit of 0.6 SEK per kWh of electricity fed into the grid. Credits cannot exceed the amount of electricity consumed from the grid, with a maximum tax credit of 30,000 kWh/18,000 SEK per year. Additionally, a solar electricity producer with one or more PV systems totaling less than 500 kWp is exempt from paying energy tax on the self-consumed electricity used on the same premises where the PV systems are installed.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Research, development, and demonstration are 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.

Previously, a research and innovation program, El från solen, covered PV and solar thermal electricity (STE). It included both national and international research and innovation projects. 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 research related to electricity use. Initially the budget for the entire program period (2022 – 2027) is 552 MSEK. International projects have been conducted in the EU-collaboration SOLAR-ERA.NET. This collaboration is now replaced by CETPartnership.

The Swedish Energy Agency also funds the centre of excellence, Solar Electricity Research Centre (SOLVE). This is a strategic partnership between research institutions and stakeholders within the private and public sectors. The activities in SOLVE are funded in equal parts by the academic partners, the public/private sector partners and by the Swedish Energy Agency. The total budget of SOLVE is more than 100 MSEK over five years (2022 – 2026).

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 120 MSEK was distributed from these four major actors to Swedish PV research in 2022.

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. There are however also some groups at universities and research institutes that focus on PV systems and PV in the energy system-oriented research. Details on active research groups are shown in National Survey Report-of PV Power Applications in Sweden 2021.

INDUSTRY & MARKET DEVELOPMENT

In Sweden, PV development is predominantly distributed, with solar PV electricity accounting for roughly 2% of the total net electricity production in 2023. A notable trend for 2023 and 2024 is the significant rise in popularity of standalone batteries paired with PV, both in large-scale electricity storage facilities and among homeowners.

The cumulative installed grid-connected PV power in Sweden approached 2.4 GW at the end of 2022. The annual market for PV in Sweden expanded by 59% in 2022, with nearly 0.8 GW added. According to the National Survey Report of 2022, PV contributed approximately 1.2% (2.0 TWh) to the total Swedish power mix in 2022.

Utility-scale solar is still in the developmental stages in Sweden, with corporate Power Purchase Agreements (PPAs) being the predominant business model. A recent development in the market is the formation of an association by large-scale solar developers to advocate for improved conditions for PV parks in Sweden, particularly addressing the challenges of permitting and processing times. There is a significant pipeline of announced PV park projects at various stages of the permitting process. The largest PV park in Sweden, located in Kungsåra, Västerås, was commissioned in October 2023 and boasts an installed peak power of 22 MW.

The Swedish PV industry is mainly comprised of small to medium-sized installers and retailers of PV modules or systems. The downstream industry of installers and retailers has been growing for several years. However, there is a trend toward a decreasing number of upstream PV industry companies. By the end of 2022, there were two active module manufacturing companies in Sweden (though the production volumes were small), 19 companies involved in the manufacturing of production machines or balance of system components, and at least 11 R&D companies, or companies with R&D divisions in Sweden.

While there are no official national targets for PV in Sweden, the industry has set an ambitious goal of achieving 30 TWh of annually generated solar electricity in Sweden by 2030.

The cumulative installed grid-connected PV power in Sweden was close to 2.4 GW at the end of 2022. The annual market for PV in Sweden grew by 59% in 2022, as almost 0.8 GW was added.

SWITZERLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 73 - Alpine test facility SedrunSolar (Source: energia alpina, X STATIK REECH). In 2022, Swiss Parliament passed the so-called "Solar Express", which heavily subsidises the installation of large (>10 GWh/a) Alpine photovoltaic plants and thus domestic winter electricity production up to 2025 and up to a maximum of 2 TWh. (Large-scale photovoltaic systems according to Art. 71a EnG in Switzerland).

NATIONAL PV POLICY PROGRAMME

After years of debate, the Swiss parliament approved in autumn 2023 the Federal Act on a Secure Electricity Supply from Renewable Energies ('Mantelerlass': overarching decree amending two existing laws)[1]. New binding targets have been set for the accelerated expansion of renewable energies of 35 TWh (not including hydropower) by 2035 and 45 TWh by 2050, which are more ambitious than those in the existing Energy Strategy 2050. Hydropower production is expected to increase to 37.9 TWh by 2035 and 39.2 TWh by 2050. Additionally, winter electricity production from renewable energies is to expand by an additional 6 TWh, with 2 TWh reliably available from storage hydropower. A new instrument with a floating market premium will be introduced for large installations: The most favorable bids from tenders will receive guaranteed remuneration at the bid price. Should the price of the energy supplied exceed the bid price, the profits will flow back into the grid surcharge fund.

1. A popular vote on this new legislation will take place on 9 June 2024.

The most important instrument for promoting renewable energies in Switzerland is the grid surcharge fund, financed by electricity consumers through a surcharge of 2.3 centimes per kilowatt hour. In the future, the fund will be authorized to issue bonds under federal law. Another innovation is the possibility of forming local electricity communities, which can cover the area of a municipality and offer up to a 60% discount on the grid usage tariff.

With the acceleration bill, submitted to parliament in June 2023, the Federal Council proposes measures to expedite the approval process for renewable energy projects. For wind and solar power plants of national interest, a new centralized cantonal planning approval procedure will be introduced. This procedure envisages a project receiving all authorizations in a single procedure within six months of submitting all necessary documents. This approach prevents the authorization process from being split into several stages, with each decision subject to appeal to the Federal Supreme Court. Although planning permission is granted by the canton, municipalities must be involved from an early stage.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In Switzerland, over 100 publicly funded research projects are currently active in the PV sector. Nearly half of the total public expenditure on these projects is directed towards the development of solar cells. Another significant area of research focuses on the integration of PV in buildings and its incorporation into the electrical grid. Beyond pure technological research and development, system issues (such as the combination of PV with storage or mobility) and topics related to implementation (like acceptance and agro-photovoltaics) are gaining importance. According to energy research statistics, an average of CHF 37 million in public funding was allocated annually to photovoltaics research from 2015 to 2020, accounting for 8.4 to 10.2% of the total funding for energy research.

The Photovoltaics RTD Programme of the Swiss Federal Office of Energy (SFOE) involves a wide array of stakeholders and is part of Switzerland's long-standing support for RTD in energy technologies. SFOE funds are utilized subsidiarily to address gaps in Switzerland's funding landscape, providing grants to private entities, the domain of the Swiss Federal Institutes of Technology (ETH), universities of applied sciences, and universities.

As part of a nationally and an European funded project, Meyer Burger, in collaboration with CSEM and other European partners, has made great progress in combining heterojunction technology together with backside cell contacting (Interdigitated Back Contact IBC). The SFOE-funded project SIRIUS is focusing on the pre-industrialisation of tunnel IBC technology, enabling silver consumption to be reduced by a factor of up to 6. The first modules produced in this way also demonstrate very high stability.[2]

INDUSTRY & MARKET DEVELOPMENT

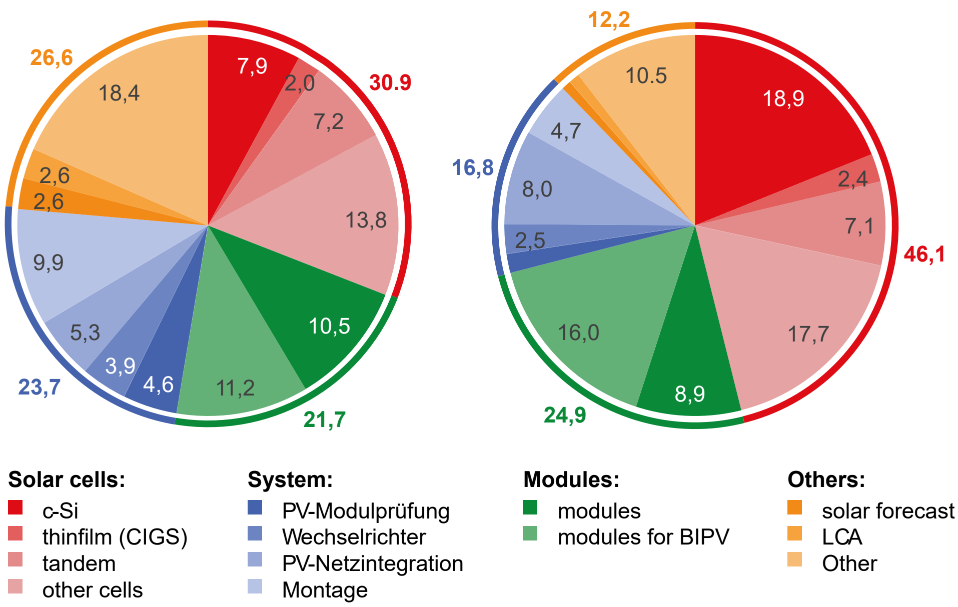
The trend in solar power production continues to strengthen significantly. In 2023, more PV systems were installed than in any previous year. 1.5 gigawatts (GW) of new capacity have been added in 2023, marking a substantial increase from 1.1 GW in 2022. The majority of new installations are on roofs and façades. The installed capacity by the end of 2023 exceeded 6.2 GW, according to Swissolar, which is expected to enable annual electricity production of around 6 TWh in 2E024. As a result, the contribution of solar power to Switzerland's total annual electricity consumption is projected to reach the 10% threshold next year.

One of the driving factors behind this increase is the price of electricity, which notably impacts large customers purchasing electricity on the free market. The median price for electricity experienced a 28.5% rise for tied customers from 2022 to 2023. Additionally, the increased adoption of electromobility and heat pumps is fostering the use of photovoltaics.[3]

Swiss industry players span a significant portion of the photovoltaic value chain. For an overview, see Here.

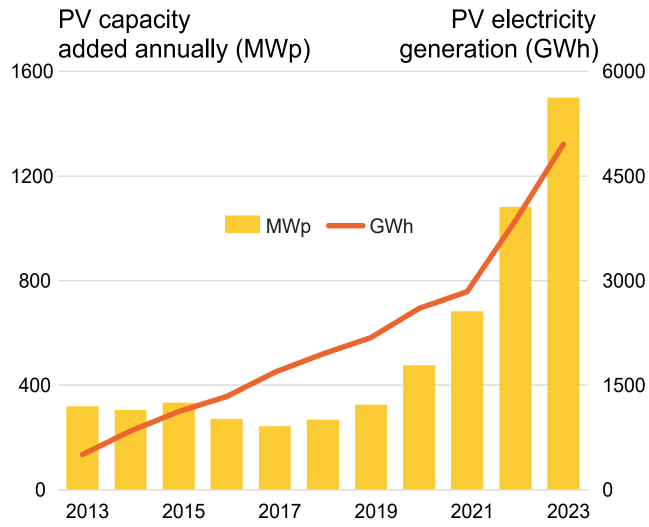
Thematic breakdown of running PV research projects by number of projects %

Thematic breakdown of running PV research projects by funding volume %



2. D, Lachenal, B. Paviet-Salomon, «Vers l'industrialisation des cellules tunnel-IBC» in Bulletin Electrosuisse 6/2023
3. https://www.swissolar.ch/de/news/detail/solarstrom-liefert-2024-10-des-schweizer-jahresverbrauchs-51518

The Swiss solar cell and module manufacturer Meyer Burger, with production sites in Germany and the USA, came under severe pressure due to the price collapse for PV modules on the European market in 2023 and will focus on further expansion in the USA in the future only. The Swiss module manufacturer 3S Swiss Solar Solutions opened a second production site near Bern in early 2024, where modules for integration into the building envelope, especially for the needs of the Swiss market, are produced on a highly modern production line.



THAILAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 74 - A centralized mini-grid system with 15 kWp solar panel with 90 kWh BESS installed under the Energy Efficiency and Renewable Energy Support Project for Royal Initiative Projects by DEDE to provide electricity and well-being for distant villagers in Om-Koy district, Chiang Mai.

NATIONAL PV POLICY PROGRAMME

Thailand has set the ambitious target of achieving carbon neutrality by 2050 and net-zero emissions by 2065. To fulfill this commitment, the National Energy Plan (NEP) framework was established, comprising the Power Development Plan (PDP), Alternative Energy Development Plan (AEDP), Energy Efficiency Plan (EEP), Gas Plan, and Oil Plan. The final objective of the NEP, which is still in progress, aims to derive at least 50% of new electricity from renewable sources.

According to the PDP 2018 (Rev.1) and AEDP 2018, the target for new solar PV installation is set at 9,290 MWAC, with floating solar PV targeted at 2,725 MWAC by 2037.
Additionally, a 10-year Clean Electricity Production Increment Plan (2021-2030) (Rev.2) was added to the current PDP 2018 (Rev.1), setting the PV installation capacity target at 7,087 MW by 2030. This includes 90 MW for solar rooftop residential projects, 997 MW for solar floating, 1 GW for solar ground-mounted with BESS, and 5 GW for solar ground-mounted.

In 2023, the cumulative installation (on-grid system only) of solar PV in Thailand reached 8,831 MWp a nearly 4 GW increase from 2022, primarily due to solar farm and solar farm with BESS installations under PPA with the government. This surge was partly attributed to the implementation of the "Solar Biglot" program, part of the 10-year Clean Electricity Production Increment Plan under PDP2018 (Rev.1).

Furthermore, the Office of Energy Regulatory Commission (OERC), along with Thailand utilities (EGAT/PEA/MEA), began implementing the Utility Green Tariff to prepare for the expansion of renewable energy demand in the coming years.

In 2023, The Solar Rooftop for Residential Sector Program continued to promote the prosumer concept among residential households. The program focuses primarily on self-consumption, but excess electricity can be sold back to the grid at a Feed-in

Tariff of 2.20 THB/kWh ($0.061 USD/kWh). The program's overall target is set at 90 MWp for 2021-2030, with a total cumulative installed capacity of 51.8 MWp in 2023.
Although still in the early stages, Thailand is developing additional solar rooftop promotion schemes for government buildings and residential sectors through tax incentives.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In some remote areas of Thailand, such as high mountains and border regions, or due to legal complications, electrification has not been achieved. To address this, several projects have been implemented by both public and private entities. In 2023, the Department of Alternative Energy Development and Efficiency (DEDE) continued its support program to provide renewable energy technologies, like solar mini-grid systems, solar water pumps, and solar dryer parabola domes, to the Royal Initiative Projects, mostly located in remote mountain areas, to enhance access to electricity and well-being.

In 2023, OERC signed MOUs with the Royal Thai Army and Bangkok Metropolitan Administration to support solar rooftop installations in their hospitals, aiming to reduce electricity bills.

Research and development in solar PV are actively pursued in Thailand by several leading academic institutions, covering a range of topics such as hybridizing silicon cells with perovskite (tandem cells), developing flexible materials from carbon/organic compounds to replace glass and rigid structures, integrating colored PV modules with agriculture under the agrivoltaics concept, studying the effects of light- and elevated temperature-induced degradation (LETID) of PERC modules, and establishing a complete recycling process for waste PV modules using mineral and metal dressing methods.

The National Science and Technology Development Agency (NSTDA), one of Thailand's leading research institutes, has developed a solar panel management platform. This platform includes a solar farm database, a tracking and grading platform for used solar panels (Solar Sure), demonstrations of second-life solar panels, and solar panel recycling.

INDUSTRY & MARKET DEVELOPMENT

In 2022, Thailand had more than 10 solar panel manufacturers, with a cumulative production capacity exceeding 9 GW/yr. The average price of solar panels in Thailand in 2022 ranged from $0.30 to $0.4 USD/Wp for small-scale installations (kWp) to $0.25 to $0.28 USD/Wp for large-scale (MWp) installations. The average system price of solar PV installation for the residential sector (<10 kWp) was §0.90 to $1.20 USD/Wp, $0.69 to $0.75 USD/Wp for commercial and industrial buildings, and $0.63 to $0.66 USD/Wp for large-scale solar farms.

To comply with the EU's Carbon Border Adjustment Mechanism (CBAM) and further implications of exporting carbon-contained products, Thailand's industrial sector had to adapt to the transition towards cleaner energy utilization. Initially, Thailand implemented carbon credit trading schemes, the Renewable Energy Certificate (REC) scheme, and the Utility Green Tariff (UGT) for electricity utilization to support cleaner energy implementation.

Initiated in 2014, the Thailand Greenhouse Gas Management Organization (Public Organization) (TGO) has continued to provide a carbon credit registration and verification platform for GHG mitigation projects under the Thailand Voluntary Emission Reduction Program (T-VER). This program encourages all sectors, especially the industrial sector that produces and consumes renewable energy, to participate in GHG emission reduction. In 2023, the cumulative verified GHG was around 17 MtCO2eq, with an expected cumulative mitigated GHG of 11.4 MtCO2eq.

In 2023, cumulative installation (on-grid) of solar PV of Thailand was 8 831 MWp – a nearly 4 GW increase from 2022.

TÜRKIYE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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NATIONAL PV POLICY PROGRAMME

According to the Strategic Plan covering the years 2019-2023 prepared by the Ministry of Energy and Natural Resources (MNR) in line with the More Local, More Renewable strategy, the installed electrical power based on solar energy is targeted to be 10 000 MW in 2023. As of the end of December 2023, the installed power of solar power plants reached 11 292 MW. While the share of solar power plants in total electricity production was zero in 2013, solar power plants will constitute 10.6% of the total installed electrical power by the end of 2023. The highest increase in electricity installed capacity in 2023 compared to 2022 was in the installed power of solar power plants with 1 681 MW, a growth of 17.4% (according to TEIAS).

Türkiye's National Energy Plan, which was created based on Türkiye's 2053 net zero emission target and shared with the public on January 19, 2023, includes predictions and projections related to energy for the period until 2035. The plan covers the energy demand in the industry, agriculture, transportation sectors, buildings and service sectors, and the supply scenarios created to meet this demand, taking into account the development trends in basic indicators such as population growth, economic growth and fuel prices. According to the Plan, the solar energy installed capacity in total electricity production is targeted to be 52.9 GW in 2035. It is predicted that the largest contribution to the total electricity installed power will come from solar power plants with 28%. To achieve these targets, the annual new capacity requirement in solar energy is 3.1 GW.

The 12th Development Plan, covering the period 2024-2028, prepared by the Presidency in the centenary of the Republic of Türkiye, was accepted by the Grand National Assembly of Türkiye on 31 October 2023 and published in the official gazette dated 1 November. According to the plan, as the transition to clean energy accelerates, the demand for critical minerals in the energy sector is expected to increase significantly, and the importance of securing cost-effective and sustainable supply of critical minerals will increase. The plan states that recycling facilities will be expanded in order to reduce the negative effects of end-of-life equipment such as solar panels and batteries on the environment and to ensure the transition to a circular economy. In the energy sector targets, according to TEIAS data, solar energy installed power is expected to reach 11 350 MW by the end of 2023 and 30 000 MW in 2028. Focusing on green and digital transformation in the 12th Development Plan, various steps have been taken in the industrial sector's fight against climate change in the fields of mitigation, adaptation, compensation for losses and damages, financing, technology development and transfer, and capacity building. Within the scope of the plan, incentives will be given to support clean energy production and energy efficiency, green transformation in industry, sustainable transportation circular economy, and green infrastructure.

RESEARCH, DEVELOPMENT & DEMONSTRATION

R&D activities for the development of photovoltaic technologies in Türkiye are carried out by universities, the public and private sectors. The majority of support for R&D projects is provided by Scientific and Technological Research Council of Türkiye (TUBITAK) and Turkish Energy, Nuclear and Mineral Research Agency (TENMAK).

TENMAK, which was established in 2020 under the Ministry of Energy and Natural Resources, conducts and supports scientific research, coordinates, encourages and supports these researches in order to increase and sustain Türkiye's competitiveness in energy-related issues. A call has been made for digitalization in renewable energy power plants in 2023. The aim of this call is to bring together public, university and industrial institutions to develop commercializable technologies related to artificial intelligence, machine learning, digital twin, cyber security, blockchain, big data, cloud computing, smart grid / charging, IoT and AR / VR for the green energy transition. In this context, it is aimed to increase projects with a TRL of at least 4 to TRL 8 level and transfer them into a technological product that can be used in the industry.

450 million USD of financing has been allocated to the Türkiye Green Industry Project, which is carried out by TUBITAK and Small and Medium Enterprises Development Organization (KOSGEB) under the coordination of the Ministry of Industry and Technology with the support of the World Bank. Within the scope of the project, TUBITAK will support the green transformation of the industry throughout the project with a financing of 175 million USD. Different types of calls will be opened by TUBITAK within the scope of the Türkiye Green Industry Project, which will last for 6 years. One of these calls is the SAYEM Green Transformation Call published in 2023. Within the scope of this call, innovation platforms will be created in cooperation with the private sector, universities and the public, and industrial R&D and innovation networks, which are a technology ecosystem for the development of high value-added products that will contribute to the green growth of Türkiye, will be supported. The establishment of a specialized R&D and Innovation Platform under the leadership of the private sector, in cooperation with universities and the public, the creation of productization roadmaps through this platform, and productization programs for the development of products or product groups for green transformation within the framework of these productization roadmaps will be supported. Photovoltaic cells, panels and systems are included within the scope of the European Green Deal and R&D and Innovation Issues for Adaptation to Climate Change.

The establishment of R&D infrastructures is supported by different mechanisms. METU-GUNAM gained the Thematic Research Infrastructure status in 2021. It operates in all scientific and technological research and development issues related to solar energy. In particular, it focuses on the development of PV system technologies and applications. It is aimed to create a comprehensive technical infrastructure and human resources related to solar energy in Türkiye.

INDUSTRY & MARKET DEVELOPMENT

ncreasing the share of renewable resources in electricity production is very important for decarbonizing the energy system. The most important synergy of the global energy transition comes from the combination of increasingly low-cost renewable energy technologies. Solar energy has spread faster than other renewable technologies in recent years, and its share in total installed capacity has gradually increased. In this development of the solar energy, the fact that it is a sustainable technology, offers environmentally friendly solutions to achieve climate targets, reduces costs and improves efficiency, and thus can be installed in the required location and offers significant financial returns play an important role. It is expected that the solar energy will continue to be the leading renewable energy source and technology in the coming period.

Türkiye has made significant progress in recent years, especially in solar energy, with the Renewable Energy Resources Support Mechanism (YEKDEM) and YEKA models. Increasing solar energy investments also increase the demand for equipment, especially solar panels. There are currently more than 35 photovoltaic module manufacturers in Türkiye with a total capacity of 12 GW. Production in the sub-industry of module frames, glasses, junction boxes and switchgear is also gradually developing. The number of companies operating in the field of solar energy is estimated to be around 1 000, including solar module, construction, cable and inverter manufacturers, operation and maintenance companies, smart grid, e-mobility, blockchain applications, energy management and monitoring, energy storage solutions, energy efficiency and consultancy services. As a result of these developments, SolarPower Europe estimates that the Turkish solar energy sector currently employs over 50 000 people.

The number of applications in the C&I rooftop PV market exceeded 2 000 projects last year, reaching an annual installed capacity of over 1 000 MW. According to SolarPower Europe, based on industry stakeholder research, there is an additional potential of at least 10 GW in the coming years, especially for unlicensed facilities with suitable roofs such as factories, hotels and hospitals, which are used by businesses for self-consumption. While it is predicted that energy resources in Turkey would increase in favor of renewable energy in the near future, 74.3% of the investments to be made in the energy sector are expected to be clean source investments such as solar, wind and geothermal. While the renewable energy installed capacity increases, it is aimed to create a 5 gigawatt electrolyzer and 7.5 gigawatt battery capacity to ensure flexibility in the electricity network. On the other hand, hybrid power plants, electric vehicle charging stations and infrastructures, and electricity storage technologies stand out as technologies and approaches that would rapidly increase solar energy capacity.

While the share of solar power plants in total electricity production was zero in 2013, solar power plants will constitute 10.6% of the total installed electrical power by the end of 2023.

THE UNITED STATES OF AMERICA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

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Fig. 75 - Staff from the National Renewable Energy Laboratory and GRID Alternatives Colorado install rooftop solar panels during a volunteer event in October 2023. The 6.7 kW solar installation project should provide the home with US$1 200 annual savings over the next 20 years. (Photo by Joe DelNero /NREL)

NATIONAL PV POLICY PROGRAMME

In the United States, photovoltaic (PV) market development is supported by both national and state-level financial incentives, though state and local policies vary widely. While there is no national-level deployment mandate, in December of 2021, President Biden signed Executive Order 14057, committing the United States to achieving a carbon pollution-free power sector by 2035 and net zero emissions economy-wide by no later than 2050. Furthermore, as of December 2023, 28 states, 3 territories, and Washington had active 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. Eleven states have also passed clean energy standards (CES), which are like an RPS, but allow a broader range of electricity generation (e.g., nuclear) resources to qualify.

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 (for certain systems). Renewable energy credits were altered considerably by the Inflation Reduction Act (IRA) in August 2022, which made the single largest investment in climate and clean energy in American history. Most of IRA’s record $370B investment into renewables will be in the form of tax credits for deployment and manufacturing, as well as grants and loans designed to spur the clean energy transition in a socially equitable manner. IRA extended the ITC at 30% through at least 2033 and allowed commercial and utility-scale systems to elect the production tax credit (PTC) instead, which provides a tax credit per kWh of electricity generated for the first 10 years of operation. For certain large projects, to receive the full credit, the project developer must satisfy certain labor and apprenticeship rules. There are also several bonus credits available for the ITC and/or PTC with the goal of incentivizing domestic manufacturing (+10% bonus), deployment within low-income communities (+10-20% bonus, depending on circumstances), and ensuring an equitable energy transition by encouraging deployment in specific "energy communities" which have been adversely impacted by the energy transition (+10% bonus). Tax exempt entities, such as non-profits and local governments, also may now directly take advantage of these tax credits. Tax credits are also provided to PV manufacturers producing certain clean energy components within the United States.

These national and state-level policies coupled with rapid declines in technology costs have enabled PV to continue to grow swiftly in the United States. At the end of 2023, the U.S. is expected to have reached 169.5 GW_{DC} of cumulative installed capacity compared to 139.9 GW_{DC} in 2022. This deployment translated to an estimated AC capacity of 134.8 GW_{AC} in 2023, compared to 111.2 GW_{AC} in 2022.[1]

RESEARCH, DEVELOPMENT & DEMONSTRATION

The U.S. Department of Energy (DOE) is one of the primary U.S. agencies that supports research, development, and demonstration (RD&D) of solar energy technologies in the U.S. In 2017, DOE announced that it had met its benchmark utility-scale 2020 goal of 6 USD cents per kWh and set a new target of 3 USD cents per kWh by 2030. However, to meet the urgency of the climate crisis and President Biden's Executive Order 14057, it is estimated that solar deployment needs to increase by three to five times, and therefore, costs need to fall faster. As a result, DOE accelerated its goal to 2 USD cents per kWh by 2030. Recognizing that cost is not the only barrier to solar deployment, DOE has also set goals to increase the reliability of solar electricity, ensure rapid solar deployment, and provide solar energy beyond electricity.

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

1. Photovoltaic (PV) Research and Development, which supports the research and development of PV technologies to improve efficiency, durability, and reliability, as well as lower material and process costs to reduce the levelized cost of solar generated electricity.

2. Concentrating Solar Power (CSP), which supports research and development of CSP technologies that incorporate thermal energy storage to supply solar power on demand, as well as heat for direct use in industrial processes.

3. Systems Integration, which develops technologies to enable improved integration of solar power with the power grid including power electronics and systems-level research on renewables integration.

4. Balance of Systems Soft Cost Reduction, which works with a diverse set of stakeholders to cut red tape, streamline processes, and aid decision-making.

5. Innovations in Manufacturing Competitiveness, which supports U.S. businesses with innovative solar products to develop prototypes and validate their technologies.

6. Workforce and Equitable Access, which supports the growth of a diverse and well-supported solar workforce and increasing equitable access to solar energy for all Americans.

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 (SC), Office of Electricity (OE), Advanced Research Projects Agency - Energy (ARPA-E), and the Solar Energy Technologies Office (SETO). In addition to the U.S. government, many states as well as public and private companies also fund solar RD&D.

INDUSTRY & MARKET DEVELOPMENT

After the rollercoaster year that was 2022, with annual grid-connected PV installations falling even as historic clean energy incentives were passed, 2023 saw a return to record growth for the United States in both the residential and utility-scale markets with a total of 29.6 GW_{DC} expected to be installed (19.6 GW_{DC} utility-scale and 10.0 GW_{DC} distributed).[2]

For the utility-scale PV market, growth in 2023 was driven primarily by easing of supply chain constraints. As 2023 progressed, importers learned how to comply with the Uyghur Forced Labor Prevention Act, which requires them to prove to U.S. customs officials that their products are not made using forced labor. At the same time, the U.S. Department of Commerce's investigation into possible circumvention of anti-dumping and countervailing duties (AD/CVD) by manufacturers in Cambodia, Malaysia, Thailand, and Vietnam concluded in August that there was circumvention by some companies in all four countries. In 2023, those four countries accounted for 74% of crystalline silicon (c-Si) module imports (34 GW_{DC}),[3] to which this investigation applies. However, the industry was insulated from any immediate or retroactive impacts by President Biden's moratorium on the imposition of any new AD/CVD resulting from the investigation on products imported prior to June 2024. The U.S. Congress attempted to revoke the moratorium in May of 2023, but the measure was vetoed.

1 . U.S. Energy Information Administration, Electric Power Monthly, Table 6.1, February 2024 combined with subject matter expert estimates.
2. Id.
3. U.S. Census Bureau. USA Trade Online. HTS code 8541430010 and 8541430080. Accessed February 2024.

For the residential PV market, several factors were at play. The California Public Utilities Commission approved Net Metering 3.0 rules in December 2022, transitioning the state's major utilities to a net billing structure with hourly avoided cost rate credits for energy exported to the grid starting in April 2023. This resulted in a surge of installations within the single largest residential installation market in the United States and a subsequently enormous backlog in interconnections as installers frontloaded their sales to take advantage of the old compensation rates.[4] This combined with high retail electricity rates in the Northeast increased installations in both markets.[5] However, this growth was counterbalanced by rising interest rates slowing installations in other major solar markets such as Texas, Arizona, and Florida.[6]

Since the passage of the Inflation Reduction Act, >250 GW of manufacturing capacity has been announced across the solar supply chain, representing more than 27 000 potential jobs and more than $14 billion in announced investments across 80 new facilities or expansions.[7] Some announced facilities have already become operational. For example, Qcells and First Solar recently reported 5.1 and 6.3 GW_{DC} nameplate domestic capacities, respectively, and there was a record 3.7 GW_{DC} of c-Si cells imported in 2023.[8]

In 2023, the United States also installed an estimated 5 GW (17 GWh) of energy storage[9] onto the grid and gained over one million battery electric vehicles,[10] while solar PV generated over 5% of U.S. electricity for the first time.[11]

2023 saw a return to record growth for the United States in both the residential and utility-scale markets with a total of 29.6 GW_{DC} expected to be installed

4. National Renewable Energy Laboratory. Winter 2024 Quarterly Solar Industry Update. March 2024
5. Wood Mackenzie/SEIA US Solar Market Insight®, Full report, Q4 2023, December 2023.
6. Id
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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
4. Photovoltaic Systems, T2-03:2002
5. The Availability of Irradiation Data, T2-04:2004
6. Country Reports on PV System Performance, T2-05:2008
7. Cost and Performance Trends in Grid-Connected
8. Photovoltaic Systems and Case Studies, T2-06:2007
9. 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 PV System Installation and Grid-interconnection Guideline in Selected IEA Countries, T5-04: 2001
4. Grid-connected Photovoltaic Power Systems: Survey of Inverter and Related Protection Equipment, T5-05: 2002
5. International Guideline for the Certification of PV System Components and Grid-connected Systems, T5-06:2002
6. Probability of Islanding in Utility Networks due to Grid Connected Photovoltaic Power Systems, T5-07: 2002
7. Risk Analysis of Islanding of Photovoltaic Power System within Low Voltage Distribution Networks, T5-08: 2002
8. Evaluation of Islanding Detection Methods for Photovoltaic Utility-interactive Power Systems, T5-09: 2002
9. Impacts of Power Penetration from Photovoltaic Power Systems in Distribution Networks, T5-10: 2002
10. 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 A PV Plant Comparison of 15 plants
2. The State of the Art of: High Efficiency, High Voltage, Easily Installed Modules for the Japanese Market
3. A Document on "Criteria and Recommendations for Acceptance Test"
4. A Paper, entitled: "Methods to Reduce Mismatch Losses."
5. 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
6. The "Guidebook for Practical Design of Large Scale Power Generation Plant"
7. The "Review of Medium to Large Scale Modular PV Plants Worldwide"
8. 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 nDeveloping 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
15. - 2013 (Fr), T9-13 :2013
16. Innovative Business Models and Financing Mechanisms for PV Deployment in Emerging Regions, T9-14:2014
17. PV Systems for Rural Health Facilities in Developing Areas, T9-15:2014
18. A User Guide to Simple Monitoring and Sustainable Operation of PV-diesel Hybrid Systems, T9-16:2015 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 – 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 In our revised structure

Task 1 is organized in four subtasks, encompassing all aspects, both new and legacy, of the activities.

Subtask 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 on important 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 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 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 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 PV Magazines monthly columns from PVPS experts have been utilized to promote the Snapshot and Trends reports, resulting in the publication of 2 columns. They can be consulted directly on the PV Magazine website.

TASK 12

Objectives

Task 12 aims to drive the sustainable evolution of photovoltaic (PV) technology by focusing on key objectives:

1. Environmental Impact
It quantifies and improves the environmental footprint of PV electricity, enabling comparisons with other energy sources to inform sustainable decision-making.

2. Circular Economy
Task 12 advances circularity within the PV industry through research, collaboration, and standards development, aiming to optimize material use and promote sustainable practices.

3. Synergetic Impacts
It studies the broader environmental and ecological effects of PV system deployment, including novel configurations like agrivoltaics and floating PV, to understand and mitigate potential impacts.

4. Social and Socio-economic Considerations
Task 12 addresses social acceptance and socio-economic factors crucial for PV market growth, advocating for best practices and evaluating assessment frameworks to guide sustainable development.

5. Knowledge Sharing
Task 12 disseminates its findings to technical experts, policymakers, and the public through various channels, facilitating informed decision-making and collective action towards a sustainable energy future powered by PV technology.

Sub-Task Structure In our revised structure

- Subtask 1 (Circular Economy - CE) now embraces a broader scope, focusing on the entire life cycle of PV technology and promoting circular economy principles, aiming to establish robust strategies within companies and nations.

- Subtask 2 (Life Cycle Assessment – LCA) maintains its focus on established Task 12 products, expanding to include peripheral balance of system technologies and improving methods for assessing primary mineral resource intensity.

- Subtask 3 (Ecosystem Integrated PV – EcoPV) is dedicated to assessing the ecological impact of PV systems, especially in emerging areas like agrivoltaics and floating PV, providing essential guidance for mitigating environmental impacts.

- Subtask 4 (Broader Sustainability Topics – BST) broadens Task 12's horizon by addressing social acceptance and human health risks associated with PV technologies, aiming to enhance support for sustainable development across various dimensions.

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 across various environments and applications. By collaborating across national boundaries, we can leverage research and experience from each member country, amalgamating this knowledge into valuable summaries of best practices and methods to ensure PV modules and systems achieve optimal performance. Specifically, our aims include:

- Gathering the most current information from each member country on a range of technical issues related to PV reliability and performance. This will encompass summaries of different practices from each country and experiences with various PV technologies and system designs.
- Collecting measured data from PV systems worldwide. This data will serve to test and compare data analysis methods for PV degradation, operation & monitoring (O&M), performance, and yield estimation, etc.
- Communicating with our stakeholders through several impactful channels, including technical reports, workshops, webinars, and scientific papers at conferences and in journals.

Sub-Task Structure In our revised 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. The subtask 2 will provide best practices and guidelines for these emerging PV applications.

Subtask 3: Techno-Economic Key Performance Indicators

It deals with the definition of techno-economic Key Performance Indicators (KPI) and how to map them in an effective way. This subtask will focus in particular 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 a 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)

During 2023, the following technical papers were prepared and published:

[1] Joshua S. Stein, Giosué Maugeri, Silvana Ovaitt, Nicholas Riedel-Lyngskær, Jan Vedde, Daniel Riley: IEA PVPS Task 13 Techno-Economic Study of Bifacial Photovoltaic Systems on Single Axis Trackers, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 21 September 2023 (Oral and Paper 4DO.12.2).

[2] Bert Herteleer et. al: Investigating methods to improve photovoltaic thermal models at second-to-minute timescales, Solar Energy 263 (2023) 111889, Investigating methods to improve photovoltaic thermal models at second-to-minute timescales - ScienceDirect, Elsevier, October 2023.

[3] Sandra Gallmetzer, Sascha Lindig, Magnus Herz, David Moser: Solution Matrix for Economically Optimized O&M of PV Systems, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 19 September 2023 (Oral and Paper 4BO.6.6).

[4] Atse Louwen, Sascha Lindig, Mohammed Gofran Chowdhury, David Moser: Climate and Technology Dependent Performance Loss in a Fleet of 10,000 PV Systems, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 18 September 2023 (Oral and Paper 4AO.8.4).

[5] Franz P. Baumgartner, Cyril Allenspacher: Performance Gain of Shading Tolerant PV Modules in Different Electrical PV System Setups, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 21 September 2023 (Oral and Paper 3DO.16.1).

[6] Cyril Allenspach, Fabian Carigiet, Franz P. Baumgartner: Lab Measurements of Power Optimizer Efficiency and Performance Simulation of Partially Optimized Systems Affected by Shading, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 21 September 2023 (Oral and Paper 4DO.1.1) - Student Award Winner 2023!

[7] Leonardo Micheli, Diego Lopez Talavera, Fredy A. Sepúlveda-Vélez: Incentives and Disincentives for Floating Photovoltaics in Europe: A Sensitivity Analysis, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 21 September 2023 (Visual and Paper 5DV.3.18) - Poster Award Winner 2023!

[8] Ioannis A. Tsanakas, Bert Herteleer, Ulrike Jahn: Towards Climate-Specific O&M for PV Plants: Guidelines and Best Practices, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 20 September 2023 (Visual and Paper 4CV.1.12).

TASK 14

Objectives

As part of the IEA-PVPS program, Task 14 is dedicated to laying the technical foundation for solar photovoltaics (PV) as a major energy source in a 100% renewable energy source (RES) based power system. Task 14 collaborates with utilities, industry, and various stakeholders to advance the technologies and methodologies necessary for the extensive and efficient integration of both distributed and centralized PV technologies into electricity grids.

Task 14 addresses the challenge of high penetration PV across the entire interconnected electricity system, which includes local distribution grids and wide-area transmission networks. Additionally, island and isolated grids in emerging regions fall within Task 14's purview.

Since its inception as a global initiative under the PVPS Technology Collaboration Programme (TCP), Task 14 has been supporting stakeholders from research, manufacturing, as well as the electricity industry and utilities, by providing access to comprehensive international studies and experiences with high-penetration PV. Consequently, Task 14's efforts foster a shared understanding and broader consensus on methods to accurately assess the value of PV in a 100% RES-based power system. The goal is to demonstrate the full potential of grid-integrated photovoltaics, alleviate concerns regarding PV, benefit a large number of countries, and connect technical expertise on Solar PV integration within Task 14 to complementary initiatives (e.g., WIND Annex 25, ISGAN).

Through international collaboration and its global membership, Task 14 serves as a platform for the exchange of expertise among countries where Solar PV already makes a significant contribution to the electricity supply, and those with emerging power systems experiencing a rising share of variable renewables.

Sub-Task Structure In our revised structure

Task 14's work program focuses primarily on technical issues related to the grid integration of PV in high penetration scenarios, especially in configurations where a major share of the energy is provided by variable renewables. The main technical topics include transmission and distribution grid planning and operation with high penetration of 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 program is organized into two technical subtasks and one cross-cutting subtask, which will serve as a hub between the technical subtasks ensuring efficient interaction, dissemination, and outreach:

Subtask A, "Dissemination and outreach", focuses on dissemination and outreach activities and enhances Task 14's role as a 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 a 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 to formulate recommendations about PV communication and control concepts to optimize PV integration into smart grids within different kinds of infrastructures.

Publications (non-PVPS)

G.Heilscher, „Integration von PV-Systemen in Smart Grids - Status und Potentiale am Beispiel aktueller Forschungsprojekte"; 38. PV Symposium, Staffelstein, Germany, Feb. 2023.

A. Altayara, „Reactive Power Management with Decentralized Renewable Energy Sources", Solar and Wind Integration Workshop, Copenhagen, Denmark, Sept. 2023.

S.Chen, Z. Lu, G. Heilscher, „Concept and Implementation of a grid simulation framework utilizing containerized IEC 61850 compatible IED", CIRED-Workshop, Rome, Italy, June 2023.

G.Heilscher, „Solar PV in the 100% RES Power System", Vollversammlung Forschungsnetzwerk Erneuerbare Energien – Photovoltaik, Leipzig, Germany, May 2023.

C. Kondzialka, M. McCulloch, R. Taubmann, J. Dierenbach, D. Graeber, G. Heilscher, „Removing barriers for participation of small PV systems in balancing energy markets by utilizing the established smart meter eco-system", 50th IEEE Photovoltaic Specialist Conference (PVSC), San Juan, Puero Rico, June 2023.

G. Heilscher, K. Schlabitz, „Kommunikation mit dezentralen Energiesystemen - CIM-Anwendung im internationalen Kontext" VDE-DKE CIM-Workshop, Frankfurt a. Main, Sept. 2023.

C. Bucher, „ Inverter Testing according to IEC 63409", Webinar on IEC 63409, Online, Sept. 2023.

G. Arnold, „Optimization Of Compliance Testing For Grid-supporting Inverter Functionalities", IRES-Conference, Aachen, Germany, Nov. 2023.

Altayara, Abdullah & Mende, Denis & Wang, H. & Stock, D. & Kraiczy, Markus & Bucher, Christof & Adinolfi, Giovanna & Graditi, G. & Bründlinger, Roland & Ogasawara, Y. & Omine, E. & Ueda, Yuzuru & Heilscher, Gerd & Chen, Shuo. (2023). Reactive power management with decentralized renewable energy sources. 575-583. 10.1049/icp.2023.2788.

Siddhi Shrikant Kulkarni, Gunter Arnold, Nils Schäfer, Vishu Verma, Optimization Of Compliance Testing For Grid-supporting Inverter Functionalities, International Renewable Energy Storage (IRES) Conference, Aachen, 2023.

TASK 15

Objectives

Building-Integrated PV (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 differences from single-family dwellings to large-scale BIPV applications in offices and utility buildings.

In its second workplan (2020-2023), Task 15 addressed barriers to the widespread implementation of BIPV by exchanging research, knowledge, and experience, and closed 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. By continuing to work together across national borders in the following years (2024-2027), the Task aims to provide valuable information to different stakeholders in the BIPV value chain, ranging from market analysis, improved BIPV assessment and characterization techniques, BIM exchange formats and simulation, gathering data from real products and projects, to communicating and developing new training models.

Sub-Task structure for the second workplan (2020-2023)

Task 15 is divided into 5 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 TIS 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 characterization methods

Subtask E carries out pre-normative international research to develop new and optimized characterization 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)

F. Frontini, H.R. Wilson, G.C. Eder, M. Babin, S. Thorsteinsson, J. Adami, R. Yang, N. Martin Chivelet, S. Boddaert. CROSS-SECTIONAL ANALYSIS OF BIPV INSTALLATIONS: performance evaluation as building component and energy generator. 40th EU PVSEC, 18.-22.9.2023, Lisbon.

M. van Noord, N. Martín-Chivelet, M. Tabakovic, R. Yang, N. Weerasinghe, O. Bernsen, W. G.J.H.M. van Sark, F. Tilli, A. Baggini, Comparison of BIPV Innovation System Structures in Multiple Countries, 40th EU PVSEC, 18.-22.9.2023, Lisbon.

R. Yang, Y. Zang, J. Yang, R. Wakefield, K. Nguyen, L. Shi, B. Trigunarsyah, F. Parolini, P. Bonomo, F. Frontini, D. Qi, Y. Ko, X. Deng, Fire safety requirements for building integrated photovoltaics (BIPV): A cross-country comparison, Renewable and Sustainable Energy Reviews, Volume 173, 2023, 113112, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2022.113112.

TASK 16

Objectives

The main goals of Task 16 are to reduce the barriers and costs associated with the grid integration of PV and to lower planning and investment costs for PV by enhancing the quality of forecasts and resource assessments. Solar resources introduce the highest share of uncertainty in yield assessments.

To achieve this main goal, Task 16 has set the following objectives:

- Reduce the uncertainty of satellite retrievals and Numerical Weather Prediction (NWP).
- Define best practices for data fusion of ground, satellite, and NWP data (re-analysis) to produce improved datasets, e.g., time series or Typical Meteorological Year (TMY).
- Develop enhanced analysis for, e.g., point-to-area forecasts, solar trends, albedo, solar cadastres, and firm PV power.
- Contribute to or set up international benchmarks for datasets and forecast evaluation.

The scope of work in Task 16 focuses on meteorological and climatological topics necessary to plan and run PV, solar thermal, concentrating solar power stations, and buildings.

The updated work program of Task 16 addresses scientific meteorological and climatological issues related to high penetration and large-scale PV in electricity networks on one side, but also includes a strong focus on user needs. Dissemination and user interaction are planned in various forms, from workshops and webinars to papers and reports, and online code archives or Wikipedia.

Sub-Task Structure In our revised 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 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)

Javier Lopez-Lorente, Jesus Polo, Nuria Martin-Chivelet, Matthew Norton, Andreas Livera, George Makrides, George E. Georghiou, Characterizing soiling losses for photovoltaic systems in dry climates: A case study in Cyprus, Solar Energy, Volume 255, 2023, Pages 243-256, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2023.03.034 .

Rey-Costa, E., Elliston, B., Green, D. & Abramowitz, G. Firming 100% renewable power: Costs and opportunities in Australia's National Electricity Market. Renew. Energy 219, (2023). https://doi.org/10.1016/j.renene.2023.119416

Ruiz-Arias J.A. and Gueymard C.A. (2023) "CAELUS: Classification of sky conditions from 1-min time series of global solar irradiance using variability indices and dynamic thresholds" Solar Energy, Vol. 263, 111895, doi: 10.1016/j.solener.2023.111895

Øyvind Sommer Klyve, Magnus Moe Nygård, Heine Nygard Riise, Jonathan Fagerström, Erik Stensrud Marstein. The value of forecasts for PV power plants operating in the past, present and future Scandinavian energy markets, Solar Energy, Volume 255, 2023, Pages 208-221, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2023.03.044

TASK 17

Objectives

The main goal of Task 17 is to deploy PV usage in transport, which will contribute to reducing CO2 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 In our revised 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)

During 2023, the following technical papers were prepared and published:

[1] Joshua S. Stein, Giosué Maugeri, Silvana Ovaitt, Nicholas Riedel-Lyngskær, Jan Vedde, Daniel Riley: IEA PVPS Task 13 Techno-Economic Study of Bifacial Photovoltaic Systems on Single Axis Trackers, 40th European PV Solar Energy Conference and Exhibition (EU PVSEC-40), Lisbon, Portugal, 21 September 2023 (Oral and Paper 4DO.12.2).
Journals

1. N. Dougier, B. Celik, S. Chabi Sika, M. Sechilariu, F. Locment, J. Emery : "Modelling of electric bus operation and charging process : potential contribution of local photovoltaic production", Applied Sciences, vol. 13, no.7, pp 4372, MDPI Ed., 2023, https://doi.org/10.3390/app13074372

2. S. Cheikh-Mohamad, B. Celik, M. Sechilariu, F. Locment : "PV-Powered Charging Station with Energy Cost Optimization via V2G services", Applied Sciences, vol. 13, no.9, pp 5627, 2023, https://doi.org/10.3390/app13095627

3. B. Robisson, V.-L. Ngo, L. Marchadier, M.-F. Bouaziz, A. Mignonac, "PV Sizing for EV Workplace Charging Stations—An Empirical Study in France", Applied Sciences, vol. 13, no.18, pp 10128, 2022, https://doi.org/10.3390/app131810128

4. N. Patel, K. Bittkau, B. E. Pieters, E. Sovetkin, K. Ding, A. Reinders, "Impact of Additional PV Weight on the Energy Consumption of Electric Vehicles With Onboard PV", IEEE J. Photovolt., Early Access, https://doi.org/10.1109/JPHOTOV.2024.3359446

Conferences

1. F. Agha Kassab, B. Celik, S. Cheikh-Mohamad, F. Locment, M. Sechilariu, S. Liaquat, T. M. Hansen : "Optimizing Microgrid Sizing, Energy Management, and Electric Vehicle Integration in Various French Cities", Electrimacs, 27-30 May 2024 Spain

2. F. Agha Kassab, B. Celik, F. Locment, M. Sechilariu, T. M. Hansen : "Combined Optimal Sizing and Energy Management of a DC Microgrid using MILP", IEEE PowerTech, 25-29 June 2023 Belgrade, DOI: 10.1109/PowerTech55446.2023.10202939

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 In our revised 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

ANNEX B

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