International Energy Agency
Photovoltaic Power Systems Programme

PVPS

COUNTRY UPDATES

2024

PHOTOVOLTAIC POWER SYSTEMS TECHNOLOGY COLLABORATION PROGRAMME

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

COUNTRY UPDATES 2024

Photo 1: Algeruz II PV power plant, located in Setúbal, Portugal. Iberdrola

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Photo 2: The Members of the Executive Committee and Task Managers at their meeting in Yokohama in October 2024.

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organisation for Economic Cooperation and Development Photovoltaic(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 the beginning of 2025, twenty Tasks were established within the PVPS programme, of which nine are currently operational. The thirty PVPS members include twenty-six countries: Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, India, Israel, Italy, Japan, Korea, Malaysia, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America; plus four sponsor members: the European Commission, Solar Power Europe, the Solar Energy Research Institute of Singapore and Enercity SA.

MISSION AND OBJECTIVES

The mission of the IEA PVPS programme is:

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

The IEA PVPS programme aims to realise its mission through the following objectives related to reliable PV power system applications, contributing to sustainability in the energy system and a growing contribution to CO_2 mitigation:

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

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 digitalisation arenas will be intensified to foster innovation and address evolving needs effectively.

AUSTRALIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Renate Egan, Australian Centre for Advanced Photovoltaics
Linda Koschier, University of New South Wales

Photo 3: Residential rooftop installation in the Blue Mountains.

PV POLICY PROGRAMME

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

The Large Scale Renewable Energy Target (LRET) of 33 000 GWh of renewable electricity annually has been met, with the installation of close to 9 GW of solar installations with a capacity over 100 kWp. Systems over 100kW still receive tradeable certificates for energy generated. The larger challenge for utility scale solar is curtailment due to excess solar. As a result programmes now focus around demand shifting and storage.

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

Complementing the national programmes, the Australian Renewable Energy Agency

(ARENA) holds a portfolio of 883 million AUD in solar projects) from R&D to deployment (ARENA Annual Report, 2024. 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 agency supports the global transition to net zero emissions by accelerating the pace of pre-commercial innovation.

With over 40% of free-standing homes, and over 1.4kW per capita installed PV, policy is now framed around dispatchable capacity. As a result, in late 2023, the Australian Government announced an expansion of the Capacity Investment Scheme to target a total of 32 GW of new capacity nationally, made up of 23 GW of renewable capacity and 9 GW of clean dispatchable capacity that will be rolled out from 2024 to 2027.

Informed by a detailed analysis of the solar supply chain, in March 2024, the Australian government committed $1 billion to an initiative to building Australian solar PV manufacturing capability and supply chain resilience.

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

RESEARCH, DEVELOPMENT & DEMONSTRATION

PV research, development, and demonstration are supported at the national, as well as the state and territory level. In 2024, research was funded by the Australian Renewable Energy Agency (ARENA), the Australian Research Council and Co-operative Research Centres. ARENA is the largest funder of photovoltaics research in Australia.

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 until 2030, supported by 45 million AUD in ARENA funds and over 10 million AUD 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 programme, aiming to drive the levelised cost of electricity from large-scale solar down from the current 50 AUD/MWhr to below 20 AUD/MWhr.

In addition, the federal government, under its Education inistry, supported an initiative in research acceleration in the area of Recycling and Clean Energy (TRACE) with a programme stream on solar technologies. The programme has an ambitious goal to move rapidly to and to 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.

INDUSTRY & MARKET DEVELOPMENT

Australia saw an estimated 4 GW of solar installed in total in 2024, with 2.9 GW of rooftop solar and 1.1 GW of utility scale solar. This number is expected to increase to around 4.2 GW once all new installations are reported. If so, the market remains stable at 4.2 GW. Total installed solar capacity is now ~38.6 GW.

We continued to observe a decline in solar costs, with the average price per watt (after incentives) dropping to $0.90 by December 2024, down from $1.05 in the previous year.

Rooftop solar claimed an annual average fraction of total electricity demand of generation of around 13%, while large-scale solar projects contributed over 6% for a total 19% of electricity needs being met by solar over 2024. In mid-Spring (October), Australia's main grid reached a record renewable (wind and solar) share of

more than 47% in the month of October, while South Australia delivered a renewables share equivalent to 85.2% of state demand.

Australia's main grid reached a record renewable (wind and solar) share of more than 47 percent in the month of October 2024.

The Australian storage market remained strong in 2024, with the Clean Energy Regulator now tracking and reporting battery installations. Over 28 262 new batteries were recorded as installed with small scale solar systems in 2024. Australia has now seen 122 000 batteries installed since 2014.The industry reports significantly higher numbers, reflecting a lack of systematic reporting to the Clean Energy Regulator.

The Australian market remains 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 number of large-scale battery deployments called for, as excess solar in the middle of the day results in curtailment, and evening peaks challenge grid capacity.

2025 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 means payback can commonly be achieved in 3-5 years; a situation that looks set to continue in 2025.

Renewed investment in large scale solar and batteries is expected to start to yield projects and connections in 2025, with a pipeline of projects aimed at 23 GW of renewable capacity and 9 GW of clean dispatchable capacity to be delivered before 2027.

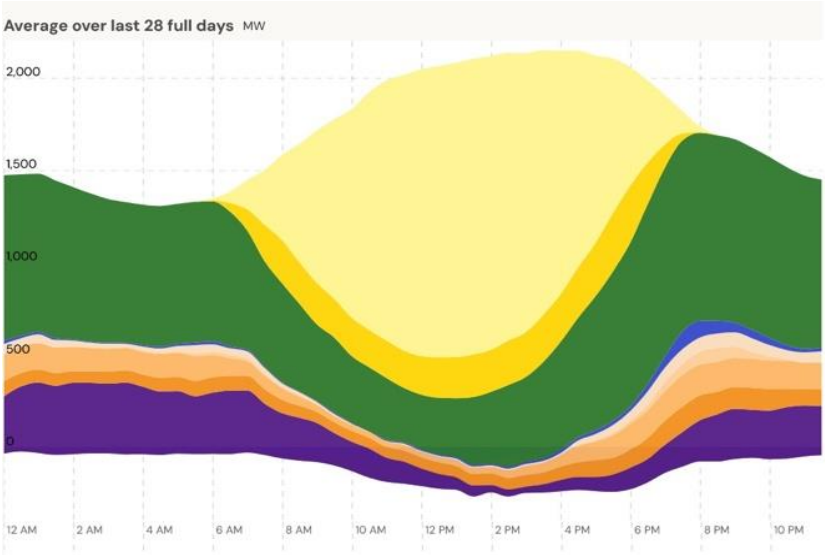

Figure 1: Solar & wind in South Australia often exceeds 100% of demand. Over 28 mid-summer days (Dec 21-Jan 11), South Australia (SA) averaged peak generation from solar & wind of 105% of demand (130% on the best day). On each day over the period, solar + wind generated between 48% and 102% of total daily electricity demand, with an average of 79%. The OpenElectricity figure shows midnight-to-midnight generation averaged over 28 days: solar rooftop & farms (light & dark yellow), wind (green), gas (orange), blue (batteries) and imports (purple). [https://openelectricity.org.au/] Source: Prof Andrew Blakers

Australian Experts participate currently in 8 PVPS Tasks involving 11 separate entities as listed here.

AUSTRIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing author: Hubert Fechner, Chair of the Austrian Photovoltaic Technology Platform

Photo 4: SOLARSKYPARK fast-charging park for e-mobility with neoom outdoor battery storage and solar carport.

PV POLICY PROGRAMME

In view of the national 2040 climate neutrality target, Austria's energy supply must be converted to 100 percent renewable energy by then. Final energy consumption shows a clear tendency towards a reduction, leading to about 1 350 TWh in 2023. Austria can already cover over 85% of its electricity needs from renewable sources on annual basis, out of which about 10% comes from photovoltaics. This development contributes to the achievement of national and EU-wide energy and climate policy targets on an ongoing basis.

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). PV currently contributes with more than 8 TWh. A further target is set in the Integrated Austrian Grid Infrastructure Plan, with 41 TWh of PV by 2040. Other studies see slightly lower PV target values, with a stronger expansion of wind power in return.

The basis of this development is the Renewable Energy Expansion Act (EAG), which has implemented a fundamentally modernised and market-oriented subsidy system for green electricity plants in 2021, thereby creating a stable long-term investment climate. In 2024, a reduction in VAT to zero per cent on systems up to 35 kWp made the PV-systems support process much easier. Since October 2022, a gradually increasing CO_2 price was introduced for fossil-based CO_2 emissions not covered by EU emissions trading.

Nevertheless, nearly 60% of the total energy used in Austria currently still comes from fossil fuels, mainly used in the transport, heating, and industrial sectors.

In 2024 Austria, coordinated by the Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology has developed an "Austrian Photovoltaic Strategy", which outlines the measures required to ensure that the PV sector helps to shape the energy transition for the optimum benefit of citizens and companies. Objectives and fields of action of a strategic expansion process as well as measures for a coordinated expansion of PV in Austria are core elements of this national strategy document.

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 an ongoing broad program of research and innovation support in the field of renewable energy and energy efficiency. PV systems are an integral part of many subsidised projects.

The Austrian PV-Technology platform, which was initially supported by the same ministry, acts as a legal body since 2012. It brings together about 35 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 programmes, and conferences, joint national and international research projects, and other similar activities are part of the work programme, 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.

Public spending on research, development, and demonstration projects in the energy sector amounted to a record of 310 million EUR in 2023, of which about 5.5 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 European research environment, Austria is coordinating the Clean Energy Transition Partnership (CETP), a co-funded Partnership in Horizon Europe. Most Austrian producers in the photovoltaic sector are struggling to compete internationally. Research and innovation will increasingly play an important role.

The European Net Zero Industry Act is seen as a great opportunity that must be utilised to strengthen the renewables sector with European partners and ensure sovereignty in the energy supply.

Aspects of sustainability, recycling and the reuse of photovoltaic modules are becoming increasingly important and are the subject of intensive research.

INDUSTRY & MARKET DEVELOPMENT

The year 2024 was characterised by a slight decline in the expansion of PV after the all-time high in 2023; however, the further addition of more than 2 GW, leading to a total of over 8 GW of PV installations, also revealed the need to manage PV generation peaks. Beside grid constraints, negative electricity prices on the European electricity market correlate more and more with the times of PV feed-in peaks. Storage and the use of local flexibilities, vertical PV, as well as dynamic grid access options are therefore at the beginning of widespread introduction. National laws and regulations in the electricity sector have been adapted to the new requirements, but due to the end of the legislative period, not all of them have yet been politically implemented.

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 organises conferences, workshops, and industry meetings.

A new brochure, published by the federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology focuses on the existing value creation within Austria's PV sector. It provides an overview of the Austrian producers in the PV sector as well as the relevant actors in the research field.

Austria has more than doubled its PV in the last 2 years and now covers around 10% of the national electricity demand.

Austrian Experts participate currently in 7 PVPS Tasks involving 9 separate entities as listed here.

BELGIUM

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Elina Bosch, Becquerel Institute
Gerrit Jan Schaeffer, Energyville
Bart Vermang, Energyville

Photo 5: 2024 BIPV Award winning BIPV solar façade from Kameleon Solar and Soltech located in the new Soltech factory in Genk.

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. As of the end of 2024, there was no final national NECP submitted yet. The regional ambitions are respectively 8.2/5.1/0.3 TWh of solar photovoltaic electricity generation by 2030 in Flanders (Vlaams Energieen Klimaatplan 2021-2030), in Wallonia (Plan regional air-climat-énergie) and in Brussels (Plan régional air-climat-énergie). Put together, this means a national generation target close to 14 TWh/year by 2030 which is not enough for Belgium to fulfil the EU requirements for climate effort sharing and falls short from the estimated 20-25 GW needed according to EnergyVille study. In 2024, two main support schemes for residential PV development

were no longer applicable. At the end of 2023, the net-metering scheme (for new PV systems) was phased out in Wallonia and the investment support was phased out in Flanders.

In addition, in 2024, the VAT reduction (from 21% to 6%) for houses less than 10 years old was no longer in force throughout the whole country. In these two regions, residential PV is now driven by self-consumption and sales of surplus electricity to a utility. In Brussels, net-billing is in place for residential PV (<5kW) and green certificates are available for various sizes and typologies (BIPV-specific green certificate grant rate exists) of PV systems. As part of the revised regional urban planning regulation, Brussels region new buildings with a flat roof area greater than 20 m² have to dedicate part of this area to renewable energy production (including PV), to urban agriculture, to recreation function or to nature development. In Flanders, companies with an electricity consumption of more than 1 GWh are required to fulfill an obligation related to the installation of renewable energy by June 2025. The obligation can be met through three different means: 1. commissioning photovoltaic systems; 2. commissioning other renewables (wind turbines, CHP, HP); 3. participating financially in renewable projects commissioning (PV, wind turbines, CHP).

RESEARCH, DEVELOPMENT & DEMONSTRATION

In Belgium, research and development efforts in photovoltaics (PV) cover the entire value chain, from the development of new cell architectures to advances in power electronics, Agri-PV, floating solar, offshore PV-wind hybridization, building-integrated PV (BIPV), and large-scale solar installations. These activities are carried out across multiple universities and research centres, fostering innovation and accelerating the integration of PV into diverse applications. A key focus remains on tandem solar cell technology. Within the PERCISTAND project, thin-film tandem solar cells have achieved efficiencies of up to 30%, providing a sustainable alternative to conventional silicon PV (EnergyVille).

Belgium is also making strides in offshore floating PV (OFPV). The SWiM project is assessing the feasibility of integrating PV into offshore wind farms within Belgium's Exclusive Economic Zone, with the aim of maximizing the complementarity of solar and wind energy production at sea (buildings (EnergyVille). Belgian research continues to prioritise sustainability and circularity. Increasing emphasis is being placed on life cycle assessments (LCA), recycling of end-of-life PV panels, and the development of low-carbon footprint solar cells and modules. Particular attention is being given to reducing dependency on scarce materials such as indium, bismuth, and silver, ensuring a more sustainable supply chain (EnergyVille). Through its broad and ambitious research agenda, Belgium continues to push the boundaries of PV technology, reinforcing its position as a key player in the transition to a sustainable energy system.

INDUSTRY & MARKET DEVELOPMENT

In 2024, the total electricity consumption in Belgium was 80.5 TWh. Solar PV represented 11.9% of the electricity generation mix in 2024, a 25% increase compared to 2023 attributable to the important and exceptional annual solar PV capacity additions throughout 2023.

In 2024, the annual installed solar PV capacity was around 947 MW with respective contributions of Flanders, Wallonia and Brussels of 729 MW (estimation based on AC capacity), 200 MW and 18 MW. This brings the cumulative installed capacity close to 11 GW and Watt per capita penetration to 924.Despite the phase-out of support schemes in the residential market segment, small PV installations(<10 kW) remained an important market development driver (44% of annual installed capacity in Flanders).

There are just a few, niche-market, solar module producers in Belgium. BelgaSolar (called EvoCells until recently) added a new 50 MWp production line in 2024. Another example is Soltech, which targets the special use market of solar PV integrated in façades, 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. In Wallonia, there is a module manufacturing project with foreseen start of operation of a 500 MW line in 2025.

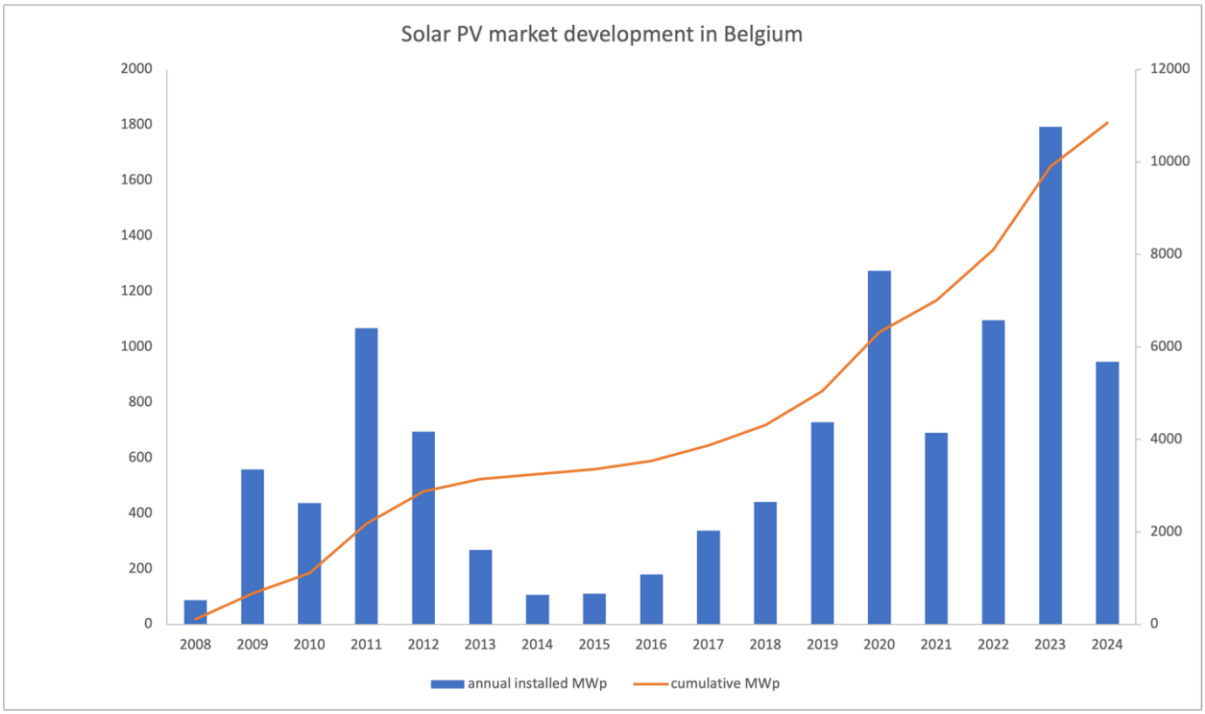

Figure 1: Solar PV market development in Belgium. Data: 2008-2023 Energy Commune; 2024 own estimate, based on primary provisional data.

Belgian Experts participate currently in 8 PVPS Tasks involving 9 separate entities as listed here.

CANADA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Christopher Baldus-Jeursen, CanmetENERGY, Natural Resources Canada
Yves Poissant, CanmetENERGY, Natural Resources Canada
Mathieu Côté, Canadian Renewable Energy Association
Marylène Roy, CanmetENERGY, Natural Resources Canada

Photo 6: The city of Lac-Mégantic in Quebec, Canada, is an example of the green transition with a 620 kW rooftop array on the city sports centre. The array is part of a community microgrid that includes battery storage, highly energy efficient buildings based on principles of sustainable development, and control infrastructure to optimise energy use. (Photo credit: Hydro-Québec).

PV POLICY PROGRAMME

The development of the photovoltaic (PV) sector in Canada fits within the broader context of efforts to decarbonise the economy and achieve a net-zero electricity supply by 2050. There are no specific capacity installation targets for PV set by the federal, provincial, or territorial governments. As of December 31, 2023, Canada's PV sector reached approximately 8.0 GW_{DC} of installed capacity, representing a 23% increase (or around 1.5 GW_{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 (NSR) provided to the International Energy Agency.

At the national level, PV is eligible for several federal support programs including the CAD 4.56 billion Smart Renewables and Electrification Pathways Program, the CAD 500 million Low Carbon Economy Fund, the CAD 520 million Clean Energy for Rural and Remote Communities program, and the CAD 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. 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.

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.

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 tend 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, 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 ground-mounted and rooftop PV systems, there is also 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, establish regulatory frameworks, and define and implement policy support mechanisms. Agrivoltaics Canada, a farmer-led not-for-profit advocacy group, was recently incorporated to help realise these goals. Agrivoltaics Canada works in partnership with representatives from the PV sector, as well as provincial and federal government agencies and academic institutions including the University of Western Ontario and the Ontario Agricultural College at the University of Guelph.

INDUSTRY & MARKET DEVELOPMENT

Approximately 67% of Canada's cumulative 8.0 GW_{DC} PV capacity consists of large ground-mounted centralised systems providing bulk power on the supply side of electricity meters without self-consumption. The remaining 33% is distributed PV capacity on the demand side of the electricity meter and is often embedded on a customer's premises. The economic value of the Canadian PV industry in 2023 was approximately CAD 3.1 billion. The combined number of full-time manufacturing, installation, distribution, and research employment in this sector was estimated to be approximately 27 900 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. Examples of several large PV manufacturers in the Canadian market include Canadian Solar, Heliene, and Silfab. Other participants in the production chain include Canadian Premium Sand, a major patterned glass supplier in North America. There is also a wide variety of array racking and component manufacturers and distributors. Turnkey prices in CAD per Watt (CAD/W), as reported in the NSR, are divided into rooftop (building-added PV) and ground-mounted systems. For rooftop PV systems from 5 to 10 kW, prices were around 2.30 to 3.90 CAD/W. Larger rooftop arrays from 10 to 100 kW had prices that were around 2.00 to 3.20 CAD/W. Commercial

roof-mounted PV from 100 to 250 kW varied between 1.90 to 2.40 CAD/W. Small centralised arrays between 1 and 20 MW were from 1.65 to 1.90 CAD/W. For systems larger than 20 MW, prices were generally less than 1.31 CAD/W.

Canadian Experts participate currently in 6 PVPS Tasks involving 7 separate entities as listed here.

CHINA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Xie Tian, LONGi Green Technology Co., Ltd.

Lyu Fang, Institute of Electrical Engineering, Chinese Academy of Sciences, Research Department of Integrated Renewable Energy Systems

Pan Wei, LONGi Green Technology Co., Ltd.

Dai Jinhong, PV Committee of China Green Supply Chain Alliance (ECOPV)

Photo 7: LONGi Back Contact Cell. Source: LONGi.

PV POLICY PROGRAMME

In 2024, various policies have been intensively issued from both national and provincial levels to boost sustainable development of China PV industry.

From an energy legislation perspective, China's first energy law “P.R.C Energy Law” was approved in November 2024. It clarifies the prioritised position of development and utilisation of renewable energy, and optimises supporting mechanism for renewable electricity consumption.

From **demand side**, a number of policies have been issued to stimulate green energy utilisation, including PV.

- In May 2024, the State Council released “2024-2025 Action Plan for Energy Conservation and Carbon Reduction”. It requires the acceleration of the construction of solar and wind mega base and promotes distributed energy to intensify efforts on non-fossil energy development.
- In July 2024, “Work Plan on Accelerating the Establishment of a Carbon Emission

Dual Control System" was released, and the Plan requires to establish a new mechanism for the comprehensive transition from dual control of energy consumption to dual control of carbon emissions.

- Also, in July 2024, <Basic Rules of Mid-Long Term Electricity Trading - Green Electricity Trading Chapter> was published, aiming to accelerate the establishment of a market system and an enduring mechanism to promote the production and consumption of green energy.

From **supply side**, policies are formulated to regulate PV product manufacturing.

- In November 2024, MIIT (Ministry of Industry and Information Technology of the People's Republic of China) issued "Photovoltaic Manufacturing Industry Specifications (2024 edition)". The requirements are mainly set out in seven aspects: production layout and project establishment, process technology, comprehensive utilisation of resources and energy consumption, smart manufacturing and green manufacturing, and environmental protection, among others.

Meanwhile, with the rapid development of PV industry, and guided by < Action Plan for Carbon Peak by 2030 >, ESG related topics have also drawn attention.

- On March 7, 2024, China issued the "Action Plan for Promoting Large-Scale Equipment Renewal and Consumer Goods Trade-Ins", proposing initiatives for recycling and circular utilisation. On August 21, the "Implementation Plan for Large-Scale Equipment Renewal in Key Energy Sectors" was released, outlining plans to achieve equipment renewal and technological upgrades in power transmission and distribution, wind power, PV, and hydropower. The plan emphasises advancing the renewal and recycling of PV equipment, while promoting the development of technologies for the recycling, processing, and reusing of PV modules.
- In May 2024, the "Implementation Plan for Establishing Carbon Footprint Management System" was issued, requiring the initial establishment of a carbon footprint management system by 2027 and ongoing system optimization by 2030, and emphasises the importance of international integration.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In 2024, China continues to hold the leading position in PV technology research and development breakthroughs.

TOPCon

- In November 2024, Trina set a new record for N-type bifacial i-TOPCon cell efficiency at 26.58%, which leads to a module efficiency of 24.8%.
- LECO/LIF technology has become the standard configuration for TOPCon production, while laser SE has been gradually replaced, leading to improved efficiency

Back Contact Cell

- In May 2024, LONGi continued to set records, achieving a cell efficiency of 27.3%, and module efficiency of 25.4%, exceeding the 24.9% IBC module efficiency set by Maxeon in January 2024 (see Photo 1: LONGi Back Contact Cell)
- Multiple manufacturers launched Back Contact product in 2024.

Tandem

- In June 2024, LONGi once again refreshed the world record for crystalline silicon-perovskite tandem cells, with an efficiency of 34.6%, breaking the world record previously created by LONGi itself.

Perovskite

- Perovskite solar cell efficiency has made breakthroughs in both commercial and laboratory products. Utmolight produces its first commercial module (2.8m^2, 16%). The first 1MW pilot perovskite power plant is commissioned in November 2023.

Application scenario development

In September 2024, China launched its first wave-resistant floating PV platform into the sea. Covering an area of 1.6 km^2, the platform was indigenously developed by HuaNeng Group, a major Chinese SOE. The platform will conduct field monitoring and experiments at sea for up to 1 year to provide data on floating PV technology in marine environments.

INDUSTRY & MARKET DEVELOPMENT

In 2024, China PV industry experienced another year of rapid growth, and surprisingly installed 277.57 GW_{ac} nationwide.

Demand Side

- In 2024, China's total electricity consumption reached 9.85 Trillion kWh, with a year-on-year increase of 6.8%.
- In terms of renewable power installation, by the end of 2024, the cumulative renewable installed power capacity in China reached approximately 1 889 GW_{ac}, with a year-on-year increase of 25%. Of this, the PV installed capacity was about 885.68 GW_{ac}, a year-on-year increase of 45.2%. Notably, in July 2024, China achieved its commitment to reach a total installed capacity of 1200 GW_{ac} for wind and solar power by 2030, 6.5-year ahead of schedule.
- For PV installation in power mix, by 2024, PV cumulative installation comprised 27% of the total installation, while it was 21% in 2023. The share of PV continuously increased.
- In 2024 alone, China PV added 277.57 GW_{ac} (approximately 309 GW_{dc}[1], hitting another record high, and amongst which:
- Utility-scale installations were 159.39 GW_{ac} (approx. 191 GW_{dc}[1]), accounting for 57% of the total incremental installation, with a year-on-year increase of 33%, thanks to the development of the Mega project programme.
- The C&I sector installed 88.63 GW_{ac} (approximately 89 GW_{dc}), accounting for 32%, with a year-on-year increase of 68%, due to the rapidly growing demand for electricity, particularly green electricity, in export-oriented enterprises in coastal provinces.
- The residential sector installed 29.55 GW_{ac} (approx. 30 GW_{dc}), accounting for 11%, with a year-on-year decrease of 32%.

	2023	2024	YoY
Utility-scale sector	120.01	159.39	33%
C&I sector	52.81	88.63	68%
Residential	43.48	29.55	-32%
Total	**216.30**	**277.57**	**28%**

Table 1: China PV Additional Installation (GWac). Source: NEA (National Energy Administration).

- With the increased PV penetration ratio, more synergies with other industries are required for a more sustainable development of the Chinese PV industry, such a PV + ES, PV + green hydrogen and its derivatives, as well as PV + Electric Vehicles etc.

[1] The DC/AC power ratio for centralized systems is evaluated differently in the IEA PVPS Snapshot giving a possible volume of utility scale installations of between 191GW_{dc} and 239GW_{dc} for a total annual capacity between 309 GW_{dc} and 357GW_{dc}.

Supply Side

- According to CPIA (China Photovoltaic Industry Association), in 2024, the total polysilicon output reached 1.82 million-ton, Wafer output reached 753 GW, Cell 654 GW, and module 588 GW, all segments achieved more than 10% year-on-year increase.

	2023	2024	YoY
Polysilicon (kt)	1472	1820	24%
Silicon Wafers (GW)	668	753	13%
Cells (GW)	591	654	11%
Modules (GW)	518	588	13%

Table 2: Chinese PV Industry Production Output. Source: CPIA (China Photovoltaic Industry Association).

Chinese Experts participate currently in 9 PVPS Tasks involving 11 separate entities as listed here.

2024 is another record year for the Chinese PV industry. In 2024 alone, China added 277.57 GW_{ac}, of PV installations, hitting another historical high. Thanks to the pledges from the central government, favorable policies covering the entire PV ecosystem, and continued efforts to enhance the product efficiency, the Chinese PV industry is increasingly becoming full-fledged, paving the way for the global energy transition.

DENMARK

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Flemming V. Kristensen, FKSOL ApS
Kenn H. B. Frederiksen, Kenergy ApS

Photo 8: European Energy and Mitsui & Co.s's PtX plant in Kassø with solar park (304 MWp), electrolyser (52 MW) and e-methanol facility (32 000 tonnes per year) co-located in the Aabenraa municipality, Denmark.

PV POLICY PROGRAMME

In 2022, the Danish Parliament decided that the country should have a unified national PV programme. Because of a parliamentary election, this decision was not realised, but finally in 2023 it was decided that this national PV programme should be worked out and will officially be presented in the first quarter of 2024. The political target of a 70% reduction in carbon oxide emissions in 2030 is followed by a goal of 100% in 2045. This was announced by the new government established after the national election November 2022. The latest forecast from the Danish Energy Agency expect PV to reach 7.5 GW by 2025, more than 12 GW by 2030, and 18 GW by 2035. These figures are periodically revised.

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

commercial PPAs or providing power to the actual market price (Nordpool).

Net-metering for privately owned and institutional PV systems was established in 1998, and is still existing, however, with consequent limitations and restrictions.

In 2024, the BAPV solar industry experienced a decline in activity. This can, among other things, be explained by rising interest rates and low electricity prices. Furthermore, rising costs for grid connection and long municipality and utility approval time negatively impacted the market. This contributed to the fact that the competition between the actors intensified for the realised projects.

Photo 9: 35 MWp east/west orientated roof top system installed on a DSV building in Horsens. The system is installed by SolarFuture.

Despite the more difficult conditions, the accumulated installed capacity reached over 5 GW in 2024 due to increased installed capacity for utility-scale projects.

To promote the development of the green transition, the plan is to increase the depreciation basis for industrial and commercial facilities to 108% in 2025. Likewise, these facilities will be able to lease or obtain other forms of third-party financing. Obtaining tax deductions for the assembly work will be possible for private installations. For solar installations on residential properties over 2 floors, it will be possible to apply for support for the project.

The government is expected to designate areas for large field installations to promote the approval process. These areas will especially be areas with low-lying soil, where the CO_2 emission is high due to drainage channels and drains.

For the reasons mentioned above, the government has now indicated that the ambitions and targets for the green transition will be revised, and some form of public guarantee will be considered. Until now, nothing has been decided.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The National Energy Research and Development Programmes have a website, where general information about the programmes and a link to the specific R&D support scheme can be found. Information about ongoing and former R&D projects can also be found there.

Innovation Fund Denmark supports early-stage R&D (TRL 1-3). EUDP, GLDK, MUDP, and GUDP support development and demonstration (TRL 4-8). EIFO and the EU Innovation Fund support market introduction (TRL 9).

The Energy Technology Development and Demonstration Programme (EUDP) under The Danish Energy Agency funds projects by enterprises and universities that demonstrate new green energy technologies. The programme can support PV and every year different PV related projects are supported. The R&D programme, as well as the ongoing and ended PV-related projects, can be found at the EUDP webpage https://www.eudp.dk/en/om-eudp.

The strategic innovation topics in the EUDP programme are:

1. Green electricity;
2. Sustainable biomass, biogas and pyrolyze;
3. Energy efficiency;
4. Power-to-X;
5. Heat and heat storage;
6. Flexible use of electricity and digitalisation and
7. Carbon capture, use and storage

Elforsk is reborn as a special program under EUDP with focus on smart energy and digitalisation.

Innovation Fund Denmark under the Ministry of Education and Research creates a framework that enables entrepreneurs, researchers and

businesses to develop innovative and viable solutions to societal challenges.

INDUSTRY & MARKET DEVELOPMENT

The total installed PV capacity in 2024 was 707.7 MWp, compared to 487.4 MWp in 2023. The increase in installed capacity was primarily due to an increase in utility-scale projects. The overall BAPV market was similar in size to 2023, with some reduction in the residential and commercial sector but with a small growth in the industrial sector.

The electricity consumption in 2024 was 38.4 TWh, a 6% increase compared with 2023. More than 80% of the electricity was covered by renewable energy, including biogas and sustainable biomass. On a national level, the CO_2 emissions per kWh used are now below 100 g. See figure 2 for the solar and wind coverage of the electricity demand from the last 15 years.

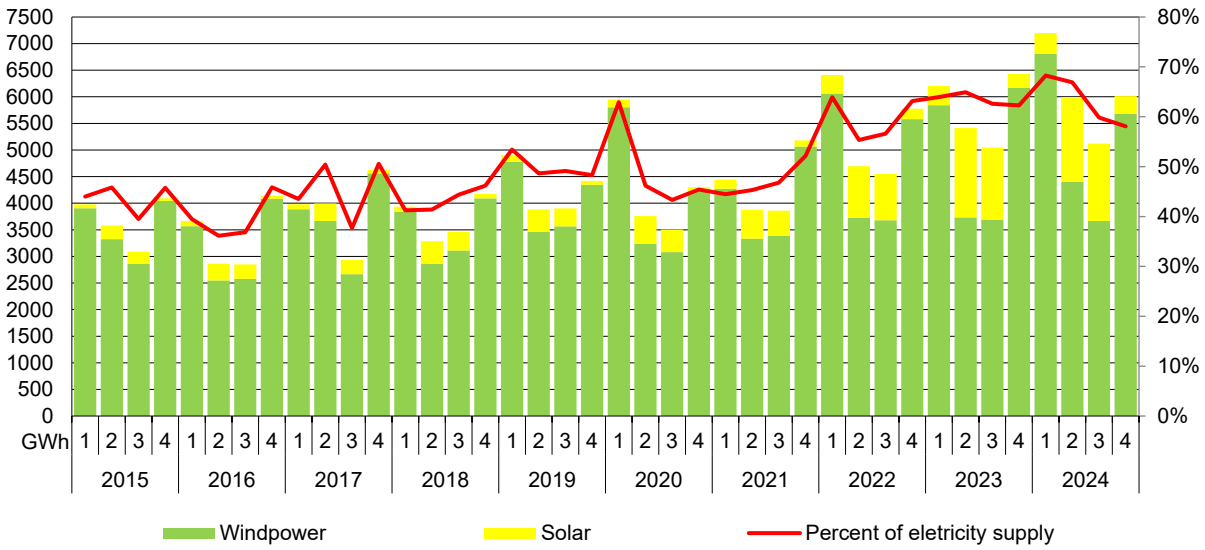

Figure 2: Electricity Production from solar and wind.

The yearly average electric price was 0.53 DKK/kWh, peaking at 7 DKK/kWh on December 12th between 5 PM and 6 PM. On the same day, prices were also almost six times lower during the night. The electricity market is very volatile and the low prices in peak production hours for solar and wind sets the business cases under pressure, especially when the electrification of the fossil fuel is progressing slower than expected.

The Danish PV Association established in late 2008 with approximately 60 members has provided the emerging PV industry with a single voice and is 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 and a vanadium redox flow battery (VFB) manufacturer is now engaged in the PV market, offering storage solutions. A few companies develop and produce power electronics for PV, mainly for stand-alone systems for the remote-professional market sector, such as telecoms, navigational aids, vaccine refrigeration, and telemetry. Many companies are acting as PV system developers or integrators designing, developing and implementing PV systems for the home market and increasingly at the international level. Danish investors have entered the international PV scene on a rising scale acting as international PV developers/owners of large-scale PV farms. Some 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.

Improved conditions for medium-sized solar installations

Green Power Denmark and the Danish Solar Association have entered into an agreement in 2024 in which a scheme will be established for inverters that are part of solar installations between 125 kW and 1 MW. These inverters can now be pre-approved by Green Power Denmark. Manufacturers of inverters that are typically included in this type of plant can therefore be content with sending documentation and test reports for one copy of each of the requested inverter types.

This saves a lot of time and bureaucracy in the installation process to the benefit of both suppliers.

Danish Experts participate currently in 5 PVPS Tasks involving 8 separate entities as listed here.

EUROPEAN UNION

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Maria Getsiou, European Commission, Directorate General for Research and Innovation - RTD C.2
Elisabeth Schellmann, European Commission, Directorate General for Energy - ENER.B.4.001
Paula Dorado Miranda, European Commission, Directorate General for Energy - ENER.DDG1. C.1

Photo 10: The European Solar Charter was signed in Brussels, 15/04/2024. © European Union 2024.

PV POLICY PROGRAMME

According to SolarPower Europe, solar PV capacity has continued to increase, reaching an estimated 338 GW_{dc} in 2024. 2024 has been the fourth consecutive record year for solar PV deployment in the EU, with approximately 65 GW_{dc} installed. To reach the ambitious solar energy targets laid down in the EU Solar Energy Strategy, further acceleration is needed.

In 2023, the Renewable Energy Directive was reviewed. The amending Directive EU/2023/2413 entered into force on 20 November 2023. There was an 18-month period to transpose most of the directive's provisions into national law, with a shorter deadline by July 2024 for some provisions related to permitting for renewables. Permit-granting procedures for renewable energy projects, including for solar energy became shorter and simpler. The Directive also asked Member States to designate renewables acceleration areas for at least one renewable energy technology where renewable energy projects would benefit from simplified permit-granting procedures. The Commission issued practical

guidance to Member States on designating renewables acceleration areas in 2024.

The revision of the Energy Performance of Buildings Directive, which entered into force in 2024, introduced a phased-in obligation for certain categories of buildings to install solar energy and a specific requirement for all new buildings to be “solar ready”. The Commission is currently preparing guidance for Member States to efficiently deliver the requirements of the EPBD.

Several measures have been taken to further support the European solar PV manufacturing sector.

In 2023 and 2024, European solar module manufacturers have faced a particular challenge due to a sharp drop in the prices of imported panels. To ensure that the green transition and the European manufacturing objectives go hand in hand, the European Commission, 23 Member States and industry representatives signed on 15 April 2024 the European Solar Charter. The Charter sets out a series of immediate, voluntary actions that are to be undertaken to support the EU solar PV manufacturing sector.

The Net-Zero Industry Act Regulation (NZIA), which provides a regulatory framework to boost the competitiveness of EU net-zero industry, including solar PV, entered into force in June 2024. It comprises a benchmark aiming 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. The NZIA intends to ease conditions for investing in net-zero technologies by simplifying permit-granting procedures, applying non-price criteriaand supporting strategic projects. The Commission is currently preparing the secondary legislation to ensure consistent and transparent implementation across EU Member States.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Under the destination of **sustainable, secure and competitive energy supply,** **the Horizon Europe - Work Programme 2023-2024 on Climate, Energy and Mobility** launched the following topics in the field of Photovoltaics in 2024:

HORIZON-CL5-2024-D3-01-01: Alternative equipment and processes for advanced manufacturing of PV technologies. The aim was to demonstrate alternative processes and equipment for PV manufacturing with reduced CAPEX, OPEX, energy and material consumption, and to increase the productivity and sustainability of large-scale PV manufacturing equipment and processing.

HORIZON-CL5-2024-D3-01-02: Low-power PV with the aim to validate novel and low-environmental impact PV materials, PV architectures and suitable substrates for specific low power applications that consider the light intensity, light spectrum, and the application itself.

HORIZON-CL5-2024-D3-02-05: PV-integrated electric mobility applications with the aim to a) demonstrate Vehicle Integrated PV concepts (VIPV), including different cell, interconnection and encapsulation technologies (with high efficiency under lower and varying lighting conditions) having a flexible design (size, shape/curvature, lightweight, aesthetics) and with PV providing a significant part of the vehicle’s energy consumption under various climatic conditions; and b) demonstrate PV Charging Stations (EVs, electric buses, etc.) able to provide a significant part of the charging demand despite the PV intermittence, guarantee the balance of the public grid, and reduce the public grid energy cost.

HORIZON-CL5-2024-D3-02-06: Innovative, Community-Integrated PV systems with the aim to demonstrate innovative community-aggregated PV systems to facilitate the energy transition to a low carbon economy.

HORIZON-CL5-2024-D3-02-07: Resource Efficiency of PV in Production, Use and Disposal, with the aim to identify the main areas of improvement for the environmental footprint and resource efficiency of PV.

The total EC financing for the above-mentioned topics was EUR 57 million.

In addition, a co-programmed partnership in Solar PV has been included in the second Horizon Europe strategic plan 2025-2027. This partnership brings together the PV industry and research community as well as the European Commission to define the research agenda for solar photovoltaics within the Horizon Europe Work Programme 2025-2027 on Climate Energy and Mobility. The objective of the partnership is to align European R&I funding with industrial R&I priorities, ensuring that public support for research can quickly translate into private sector efforts to bring innovation to the market.

The partnership builds on the European Technology and Innovation Platform and the various associations that structure the PV R&I landscape (SolarPowerEurope, EERA-PV JP, ESMC, EUREC, PVthin).

INDUSTRY & MARKET DEVELOPMENT

Solar photovoltaics (PV) is the fastest-growing electricity production technology from renewable sources. In 2024, the EU was on track to achieve the target of the EU Solar Energy Strategy of 600 GWac (~720 GWp) installed PV capacity by 2030[2]. Based on preliminary data for 2024, the annual growth slowed down, but installations still grew substantially from more than 56 GWp in 2023 to 63 GWp in 2024. In both years, the EU ranked second after China (374 GWp in 2024) in deployment, followed by the US (45 GWp in 2024)[3]. PV electricity generation costs are now lower than fossil fuel-based alternatives in most countries[4].

The NZIA refers to the goal of the European Solar Photovoltaic Industry Alliance of reaching 30 GWp of annual solar PV manufacturing capacity across the value chain by 2025[5]. This objective is currently surpassed for inverters (82 GWp in 2023[6]) and close to be achieved for polysilicon (29 GWp in 2024). However, the situation is different for other parts of the value chain. The current EU PV manufacturing capacity for ingots and wafers is below 1 GWp, below 3 GWp for cells and for modules[7], with indications that actual production in 2023 was around 2 GWp for the latter[8]. Overall, the EU is heavily dependent on PV imports from China, where 91% of the global commissioned manufacturing facilities are situated. In contrast, the EU, US and India each count for a respective share of 1%[6].

The cost of producing a PV module is estimated to be about 60% higher in the European Union than in China[9].. Additional challenges for European manufacturers are high inventory levels and oversupply from China driving a sharp decline of spot market module prices, which decreased over 25% year-on-year to EUR 0.105/Wp in January 2025[10]. While this decrease in prices pushes deployment, it puts high pressure on manufacturers. Facilities producing cells and modules are seeing low average utilisation rates of around 50% globally[8].

Overall, EU PV manufactures are struggling to compete globally, particularly on price. The concentration of PV manufacturing capacity in a

[2] COM/2022/221 final
[3] Jaeger-Waldau, A., *Snapshot of Photovoltaics*, 2025 (forthcoming)
[4] IEA, *Advancing Clean Technology Manufacturing*, 2024
[5] OJ L, 2024/1735, 28.6.2024, Recital 16
[6] Solar Power Europe, Inverter Explained 2.0, June 2024
[7] European Commission, JRC, Chatzipanagi, A., Jaeger-Waldau, A., Letout, S., Mountraki, A., Gea Bermudez, J., Georgakaki, A., Ince, E. and Schmitz, A., CETO, Photovoltaics in the European Union, 2024
[8] ESMC, Letter to the European Commission, January 2024
[9] IEA, *Renewables 2023 - Analysis and forecast to 2028*, 2024
[10] PV Exchange, Solar Market Analysis January 2025 - PV module prices at crossroads

single country, China, creates risks for the resilience of the value chain and price stability[11].

The EU still has a strong role in research and innovation on solar PV especially with regard to specific PV applications such as PV integrated in buildings, agriculture, infrastructure or vehicles[6].

For the EU to gain competitiveness in PV manufacturing, it would need to scale-up innovative technologies in large gigawatt-scale factories that are integrated across the value chain

EU Experts participate currently in 4 PVPS Tasks involving 2 separate entities as listed here.

[11] European Solar Charter, 2024

FINLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Tuula Mäkinen, VTT Technical Research Centre of Finland
Karin Wikman, Innovation Funding Agency Business Finland

Photo 11: Courtesy of Renewables Finland, https://suomenuusiutuvat.fi/en/. Photographer: Christa Könönen.

PV POLICY PROGRAMME

Finland has an objective to become a carbon-neutral society by 2035 and proceed to carbon negativity. The Government of Prime Minister Petteri Orpo will prepare a new national Energy and Climate Strategy during 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 direct and indirect electrification of energy use with carbon-free electricity. In 2024, carbon-neutral electricity already accounted for 95% of Finland's electricity production. 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. In addition, 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. Earlier 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 utilisation. The support is only intended for companies, communities, and public organisations, and it is provisioned based on applications. The need for and level of aid are assessed on a case-by-case basis. Agricultural companies are eligible to apply for an investment subsidy of up to 40% 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. In 2024, the sum was up to 40% of the total labour cost, including taxes, resulting in up to about 10-15% of the total PV system cost.

RESEARCH, DEVELOPMENT & DEMONSTRATION

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

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, as well as the European Union funding programmes.

Research and development topics related to PV range from material science to PV systems, grid integration, and solar economy. Research and development activities are spread out over a wide array of 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 2023, the installed off-grid PV capacity was estimated to be approximately 23 MW.

Presently, the market for grid-connected systems heavily outnumbers the market of off-grid systems. Since 2010, the number of grid-connected PV systems has gradually increased. In early 2024, the installed grid-connected PV capacity was estimated to be approximately 1 000 MW. In 2024, PV represented 1.4% of the total electricity production in Finland.

The grid-connected PV systems are still mainly roof-mounted installations on public and commercial premises and in private dwellings. The first multi-megawatt ground-mounted PV plant in Finland, with a total power of 6 MW, started its operation in 2018 in Nurmo. The largest PV plant in Finland started its operation 2024 in Rauma. This PV plant of 32 MW is owned by CPC Lakarin Aurinkovoima Oy. In recent years several companies have announced their plans for multi-megawatt-scale PV plants, even up to a scale of hundreds of MW. According to Renewables Finland, by January 2025, more than 23 300 MW of planned solar power projects had been published in Finland.

Integrating power storage in PV plants is often considered beneficial for balancing variable PV production. In addition, there is an increasing

interest in combining PV production with wind power production, thus balancing the variation of power production, using a common infrastructure, and improving the cost-effectiveness of the projects.

Finnish Experts participate currently in 4 PVPS Tasks involving 7 separate entities as listed here.

FRANCE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Melodie de l'Epine, Becquerel Institute France for ADEME
Anna Barguès, Becquerel Institute France for ADEME

Photo 12: Legislation in France is increasingly being adapted to allow the use of land in risk prone areas such as flood prone rivers banks. PV system in Saint-Clair-du-Rhône (Isère). Photo Credit: CNR.

PV POLICY PROGRAMME

The current 10-year Energy Programme Decree PPE, published in 2020, targets 3 GW to 5 GW of new capacity a year, to reach 20 GW in 2023 and 35 GW to 44 GW in 2028.

After being delayed from 2023, the update to the PPE was submitted to the public for consultation in November 2024, with the goal of doubling the rhythm of PV development (5.5 GW_{AC}/year to 7 GW_{AC}/year) to reach 75-100 GW in 2035, as proposed in the 2023 draft Energy-Climate Strategy. It proposes a distribution of 55% residential/ commercial rooftop systems; 10% large-scale industrial rooftop systems; 10% small ground mounted systems and the remaining 25% as utility scale ground mounted and AgriPV systems. More AgriPV and the development of Gigawatt factories for

local manufacturing are also components of the draft documents.

National policy is built around reaching the PPE targets, with a series of support mechanisms including Tenders for systems over 500 kWp (separate calls for systems on buildings, ground-mounted systems, systems in overseas territories, innovative systems and others). Winning candidates are selected on a mostly price-based score, although some calls have other criteria to encourage lower carbon footprints and preservation of natural spaces. Building-applied systems under 500 kW have access to feed-in tariffs and in some cases capital subsidies. Most systems accessing the feed-in tariff opt for net-billing with self-consumption as feed-in tariffs have dropped well below electricity consumption prices.

As module prices dropped and new capacity increased, the mechanisms for reducing tariffs with increased capacity were adjusted, increasing target volumes but decreasing tariffs.

The much-awaited publication of feed-in tariffs for systems between 100 kW and 500 kW in overseas departments and territories in January was accompanied by dispositions for curtailment. Unpublished as of early 2025, a feed-in tariff for ground mounted systems under 1 MW was submitted to the Higher Electricity Council after several years of discussion with industry.

By 4th quarter 2024, the increasing volume of systems requesting feed-in tariffs (6.5 GW_{DC} in 2024 vs 5.1 GW_{DC} in 2023 and 3.8 GW_{DC} in 2022) triggered inter-ministry discussions amid significant budget projections, and industry consultations were opened to evaluate modified mechanisms including fixed quotas and a return to simplified tenders.

Policies for mandating solar on buildings and sealed parking lots came into effect over 2024 and 2025. Modifications to permitting procedures were applied in 2024, with the goal of simplifying for parking canopies on one hand and increasing the coordination of consultative processes for utility scale systems on the other hand. Pre-identification of solar as being “in the public interest” may allow exemptions to some environmental procedures. The definition, by local authorities, of renewable energy acceleration zones gives access to further simplifications and was created to give them more control over system siting.

System type and size	PPE2 2021-2026: Building mounted systems, greenhouses and parking canopies	PPE2 2021-2026: Ground based systems	PPE2 2021-2026: Technology neutral*	ZNI 2023 -2028: Systems in overseas departments and territories
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
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	2.5 GW in 5 calls of 500 MW	1.1 GW in 11 calls of 99 MW
Most recent average tender price	99.95 EUR/MWh	79.28 EUR/MWh	80.6 EUR/MWh	105.99 EUR/MWh

*Table 3: Competitive Tenders called in 2024; * Call for Tender is not limited to photovoltaics systems; other RES technologies are eligible as well.*

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)
≤3 kW	103.1 EUR/MWh	126.9 EUR/MWh (+0,22 EUR/W installed)
3 kW to 9 kW	87.6 EUR/MWh	126.9 EUR/MWh (+0,16 EUR/W installed)
9 kW to 36 kW	130.2 EUR/MWh	76.1 EUR/MWh (+0,19 EUR/W installed)
36 kW to 100 kW	113.2 EUR/MWh	76.1 EUR/MWh (+0,10 EUR/W installed)
100 KW to 500 KW	105.2 EUR/MWh*	105.2 EUR/MWh*

*Table 4: Feed in tariffs for 4th quarter 2024; *indexed; coefficient depends on the commisioning date.*

RESEARCH, DEVELOPMENT & DEMONSTRATION

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

The National Energy Research Strategy is a focal point for various organisations including: the National Alliance for the Coordination of Research for Energy (ANCRE) that groups 16 research organisations and competitive clusters, coordinating national energy research efforts; the National Association for Technology Research, a public-private network that produced the 2023 report “Game changers for the energy transition 2030-2050”, with specific recommendation for PV research including focusing on upstream research, tandem and perovskites, new supports for integrated PV (buildings, vehicles etc.), digital twins, eco-conception and materials re-use.

France’s public financing of Research and Development for photovoltaics was 80 million EUR in 2022 (latest data), whilst 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, on silicon tandem modules and III-V materials (and others), with a clear goal of industrial transfer. 2023 included a partnership with Holosolis, future GW scale manufacturer working towards 2T perovskite on cSI tandem, and a number of projects developing perovskite technologies.

INES works with industrial partners on a wide range of subjects, as well as fundamental research on silicon and cell technologies and applied research on module technologies. Recent work includes low carbon modules, low silver cells (module at < 14mg/Wp), record efficiencies for tandem perovskite/silicon cells (up to 29.8% in September) and heterojunction silicon cells, flexible perovskite modules, and solar (TOPCon, HJT) for space applications with a number of innovations carried by spin off companies (ultra-light modules, for example).

The principal state agencies that are financing research are:

- the National Research Agency (ANR), which finances projects through topic-specific and generic calls and also through tax credits for internal company research.

The French Agency for Ecological Transition (ADEME) runs its own calls for R&D on renewable energies and supports PhD students. It is the French relay for the IEA PVPS and M-ERA.net pan-European network.

INDUSTRY & MARKET DEVELOPMENT

The main market segments in France are residential systems (under 9 kWp), roof mounted systems on commercial, public and agricultural buildings (up to about 500 kWp), solar parking canopies (up to several MW) and ground mounted systems from 1 MW up. There are many agrivoltaics projects in development or in the early phases of production and other segments such as floating or vertical PV exist in small numbers.

The annual new capacity in 2024 grew more than 150% to 6 GW_{DC}, up from 4 GW_{DC} in 2023 and 2.8 GW_{DC} in 2022, reaching a cumulative capacity of approximately 20.9 GW_{DC}. The number of new installations passed the 1.1 million mark in 2024 – most (nearly 95% in number) are residential or small rooftop systems, but they only represent about 20% of cumulative capacity. However, the fastest growing segment was for systems between 100 kWp and 500 kWp, as projects planned in the 2021 feed-in tariff framework are progressively completed and connected to the grid. Growth in this sector has seen an increase in the number of "full injection" systems (i.e. without self-consumption). Storage continued to grow, with just over 4 000 new systems added in the residential sector (and approximately 100 additional new storage systems for 150 MW added to the medium voltage grid not linked to photovoltaic systems).

The stock of systems in the grid connection queue (fully permitted systems only) reached 38.4 GWDC (32 GWAC), up from 26 GW_{DC} in 2023 – although less than half are in the distribution grid managed by the monopolistic DSO Enedis, the rest either on the high voltage grid managed by RTE or in overseas territories and smaller municipality managed grids. The publication of feed in tariffs for non-interconnected zones (i.e. French Caribbean, Corsica), has increased the stock there fourfold. There is much interrogation on the quality of projects in the queue, as only about 35% of large-scale systems (10% / 3 GW_{DC} in capacity) over 250Wc have signed preliminary grid connection contracts, where nearly 40% in number / 75% in capacity has for systems below this peak power.

2.9 GW_{DC} of capacity was called / 2.7 GW_{DC} awarded in tenders operating on contract-for-difference (CfD) contracts in 2024 (down from 4.6 GW_{DC} called / 2.4 GW_{DC} awarded in 2023). With a 2-to-3-year lead time between publishing winners and grid connection, at least 5 GW_{DC} of large-scale systems in the grid connection queue should be connected over 2025 and 2026. Nearly all tenders were well subscribed as market conditions become less attractive for corporate PPA's and state backed CfD contracts become more secure.

Continued low module prices, large volumes in grid connection queues and a backlog of C&I projects waiting for contracts should see 2025 volumes progress once more, reaching between 7.5 GW_{DC} and 8.5 GW_{DC}.

There are now more than 1 million decentralised systems in France. Cumulative capacity exceeds 20.9 GW_{DC}.

French Experts participate currently in 8 PVPS Tasks involving 21 separate entities as listed here.

GERMANY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Klaus Prume, Projektträger Jülich (PtJ), Forschungszentrum Jülich GmbH
Christoph Hünnekes, Projektträger Jülich (PtJ), Forschungszentrum Jülich GmbH

Photo 13: Balcony power plants in a terraced housing estate (© embeki – stock.adobe.com).

PV POLICY PROGRAMME

In Germany, the switch to renewable energies is being driven forward, with photovoltaics (PV) playing a central role. In May 2024, the law amending the Renewable Energy Sources Act (EEG) and other energy industry regulations to increase the expansion of photovoltaic energy generation—known as 'Solar Package 1'—came into force. The German government's solar package simplifies the construction and operation of photovoltaic systems and accelerates the expansion of solar energy. One component is the greatly simplified commissioning of balcony solar power plants with 800 to 1 000 W power each. Currently, around 730 000 of them are already in operation. This high number shows that PV has reached the centre of

society and enjoys a high level of social acceptance.

Photo 14: Solar Panels on Balcony of Residential Apartment Building (© Maryana – stock.adobe.com).

By 2035, the German electricity supply should be almost climate-neutral, i.e. nearly 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 this end, the Renewable Energy Sources Act (EEG) provides for 215 gigawatts of installed photovoltaic (PV) capacity in 2030. This means that the annual expansion of photovoltaics needs to increase up to 22 GW within just a few years. With a further increase in newly installed PV systems, the total installed capacity has already reached the 100 GW mark by the end of 2024 (see Fig. 3).

So, Germany is well on the way to achieving its solar goals. This is also reflected in the consistently high participation in the Federal Network Agency's tendering rounds for ground-mounted PV systems. The tender volumes of 2 GW each in July and December were oversubscribed twice, and the average award values determined were again only 5.05 eurocent/kWh and 4.75 eurocent/kWh, respectively. The total tender volume in 2024 was 7.3 GW for ground-mounted and rooftop systems together.

This strong expansion is sensible and necessary, as photovoltaics is one of the cheapest sources of energy and therefore one of the most important sources of electricity generation in the future.

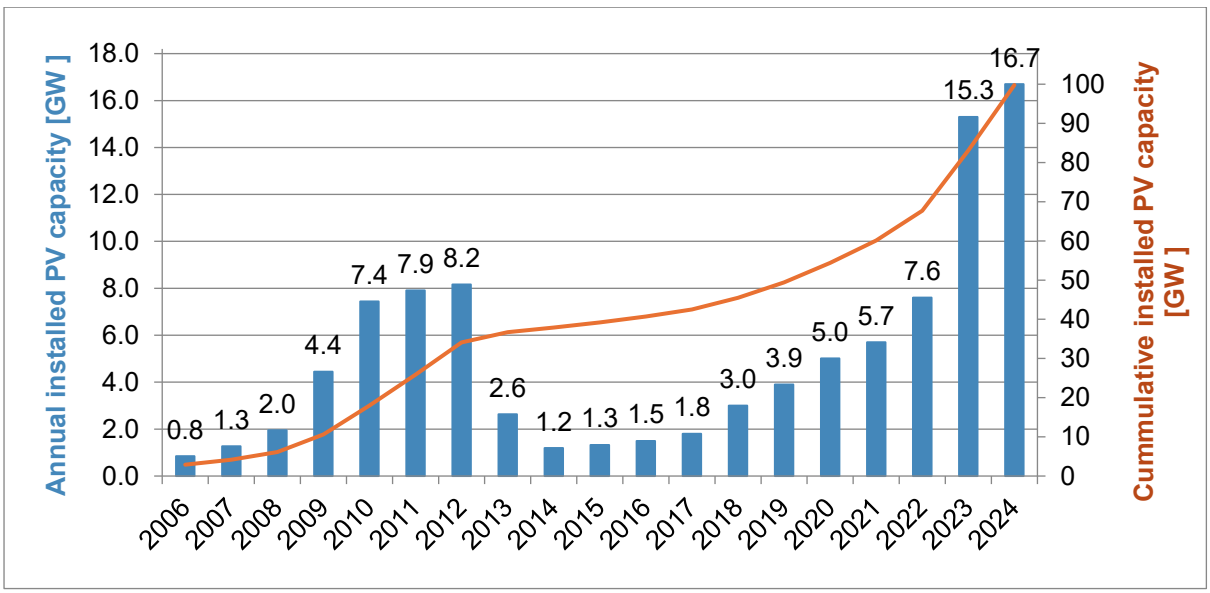

Figure 3: Development of annual PV installations and cumulated installed capacity.

RESEARCH, DEVELOPMENT & DEMONSTRATION

For many years, industry-related applied energy research has been supported by specific funding programmes (see here and Fig. 4 for granted PV projects under the Federal Energy Research Programmes – ERP).

The funding announcement for the most recent 8th Energy Research Programme for applied energy research, entitled 'Research Contracts for the Energy Transition,' has been in force since April 2024. It sets out 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.

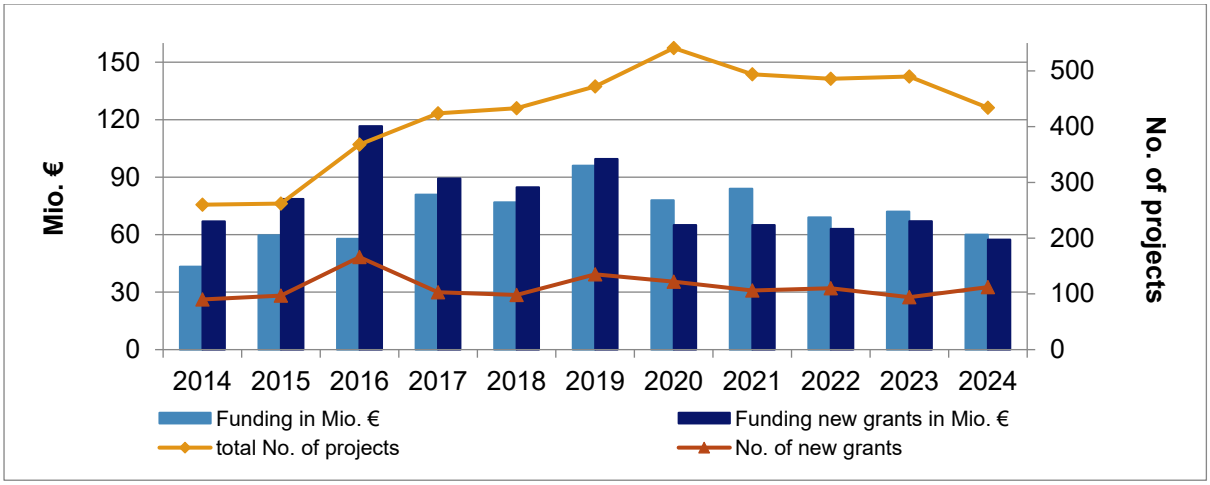

Figure 4: R&D support and quantity of PV projects funded by BMWK in the 6th and 7th ERP.

The five missions of the BMWK's energy research programme 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

PV is an important part of the Mission Electricity Transition. The main focal points for photovoltaics research in 2024 were again topics relating to technology developments for highly efficient solar cells and modules, silicon-perovskite tandem solar cells, and issues of reliability and sustainable operation of photovoltaic systems. A secondary topic deals with the integration of PV systems in both the built environment and the energy system.

INDUSTRY & MARKET DEVELOPMENT

The positive development of the German photovoltaic market over the last ten years has continued with a further strong increase. With 59% of total electricity generation, renewable energy generation plants were the most important source of energy in Germany. PV accounted for 15%, or 63.3 TWh, of this.

By the beginning of 2024, the number of employees in the photovoltaic sector had risen to over 100 000. This increase of 35% compared to 2022 is primarily due to additional employees in the operation and maintenance of PV systems.

Nevertheless, the market environment is extremely challenging for German photovoltaic manufacturers, particularly due to low prices for modules and other components, especially from Asia. To meet this hurdle, the BMWK has initiated a recently published feasibility study on the reconstruction of an integrated PV industry in Germany and Europe. The study, called Libertas, aims to determine how the entire ecosystem of manufacturing, mechanical engineering, supply chain, research institutes, and qualified personnel could be fully (re-)established in the shortest possible time. In addition to competitive and innovative products, sustainable, CO_2-neutral production is taken into account. Some key elements of the Libertas findings will soon be addressed by targeted research activities.

German Experts participate currently in 9 PVPS Tasks involving 16 separate entities as listed here.

The impressive number of installed balcony solar power plants in Germany testifies to high social acceptance of the technology.

ISRAEL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Shay Yagel, Renewable Energy Department, Ministry of Energy and Infrastructure, Israel
Eliraz Shifman Berman, Head of Renewable Energy, Ministry of Energy and Infrastructure, Israel

Photo 15: Agrivoltaic Field in Israel – Integrating Solar PV with Agriculture.

PV POLICY PROGRAMME

The Ministry of Energy has set a strategic goal of leading Israel towards a reliable, efficient, and clean energy sector, establishing a target of reaching 30% of the country's electricity consumption from renewable sources by 2030, with an interim goal of 20% by 2025, as part of Israel's global climate commitments.

By the end of 2023, Israel had reached approximately 12.5% renewable electricity consumption, with a total installed renewable energy capacity of roughly 7 000 MW by 2024, primarily solar PV. Achieving the 2030 target requires an additional 10 000 MW, highlighting both significant progress made and the considerable efforts still needed, emphasizing solar energy as the cornerstone of Israel's renewable strategy.

Israel faces unique challenges in renewable integration, including rapid population growth, limited land availability, and geographic disparities between high renewable potential in peripheral regions and concentrated energy demand in urban centres. Given these constraints, Israel relies almost exclusively on solar energy and has adopted a strategic "both–and" policy approach, promoting dual-use PV systems alongside ground-mounted solar facilities.

Recent key measures to accelerate renewable adoption include substantial investments in electricity transmission and distribution infrastructure, additional land allocations for ground-mounted solar installations, and regulatory reforms mandating solar installations in new buildings. Special emphasis has been placed on agro-voltaic (dual-use agricultural and solar) installations, with targeted regulatory frameworks and national planning initiatives established to significantly expand this promising sector. Other notable actions include nationwide expansion of expedited permitting ("Green Track") for small-scale systems and introduction of an "Urban Premium" incentive for urban PV and storage installations. Additionally, detailed planning for large-scale PV projects and extensive support for energy storage aim to enhance grid stability and resilience.

Further strategic initiatives include formulating a National Renewable Energy Strategy for 2035, launching the "100 000 Solar Rooftops" program targeting residential buildings, and introducing dedicated recovery and development plans for conflict-affected regions emphasizing renewable and storage projects. Finally, nationwide public-awareness campaigns and digital platforms providing centralised regulatory information aim to streamline renewable-energy adoption across Israel.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Israel recognises the critical role of research, development, and demonstration (R,D&D) in supporting the long-term transition to a sustainable and resilient energy system. The Office of the Chief Scientist at the Ministry of Energy supports energy-related R&D through targeted national and international programs, prioritizing innovation, technological breakthroughs, and practical demonstration of advanced solutions. Key national support channels include full funding for academic research projects, grants of up to 62.5% for innovative startup initiatives, and up to 50% co-funding for pilot and demonstration projects aimed at commercial deployment of novel technologies.

Internationally, the Chief Scientist participates actively in the EU Horizon Europe framework, publishing annual joint calls for proposals in collaboration with programs such as Water4All, CETP, and M-era.net. Additionally, the BIRD Energy fund, operated jointly with the U.S. under the Binational Industrial Research and Development Foundation, supports collaborative US-Israeli projects in the energy sector.

In 2024, the Chief Scientist invested over USD 8 million in diverse R&D initiatives. Notable funded projects include a highly cost-effective Building-Integrated Photovoltaic (BIPV) technology, Vehicle-to-Grid (V2G) applications, sensors for optimizing grid space utilisation, and advanced research into ultra-deep geothermal energy.

These R&D initiatives directly align with Israel's strategic energy objectives, particularly enhancing renewable energy integration, advancing grid efficiency, and fostering technological innovation to meet national and international climate targets.

INDUSTRY & MARKET DEVELOPMENT

In recent years, Israel's PV sector has experienced steady and significant growth, both in installed capacity and in its role within the national power mix. By the end of 2023, approximately 12.5% of Israel's electricity consumption came from renewable energy sources—up from 10.1% in 2022. Of this, over 90% was generated by solar PV systems, underscoring the central role of PV in Israel's renewable energy landscape.

While official figures for 2024 have not yet been published, it is estimated that around 1 GW of new renewable capacity was added during the year, bringing total installed renewable capacity to nearly 7 GW—most of it solar. This continued growth is driven by Israel's high solar potential, supportive policies, and a regulatory framework that encourages both rooftop and ground-mounted PV installations. The Israeli electricity market features a high share of distributed generation, with thousands of small to medium-

scale PV systems installed on residential, commercial, and agricultural rooftops.

Photo 16: Rooftop PV System in Northern Israel.

Although Israel does not maintain a significant domestic manufacturing base for PV panels or inverters, the local solar industry benefits from strong expertise in project development, engineering, energy management, and digital optimization. Dozens of private developers and EPC companies operate across the market, participating in public tenders and offering private PPA models.

Key market trends include the expansion of dual-use systems—particularly agro-voltaic installations—rapid adoption of hybrid PV-plus-storage projects, and the rollout of urban-targeted incentives such as the “urban premium.” As part of its broader energy transition, Israel is committed to reaching 30% of electricity consumption from renewables by 2030, with solar PV expected to contribute the vast majority. Continued investment in grid infrastructure, regulatory streamlining, and innovation in energy technologies are expected to sustain the sector’s growth in the years ahead.

Photo 17: Hybrid PV-plus-Storage Installation in a Solar Farm.

In Israel, solar PV generates over 90% of all renewable electricity, making it the dominant renewable source by far. Faced with severe land scarcity, the country is pioneering dual-use applications such as rooftop and agro-voltaic systems. These innovations are key to meeting Israel’s ambitious target of 30% renewable electricity consumption by 2030.

Israeli Experts participate currently in 2 PVPS Tasks involving 4 separate entities as listed here.

ITALY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Salvatore Guastella, Ricerca sul Sistema Energetico (RSE)

Alessandra Scognamiglio, National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)

Photo 18: Customised, decorative, patterned PV glass, for greenhouses applications. Design ENEA, Module Sunage, Agricultural Sciences Museum (MUSA), Royal Palace of Portici (Naples).

PV POLICY PROGRAMME

The Integrated National Plan for Energy and Climate (PNIEC), bolstered by various initiatives under the National Recovery and Resilience Plan (PNRR), serves as the definitive framework for advancing energy decarbonization in Italy. In 2023, the PNIEC was revised to enhance the targets for 2030, aligning with the new objectives set forth by the Fit for 55% initiative and the REPowerEU strategy, which allocates 39% of the available funds (as opposed to the original 37.5%) to support climate-related goals. The primary objective for 2030 is to achieve a 30% share of renewable energy sources (RES) in gross final energy consumption, necessitating the installation of new photovoltaic (PV) systems to attain a cumulative capacity of 80 GW and an annual production of 100 TWh. While the trajectory of PV installations appears to be progressing in accordance with the required advancements in photovoltaic

deployment, challenges persist in securing the necessary permits for installation, despite the costs being competitive enough to enable market parity for PV plant installations.

In 2024 in Italy has been added 6.79 GW of PV capacity, reaching 37.1 GW of cumulative capacity (+29% compared to 2023) (see Figure 5).

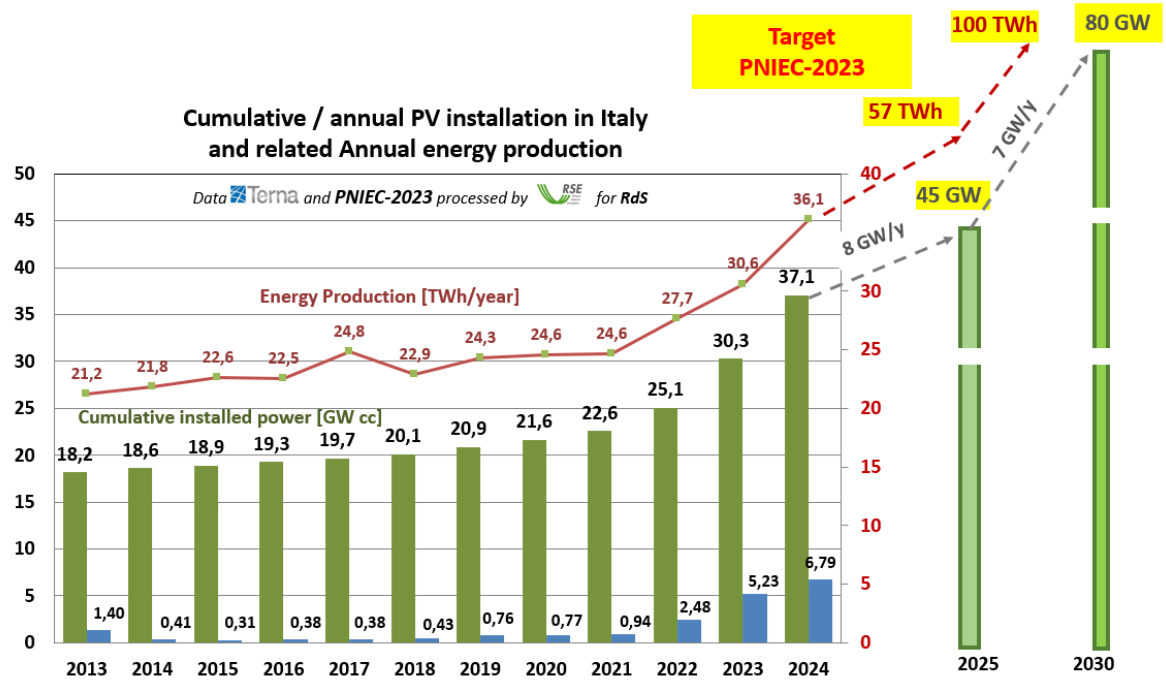

Figure 5: Cumulative and annual PV installations in Italy [GWdc] and related Annual energy production [TWh] at 2024. Data source: RSE.

Below are some of the main measures to support PV installations:

a) Economic support

- The tax relief mechanism for the installation of residential systems (up to 200 kWdc) reimbursing 50% of the photovoltaic installation costs up to a maximum cost of 96 000.
- A feed-in tariff mechanism, provided by Ministerial Decree, is in place for supporting less “mature” RES (biomass, offshore winds and so on).
- A premium tariff for shared and self-consumed energy in the Renewable Energy Communities (CER), thanks to the recent decree that increased the single plant power limit to 1 MW and enlarged perimeter to primary electric station.
- A PNRR investment promoting advanced Agri PV (with certain requirements in terms of height from ground and monitoring systems) developed by agricultural companies (or temporary associations between investor and agricultural companies), composed of an incentive tariff granted for 20 years and capital contributions up to 40% of the investment costs (competitive auctions are foreseen)
- PNRR investment of 2.5 billion euro for industrial transformation, development of 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 carbon dioxide), energy efficiency and sustainability of production processes.
- A feed-in tariff mechanism, provided by Ministerial Decree, has been defined for supporting “mature” RES (PV plants, on shore wind and so on), adopted and entered into force in early 2025.

b) Structural reforms for an easier market penetration.

- Simplification and rationalisation of environmental regulations concerning permitting procedures have been enacted through a new regulation adopted in late 2024 (TU FER), which aims to streamline and expedite the authorization processes for renewable energy facilities.
- The law has established fast-track authorization procedures for sites designated as suitable special areas for renewable energy systems (RES), including but not limited to abandoned industrial zones, degraded and marginal lands, and former quarries and mines. The criteria for identifying regional "Suitable Areas" (“Aree Idonee”) have been delineated in a Ministerial Decree, which is currently under judicial review, and the respective Regions are in the process of implementing the necessary regulations. Further clarity is anticipated upon the resolution of the ongoing legal proceedings concerning the Ministerial Decree.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The advancement of next-generation photovoltaic technologies and the exploration of integrated and innovative photovoltaic solutions are of paramount significance in achieving the national objectives outlined in the National Integrated Energy and Climate Plan (PNIEC) and the National Recovery and Resilience Plan (PNRR). These efforts are also aimed at providing new competitive growth opportunities for the national industry within this sector, while simultaneously enhancing the benefits for end-users of the electricity system, both in economic terms (through reductions in electricity bills) and in terms of environmental sustainability.

It is therefore deemed a priority that research activities within the photovoltaic sector focus on enhancing the generation efficiency of photovoltaic modules and minimizing the spatial requirements for the installation of photovoltaic systems, while maintaining equivalent installed capacity. Such initiatives are expected to yield short- to medium-term effects.

A key priority associated with renewable energy sources (RES), particularly photovoltaics, is to foster the development of competitive supply chains within Italy. This initiative aims to diminish reliance on imported technologies and to bolster research and development in the most innovative domains, including photovoltaics, electrolysers, and batteries.

In this context, the Research Fund for the Italian Electrical System (RdS), financed by the Ministry of the Environment and Energy Security (MASE) and the PNRR, provides substantial support for research, development, and demonstration activities pertaining to new photovoltaic technologies, in which various research institutes and photovoltaic operators are actively engaged.

Among them, ENEA is focused on high efficiency solar cells based on perovskite/c-Si tandem structure, on the development of module ecodesign, on the advancement PV systems digitalisation and on original conceptualisation and promotion, of the “Sustainable Agrivoltaics”, also through the realisation of demonstrators.

Photo 19: Agrivoltaic demonstrator (fixed system) with lemon trees, in Scalea, realised by ENEA in collaboration with EF Solare Italia, Le Grenhouse and SET Energie. Iimage: ENEA.

Furthermore, RSE, a research company on the energy system, is carrying out activities on 1) multi-junction PV cells, 2) studies on thin film deposition on Si for tandem cells, 3) advanced PV plant O&M strategies to contribute to their optimal production (through anomaly detection and fault recognition techniques, also making use of a specially developed public fault-data-repository) and 4) Life Cycle Assessment (LCA) of most promising innovative PV technologies. Other major research organisations are: CNR, a public research institution, active in the evaluation of innovative low-cost processes for thin film on SI cells and EURAC Research, a private research organisation, working on the improvement of PV plant performance and reliability and on BIPV (Building Integrated Photovoltaics). Additional contributions are supplied by numerous university labs among which the CHOSE Centre of the University of Rome Tor Vergata, the University of Milano Bicocca and the University of Turin and by PV operators, covering the entire PV value chain (mainly PV cells and modules, inverters and sun tracking systems).

It should be also mentioned the network ReteIFV "Italian Network for Research, Development and Innovation in Photovoltaics", with the aim of sharing initiatives of photovoltaic projects and research infrastructures throughout the country and which sees an active collaboration of the research institutes mentioned above, other research institutes and numerous manufacturers of PV components and plants.

The trend of photovoltaic (PV) installations in Italy is on track to meet the national decarbonization goals. Promising new applications include agrivoltaics, energy communities, and floating photovoltaics. However, challenges remain, particularly in the permitting process for PV installations. Streamlining these procedures is essential to fully harness Italy's renewable energy potential and support the growth of solar projects. Collaboration among stakeholders will be key to overcoming these obstacles.

INDUSTRY & MARKET DEVELOPMENT

An interesting sign of the excellent recovery of the photovoltaic market in Italy comes from the numbers of installations registered in 2024.

In 2024, according to data provided by TERNA and RSE, the total increase in renewable capacity in 2024 amounted to 7 480 MW, exceeding the 2023 figure by 1 685 MW (+29%). As of December 2024, Italy's installed renewable capacity totalled 76.6 GW, including 37.1 GW of solar and 13 GW of wind power. The 2021-2024 installation target set by the DM Aree Idonee (June 21, 2024) was surpassed by 1 609 MW. From January to December 2024, nominal storage capacity increased by 2 113 MW. Italy now has approximately 730 000 storage installations, corresponding to around 12 942 MWh of capacity and 5 565 MW of nominal power, of which 1 065 MW is utility-scale. On the supply side, 2024 saw significant growth in renewable generation (+13.4%) and a slight decline in net foreign exchange (-0.5%), driven by a sharp increase in exports (+47.9% compared to 2023) and a modest rise in imports (+2.4%). In December, for the first time, Italian electricity exports surpassed 4 000 MW during certain hours, highlighting the critical role of interconnections in importing cost-effective energy and, increasingly in the future, in providing a flexible mechanism to share generation and storage resources in response to the growing variability of renewable generation More specifically, Italy's electricity demand in 2024 was met 83.7% by domestic production and 16.3% by net imports. domestic net production (264 billion kWh) increased by 2.7% compared to 2023.

On the fronts of economic support and structural reforms the government has made further efforts to promote the photovoltaic objectives indicated above.

The region with the greatest increase is Lazio with +1 256 MW, followed by Lombardy (+766 MW) and Sicily (+505 MW).

Among the initiatives of PV producers, FuturaSun (Photo 20) FENICE project has been funded through Innovation Fund. It will introduce the production of PV modules based on

advanced technologies liken-type and xBC (Back Contact) The new factory will produce over 7.6 GW of high-efficiency PV modules within its first 10 years of operation.

Photo 20: Bifacial cells string deposition after soldering. Photo courtesy of FuturaSun.

Agrivoltaics is generating significant interest among agricultural and photovoltaic operators, with a considerable amount of GW currently in the permitting process. These systems enable the dual use of land for both energy production and agriculture, addressing concerns about land use and landscape preservation. The Italian Association for Sustainable Agrivoltaics (AIAS), established in November 2022 and chaired by ENEA, has grown to over 100 members from various sectors, including energy, technology, agriculture and research. To facilitate the permitting process and distinguish agrivoltaics from traditional ground-mounted PV systems, several guidelines and technical specifications have been published at both national and regional levels. Key documents include:

- UNI/PdR 148:2023: Guidelines for integrating agricultural activities with photovoltaic systems.
- CEI PAS 82-93 ed. 2 (2024-01): a Public Available Specification on agrivoltaic systems developed by the Italian Electrotechnical Committee, involving input from experts in both fields.
- Ministerial Decree on Agrivoltaics (February 24): this decree defines "advanced agrivoltaics" and includes an incentive tariff for 20 years, along with capital contributions of up to 40% of investment costs, with competitive auctions planned.[12]

Italian Experts participate currently in 7 PVPS Tasks involving 13 separate entities as listed here.

[12] 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).

JAPAN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Atsuyuki Suzuki, New Energy and Industrial Technology Development Organization (NEDO)
Osamu Ikki, RTS Corporation

Photo 21: Wall-mounted PV system at Sekisui Chemical's Osaka Headquarters building (48 pieces of building-integrated film-type perovskite PV modules manufactured by Sekisui Chemical) in Osaka City, Osaka Prefecture, Japan

PV POLICY PROGRAMME

Based on the Sixth Strategic Energy Plan by the Ministry of Economy, Trade and Industry (METI) and the Plan for Global Warming Counter-measures by the Ministry of the Environment (MoE), the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the Ministry of Agriculture, Forestry and Fisheries (MAFF), and other relevant ministries have joined forces to expand the introduction of PV power generation. They have mobilised all available laws, systems, policies, regulatory reforms, and budgets under their jurisdiction. Also, the government has approved the GX Promotion Strategy in a Cabinet decision and is shifting towards expanding PV deployment under this strategy.

The decarbonisation efforts towards GX (green transformation) under this strategy consist of

four key pillars: thorough promotion of energy conservation, making renewable energy a main power source, utilisation of nuclear power; and eleven other important initiatives.

Regarding making renewable energy a main power source, relevant ministries and agencies have been working in close coordination based on the Sixth Strategic Energy Plan to ensure the achievement of a renewable energy share of 36-38% in the FY 2030 energy mix. In addition to the 2030 targets, the government has formulated a new draft plan of Seventh Strategic Energy Plan aiming for 2040, with a view to achieving carbon neutrality by 2050.

The GX Promotion Strategy has been revised into the GX 2040 Vision (draft) from a long-term perspective, covering energy, GX industrial location, GX industrial structure, and GX market creation. The draft of the Seventh Strategic Energy Plan, which sets 2040 as the target year, has been presented. According to this draft, the projected energy mix for 2040, based on an estimated total electricity generation of 1.1-1.2 trillion kWh, is as follows: renewable energy at 40-50%, nuclear power at 20%, and thermal power at 30-40%. Renewable energy is positioned as the largest power source, surpassing thermal power. Among them, PV power generation is expected to account for approximately 23-29%, making it the country's top power source in terms of both capacity and generation, surpassing all other power sources (thermal power was not categorised by fuel type).

The revised draft of the new Plan for Global Warming Countermeasures has set greenhouse gas reduction targets of a 60% reduction by 2035 and a 73% reduction by 2040, compared to 2013 levels.

METI has enforced the revised Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities (Renewable Energy Act) and initiated efforts to strengthen business discipline aimed at ensuring harmony with local communities. To promote the stabilisation of renewable energy as a power source and its expansion, METI has introduced the Renewable Energy 100-Year Initiative and announced the Action Plan for Making Renewable Energy a Main Power Source. Additionally, it has formulated the Next-Generation Solar Cell Strategy to establish a domestic PV supply chain.

MoE has continued the Decarbonisation Leading Areas Promotion Project while expanding support for PV deployment by local governments and private companies. Furthermore, MoE has set a target of installing 4.82 GW of PV systems by local governments on their land and facilities by 2030.

As part of inter-ministerial policy initiatives, MoE and METI have formulated a recycling system aimed at mandating the recycling of PV modules, which are expected to be discarded in large quantities from PV power plants. METI and MLIT have set PV installation goals for newly built homes in FY 2027 at 37.5% for ready-built detached houses and 87.5% for custom-built ones.

The annual PV installed capacity in 2024 is estimated to be 5.5 GWdc (preliminary figure).

The draft of the Seventh Strategic Energy Plan, which sets targets for 2040, has been presented. According to this draft, the projected energy mix for 2040, based on an estimated total electricity generation of 1.1-1.2 trillion kWh, is as follows: renewable energy at 40-50%, nuclear power at 20%, and thermal power at 30-40%. Renewable energy is positioned as the largest power source, surpassing thermal power. Among them, PV power generation is expected to account for approximately 23-29%, making it the country's top power source in terms of both capacity and generation, surpassing all other power sources (with thermal power not categorised by fuel type).

RESEARCH, DEVELOPMENT & DEMONSTRATION

As for research, development, and demonstration activities concerning PV, technology development for commercialisation administered by METI has been conducted by the New Energy and Industrial Technology Development Organisation (NEDO), and fundamental R&D administered by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has been promoted mainly by the project of the Japan Science and Technology Agency (JST) and the project to subsidise the Grants-in-Aid for Scientific Research.

NEDO is conducting the Development of Technologies to Promote Photovoltaic Power Generation as a Primary Power Source (FY 2020-FY 2024). As part of technology development to create new markets for PV power generation, research and technology development are being conducted on ultra-lightweight film-type solar cells, wall-mounted PV systems, solar cells for mobility applications, and multi-junction solar cells. As part of this project, a thin-film triple-junction compound solar cell developed by Sharp was installed on the Japan Aerospace Exploration Agency (JAXA)'s small lander SLIM (Smart Lander for Investigating Moon) and began generating power on the lunar surface in January 2024.

In the development of technologies for making PV a long-term stable power source, the 2024 edition of the Design and Installation Guidelines for Building-mounted PV Systems, which supports rooftop and wall-mounted installations, was published in August 2024. In the development of separation and material recycling technologies for PV modules, Tokuyama, a collaborative research partner, is advancing a recycling business for disposed PV modules. Additionally, as part of common foundational technologies, efforts are ongoing to develop high-precision performance evaluation techniques for new types of solar cells and solar radiation forecasting technologies to support next-generation O&M.

NEDO is implementing the Next-Generation Solar Cell Development Project under the Green Innovation Fund (GIF) project, developing fundamental and commercialisation technologies of film-type perovskite solar cells (PSCs) for the project term of ten years from FY 2021 to FY 2030, and demonstration projects started in FY 2024. As the first phase, Sekisui Chemical and Tokyo Electric Power (TEPCO) are conducting mass production technology development and field demonstrations over a five-year period. In 2024, Sekisui Chemical, Enecoat Technologies, Toshiba, Peccel Technologies, Ricoh, and PXP began demonstrative installations at various facilities in collaboration with local governments and private sector users.

As for demonstrations on PV system utilisation technology, METI, NEDO, and MoE are conducting demonstration projects on power grid control, including PV and storage batteries. In 2024, METI and MoE jointly continued the Net Zero Energy Building (ZEB) demonstration project. MoE is conducting technology development and demonstrations aimed at achieving carbon neutrality. In 2024, technology development and demonstrations for direct current power supply from PV systems and road surface PV power generation were conducted, along with a landscape evaluation test of PV module installations in national parks. In the Decarbonisation Leading Areas selected by MoE, demonstrations related to PV power generation are also planned as part of local governments' decarbonisation efforts.

INDUSTRY & MARKET DEVELOPMENT

As of the end of December 2024, Japan's cumulative PV installed capacity is estimated to have reached the 100 GWdc level (RTS estimate, preliminary data). Meanwhile, the annual PV installed capacity in 2024 is estimated at 5.5 GWdc (RTS estimate, preliminary data), an approx. 11% decline from 6.2 GWdc in 2023, continuing the downward trend in PV installations.

Until around 2022, most PV installations in Japan were driven by the FIT programme. However, due to the decline in FIT purchase prices, the growing demand for renewable energy procurement among consumers, and rising electricity prices, installations independent of the FIT programme, such as those utilising PPAs, subsidies, or self-financing, have surged. These non-FIT installations are estimated to account for approx. 18% of the annual installed capacity.

The business environment for PV power generation is undergoing significant changes, with trends shifting towards self-consumption models, community-based utilisation, battery storage integration, virtual PPAs, and VPP applications. There is increasing demand for solutions that contribute to decarbonisation and respond to disasters. As a result, businesses and local communities are taking the lead in developing new approaches to energy utilisation.

As new installation schemes, numerous cases and plans have been announced for virtual PPAs, which trade only environmental value, in addition to offsite PPAs, which enable the simultaneous trading of electricity and environmental value from remote power plants.

As a new installation location, the adoption of solar carports in parking lots has increased. Installations have expanded from large-scale MW-class projects at commercial and public facilities, airports, and universities, etc., to smaller residential systems. The added benefits of providing shade and shelter from rain have contributed to the growing recognition of solar carports as a viable new installation option.

The number of farmland conversion permits for agrivoltaics utilising arable and idle farmland has been increasing linearly in recent years. While most installations were previously under 50 kW, their scale has expanded to several hundred kW to several MW, and such initiatives are spreading across various regions. The permit criteria for temporary farmland conversion to install agrivoltaics, which were previously specified in a director-general notice, have been codified in the Enforcement Regulations of the Farmland Act, and guidelines for the permit criteria have also been established. On the other hand, strict measures such as the temporary suspension of FIP/FIT subsidies have been implemented for improper cases, such as the failure to produce crops on the farmland beneath PV systems.

For floating PV (FPV) installations, a small-scale demonstration test at sea has begun in Tokyo Bay, raising expectations for future expansion to offshore installations.

Cable thefts have become widespread in Japan, especially in the northern Kanto and Tohoku regions, leading to measures such as the installation of surveillance cameras and alarms, as well as the switch to cheaper aluminium cables with low market prices of raw materials. Additionally, due to an increase in cases of damage to PV power plants from extreme storms and heavy rain, as well as cable thefts, insurance premiums for PV systems have risen, and some new insurance contracts have been suspended. Industry organisations are working with related companies to consider countermeasures.

Japanese Experts participate currently in 7 PVPS Tasks involving 9 separate entities as listed here.

KOREA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing author: Jihye Gwak, Korea Institute of Energy Research (KIER)
Kang-Won Kim, Korea Energy Agency (KEA)

Photo 22: Agrivoltaic demonstration complex (Gwandang Village, Namhae, Gyeongnam Province). Courtesy of Hanwha Qcells.

PV POLICY PROGRAMME

South Korea finalized and announced the 11th Basic Plan for Electricity Supply and Demand in February 2025, which was originally scheduled for completion in 2024, following discussions that began in July in 2023. Disagreements over the scale of new nuclear power plant construction delayed the process, resulting in its confirmation approximately 19 months later. This Basic Plan, which is revised every two years and outlines a 15-year outlook, presents projections for power supply and facility deployment from 2024 to 2038. Taking into account the 2030 Nationally Determined Contribution (NDC) targets, the plan outlines a pathway to accelerate the deployment of solar and wind energy through coordinated, cross-ministerial policy efforts. It sets a goal of adding an average of 7 GW of solar and wind capacity annually by 2030.

The year 2024 marks a period during which the South Korean government has been actively seeking ways to reverse the stagnation in solar

deployment observed in recent years. The major policy efforts can be summarized as follows:

- Strategies for Expanding Supply and Strengthning the Supply Chain for Renewable Energy. In May 2024, the Ministry of Trade, Industry and Energy (MOTIE) announced *Strategies* to ensure the stable deployment of around 6 GW of solar and wind energy annually while strengthening the domestic renewable energy industry. The strategy addresses challenges such as site conflicts, grid constraints, and costs, while promoting technological self-reliance and local manufacturing. Key measures include support for domestic solar modules, activation of self-consumption PPAs—especially in commercial and industrial sectors—and streamlined permitting and institutional support to attract investment. These efforts align with expected RPS reforms and aim to create a more stable, investor-friendly environment for solar PV.
- 11th Basic Plan for Electricity Supply and Demand. Compared to the above-mentioned *Strategies*, the finalized Basic Plan raises the 2030 solar energy target by an additional 1.9 GW. It also includes measures to strengthen grid stability, such as grid expansion and the deployment of backup systems like ESS. The cumulative solar PV installation target is set at 55.7 GW by 2030 and 77.2 GW by 2038.
- National Strategy for the deployment of agrivoltaics. In April 2024, the Ministry of Agriculture, Food and Rural Affairs announced a strategy to promote agrivoltaics, aiming to boost farmers' income while ensuring food security. The strategy positions farmers as key participants, supported through institutional measures, insurance, and training. Key measures include encouraging the use of lower-quality farmland, extending temporary land-use permits from 8 to 23 years, providing incentives for projects in designated renewable energy zones, and establishing a strict management system to ensure continued agricultural activity.
- Special Act on the Promotion of Distributted Energy. The Act inacted in June 2023, which came into effect in June 2024, provides a legal framework to promote diverse solar PV models—such as agrivoltaic, floating, and building-integrated systems—through distributed energy zones, regulatory easing, and enhanced local government participation.
- Industrial Complex Solar Promotion Strategy. In July 2024, MOTIE announced a policy to promote solar PV deployment in industrial complexes by easing regulations, providing financial incentives, and supporting corporate PPAs. The strategy supports broader goals such as expanding renewable energy, reducing electricity costs, improving grid integration, and facilitating RE100 compliance.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In December 2024, Hanwha Qcells achieved a power conversion efficiency (PCE) of 28.6% with its self-developed tandem solar cell on a large-area M10 wafer. This achievement received official certification from the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE) in Germany. It marked the first time in the world that a tandem solar cell of such a large area (330.56 cm²), applicable to commercially available modules, was certified by an independent third-party institution.

The previously mentioned *Strategies for Expanding Supply and Strengthening the Supply Chain for Renewable Energy* also outline key initiatives for the development of solar PV technologies. At the heart of this strategy is government support for strategic R&D, aimed at the early commercialization of next-generation tandem solar cells and achieving a conversion efficiency of 35% by 2030. To support these efforts, the government promoted the establishment of the Center for Advanced Solar PV Technology (CAST), which was inaugurated in Daejeon in March 2024. This center serves as an open innovation platform for pre-production verification of solar cell technologies developed by PV-related industries. It is designed to consolidate research capabilities across industry,

academia, and research institutes in the areas of next-generation tandem cells, modules, and measurement technologies. The center is equipped with a 100 MW-scale pilot production line capable of manufacturing solar cells up to M12 size and modules. It also conducts R&D on reliable measurement and evaluation techniques for next-generation solar PV technologies such as tandem cells.

Photo 23: Center for Advanced Solar PV Technology (CAST), inaugurated in March 2024. Courtesy of KIER.

In addition, Korea undertook various efforts in 2024 to promote the development of solar PV technologies as outlined below:

- Strategy for Next-Generation Solar Cell Technology Development and Early Commercialization. On November 14, 2024, MOTIE held a task force (TF) meeting to discuss the strategy for the early commercialization of tandem-type next-generation solar cells. The TF has conducted several working-level sessions since its first meeting in January 2024. The strategy focuses on goal-oriented R&D across the entire value chain—including cells, modules, and materials. It involves the formation of public-private working groups, the design of mission-driven R&D programs, and enhanced collaboration among companies to accelerate commercialization.
- Strategy for Technology Innovation for Carbon Neutrality. The government has established the "Roadmap for Innovation in 17 Core Technologies" as part of its strategy to achieve carbon neutrality. This roadmap has been developed in phases since 2022 and was finalized on December 12, 2024, during the 9th meeting of the Special Committee on Carbon Neutral Technologies, hosted by the Ministry of Science and ICT. The solar PV sector focuses on the development of ultra-high-efficiency solar cells, diversified applications of solar PV systems, and technologies for the reuse and recycling of end-of-life modules.
- 5th National Energy Technology Development Plan. On December 18, 2024, MOTIE finalized the Plan, which outlines a mid- to long-term investment strategy in energy R&D. In the solar sector, it specifically supports the commercialization of tandem solar cells, the development of solar power systems with a levelized cost of electricity (LCOE) below $0.03/kWh, the development of standardized technologies for solar operation and maintenance (O&M), and the minimization of carbon emissions throughout the entire lifecycle of solar technologies.
- Action Plan for Development and Promotion of New and Renewable Energy Technologies. On December 19, 2024, MOTIE announced the 2024 Action plan under the "Act on the Promotion of the Development, Use, and Diffusion of New and Renewable Energy." The plan includes detailed actions to promote both R&D and the deployment of renewable energy technologies.

As part of international collaborative research, Korea is participating in the SOLMATES project (Horizon-CL5-2022-D3-03-05), which held its kick-off meeting in Innsbruck, Austria, in January 2024. *SOLMATES* stands for Scalable High-power Output and Low-Cost MAde-to-measure Tandem Solar Modules Enabling Specialized PV Applications.

INDUSTRY & MARKET DEVELOPMENT

As of 2023, the cumulative installed solar capacity totaled 28.0 GW, of which 24.2 GW—approximately 86%—was accounted for by power generation businesses. In contrast, residential installations made up 2.2 GW (8%), industrial and commercial applications 1.3 GW (5%), and other uses only 0.3 GW (1%). Based on capacity, of the total 28 GW installed, ~12 GW (42.9%) comes from systems of 100 kW or less, ~11 GW (39.2%) from systems between 100 kW and 1 MW, and approximately 5 GW (18%) from systems larger than 1 MW. These figures are derived from the nationally approved "Renewable Energy Deployment Statistics" published by the Korea Energy Agency and restructured by application category. This indicates that despite the dominance of power generation businesses, small- and mid-scale solar systems still account for a significant portion of Korea's overall solar PV capacity.

Year	PV	Wind	Other	Total
2025	32.0	3.0	4.0	39.0
2030	55.7	18.3	4.0	78.0
2036	72.9	35.5	4.0	112.5
2038	77.2	40.7	4.0	121.9

*excluding self-consumption

Table 5: 11th Basic Plan for Electricity Supply and Demand : RE capacity deployment outlook (Unit: GW)

According to the Export-Import Bank of Korea, the domestic solar PV market is expected to maintain an annual installation level of around 3 GW through 2030. However, to meet the 2030 target outlined in the Basic Plan, an average of 4.5 GW of new solar capacity must be installed annually. Extending the timeline to 2038, this translates to an average of approximately 3.5 GW per year. Given that the current short-term target is around 4 GW annually over the next two years, more aggressive efforts will be necessary to stay on track.

Considering Korea's industrial structure, which is heavily reliant on manufacturing and exports, demand for renewable energy—particularly in response to global initiatives such as RE100—is expected to grow. In this context, demand-driven deployment models such as PPAs, which allow companies to voluntarily secure renewable energy, are likely to expand. This indicates a potential shift from a utility-centered deployment structure toward more self-consumption and distributed energy systems in the future.

Although the solar PV market in Korea has strong growth potential, it still faces several structural challenges, including grid constraints, policy uncertainty, complex permitting processes, high generation costs, declining profitability, and supply chain vulnerabilities. The aforementioned renewable energy strategies and government policies have been designed to address these challenges. Furthermore, the 2nd Presidential Commission on Carbon Neutrality and Green Growth, launched on February 27, 2025, convened its Energy and Just Transition Subcommittee on March 25 to discuss institutional reform measures. Key initiatives announced include mandating solar PV installations at 2,995 public parking lots, establishing guidelines to expand the available area for floating solar systems on multipurpose dams, and launching a funding program for local governments to ease setback regulations related to solar installations. These efforts, along with a range of other cross-sectoral policies, are expected to have a positive impact on the future expansion of solar PV in South Korea

Korean Experts participate currently in 2 PVPS Tasks involving 4 separate entities as listed here.

MALAYSIA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Nurul Nazli Rosli, SEDA Malaysia
Saiful Hakim Abdul Rahman, SEDA Malaysia

Photo 24: Aerial view of the largest floating solar in Malaysia located at Danau Tok Uban in the state of Kelantan. The solar plant has achieved its commercial operation date in January 2025 with total generation capacity of 60MWac.

PV POLICY PROGRAMME

Malaysia's energy policy has significantly evolved to facilitate national economic progress while also aligning with sustainability objectives and global energy transition trends. The energy-dependent Malaysian economy has developed comprehensive roadmaps and frameworks to enhance energy security, increase the utilisation of renewable energy, and safeguard sustainable energy development.

Several key policies and initiatives, including the National Energy Policy 2022-2040, the National Energy Transition Roadmap (NETR), and the Malaysia Renewable Energy Roadmap (MyRER), form the backbone of Malaysia's energy strategy. As indicated in NETR, Malaysia aims to achieve 70% RE installed capacity and carbon neutrality by 2050, dominantly through solar PV installation. Numerous strategic initiatives and innovations are in the pipeline to expedite the nation’s ambitions for a cleaner future.

The ministry supports multiple PV programmes, including Feed-in Tariff (FiT), Net Energy Metering (NEM), Large Scale Solar (LSS), and self-consumption (SELCO). These programmes are overseen by two statutory bodies: the Energy Commission (ST) oversees LSS and SELCO, and the Sustainable Energy Development

Authority (SEDA) oversees FiT and NEM. However, the state of Sarawak cannot implement these initiatives due to its own electricity supply ordinance. Meanwhile, in Sabah, the energy sector (gas and electricity supply) is governed by the Energy Commission of Sabah (ECoS).

In early 2024, ECoS reinstated the SELCO and LSS projects, designated as SELCO-PV Sabah and LSS-SABAH2024. These projects align with the Sabah Energy Roadmap and Master Plan (SE-RAMP 2024), introduced in September 2023, to enhance renewable contributions to the Sabah energy mix. The Fifth LSS, referred to as LSS-Peralihan Tenaga Suria or LSS PETRA, was initiated with a 2 000 MW quota by the Ministry of Energy and Water Transformation (PETRA) in early 2024. In addition to rooftop and ground-mounted solar projects of varying capacities, 500 MW is allocated for floating solar. The project granted for this cycle is anticipated to commence operations in 2026.

In December 2024, PETRA and ST announced the forthcoming revisions to SELCO guidelines, which will include the following enhancements: expanding installation options to encompass ground-mounted and floating PV systems, alongside rooftops; allowing PV installation systems for electricity users in the agriculture category; and abolishing the 85% capacity limit for non-domestic users. The NEM programme will also open for agricultural electricity users for PV installation, supporting both the national energy transition agenda and food security.

Financial aid, investments, incentives, and rebates were made available to encourage the adoption of solar energy to further accelerate the energy transition. In 2023, the Malaysian Investment Development Authority (MIDA) sanctioned 565 green technology initiatives valued at RM 3.2 billion, with 94% of these pertaining to solar-related projects.

Green Technology Financing Scheme (GTFS) with 1.0 billion allocation was extended until the end of 2025 or until the fund is fully utilised.

LSS Update: The LSS programme, implemented in 2016, has seen a total of 2 131.5 MW cumulative capacity awarded by the end of 2024.

FiT Update: As of 2024, the cumulative FiT capacity (biogas, biomass, WTE, small hydro, and PV) for Peninsular Malaysia and the Federal Territory of Labuan is 1 203.27 MW, of which 592.35 MW is operational. Solar PV projects are fully operational and represent the largest segment of active projects, with a total capacity of 321.4 MW.

NEM Update: Since 2016, the NEM programme has provided a cumulative quota of 2 900 MW through a series of implementations. NEM 3.0 operates across three distinct categories: NEM Rakyat, NEM GoMEn, and NOVA (Net Offsets Virtual Aggregation), with corresponding quotas of 600, 100, and 1 700 MW. By the end of 2024, 67% of NEM 3.0 quotas have been reached, with a cumulative capacity of 1 548.14 MW. Among these, 1 047.69 MW is already operational, constituting 42% industrial, 33% domestic, 24% commercial, and 1% agricultural-based projects.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Malaysia Renewable Energy Roadmap (MyRER) is paving the path to realise Malaysia's aim of decarbonising the electricity supply sector by increasing RE installed capacity by 31% by 2025 and 40% by 2040. As of 2024, Malaysia has achieved a 26% RE capacity mix in electricity supply, demonstrating steady progress towards low-carbon goals. The growth of the PV sector has contributed significantly to this progress.

In 2024, Malaysia achieved a total cumulative capacity of 4 374.6 MW PV, with an increase of 1 272.8 MW from 2023. The breakdown of the installations is shown in the following table and chart.

MECHANISM	2023 (MW)	2024 (MW)
LSS	1249.8	2131.5
FIT	288.1	321.4
NEM	1292.0	1466.0
OFF-GRID	4.5	63.7
SELCO	267.4	346.5
TOTAL	**3101.8**	**4329.1**

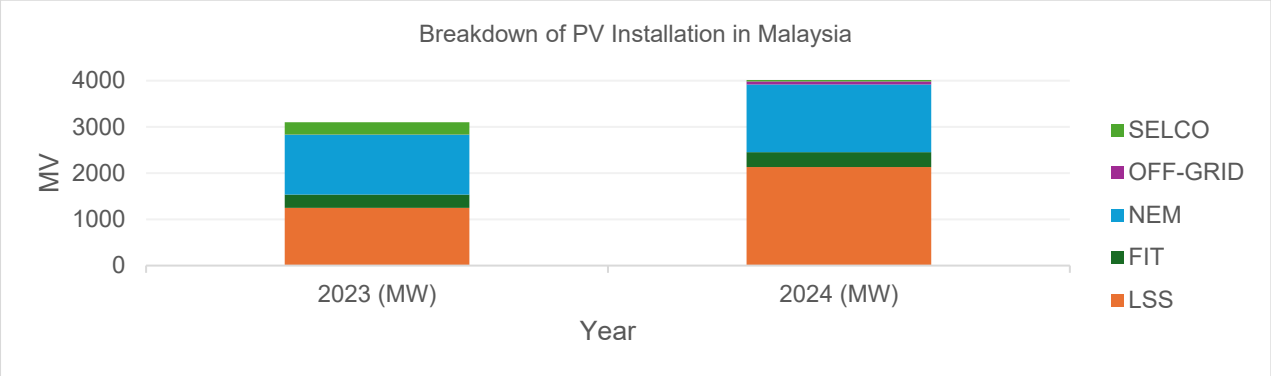

Figure 6: Breakdown of PV installations in Malaysia by support program and system type.

The PV sector is anticipated to see substantial expansion due to the proposed efforts outlined in the NETR, which include hybrid hydro-floating solar PV (HHFS), solar parks, and residential solar installations. Tenaga Nasional Berhad (TNB) is advancing the development of 2 500 MW at its hydropower facilities.

INDUSTRY & MARKET DEVELOPMENT

The PV industry in Malaysia is experiencing tremendous growth, garnering substantial investment. Longi Green Energy Technology, a Chinese solar manufacturing company, is investing RM 1.8 billion to establish a PV manufacturing facility in Serendah, Selangor. The plant is expected to produce 8.8 GW PV annually. Longi is also expanding its operations in Sarawak by investing RM 1.3 billion in a second plant with a capacity of 6 GW. Consequently, these investments will generate numerous job opportunities in the PV industry.

The government has also started the Solar for Rakyat Incentive Scheme (SolaRIS), a programme that provides rebates of up to RM 4 000 to encourage people to install PV systems in their homes. Concurrently, this incentive will lead to more people signing up for the NEM programme. The SolaRIS rebate is only applicable for applications from 1 April 2024 onwards.

Following the lifting of the ban on energy exports, the government launched Energy Exchange Malaysia (ENEGEM), a trading platform for cross-border transactions of green electricity to neighbouring countries through a bidding procedure. The trading takes place in phases, with an overall capacity of 300 MW, commencing with an initial offering of 50 MW in the first phase (end of 2024).

Malaysian Experts participate currently in 3 PVPS Tasks involving 3 separate entities as listed here.

MOROCCO

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Dr. Soukaina Boudoudouh, Head of department R&D and Innovation Programs
Said Elhamaoui, R&D Project Manager - PV Group
Khadir Badri, Technical Monitoring Officer for R&D and Innovation Programs

Photo 25: Media PV inauguration.

PV POLICY PROGRAMME

Morocco has demonstrated a strong commitment to renewable energy development in 2024, maintaining its national target of 52% renewable electricity by 2030. The country has made significant progress in renewable energy capacity, grid expansion, and regulatory frameworks to support this transition.

One of the key regulatory advancements is the introduction of Decree No. 2-24-761, which establishes a guarantees of origin (GoOs) system for renewable electricity. This decree aligns with Morocco's broader renewable energy strategy and enhances transparency, credibility, and international competitiveness by ensuring that electricity generated from renewable sources is verifiable and traceable.

Decree No. 2-24-761 introduces a Guarantees of Origin (GoOs) system for renewable electricity, marking a key regulatory advancement.

The key provisions of the decree include:

- A structured tracking system: Ensuring the traceability of renewable energy from production to consumption, with certificates valid for 12 months.
- A standardised certification process: Producers must submit requests to the competent authority, with a 30-day evaluation period.
- A robust verification mechanism: Accredited inspection bodies, certified under NM ISO/CEI 17020, will monitor and audit installations, with provisions for random inspections.
- The introduction of certificates of origin (GoOs) has been positively received by industry players and stakeholders, as it enhances the credibility and attractiveness of Morocco's renewable energy sector. This system is expected to:
- Reassure investors by ensuring transparent and verifiable renewable energy consumption.
- Boost interest in green energy by enabling businesses to prove compliance with sustainability commitments.
- Facilitate the development of PPAs (Power Purchase Agreements), allowing industries to source electricity directly from renewable producers with verified origins.

Additionally, this framework aligns with the EU's Carbon Border Adjustment Mechanism (CBAM), making Moroccan industries more competitive in international markets.

Morocco has been making significant strides in solar PV deployment and manufacturing, supported by its new certification system and renewable energy expansion initiatives. The country's total installed power capacity reached 11 474 MW (+3.8%), with renewables now representing 40.7% of the energy mix. Key infrastructure developments include the Boujdour Wind Farm (300 MW) and Aftissat II Wind Farm (200 MW), further strengthening Morocco's renewable portfolio. Additionally, the expansion of solar monitoring infrastructure, from 5 measurement stations in 2020 to 13 in 2024, has significantly improved data accuracy for PV project planning and performance optimisation, ensuring better integration of solar energy into the national grid.

Morocco aims to reach 52% renewable electricity generation by 2030, and the guarantees of origin system will play a crucial role in achieving this goal by:

- Facilitating green energy trade and exports,
- Supporting green hydrogen production and certification
- Aligning Morocco's energy transition with international markets (EU, MENA, Africa)
- Strengthening industrial decarbonisation and corporate sustainability strategies

RESEARCH, DEVELOPMENT & DEMONSTRATION

Morocco continues to strengthen its position as a leader in photovoltaic (PV) research, development, and demonstration (RD&D) as part of its ambitious renewable energy strategy, aiming to increase the share of renewables to 52% by 2030. Key efforts focus on grid integration, advanced technology development, energy storage solutions, and diversified PV applications, including Floating PV, Agri-PV, and Power-to-X.

The country's RD&D efforts are currently centered on:

- Grid Integration of PV Plants: Developing advanced grid management solutions to enhance stability and optimise energy distribution.
- Technology Development and Innovation: Advancing high-performance PV modules, bifacial technologies, and innovative cooling and cleaning systems tailored for desert environments.
- Energy Storage Solutions: Expanding research on battery storage, hydrogen-based storage, and hybrid energy solutions to ensure round-the-clock energy availability.
- Diverse PV Applications: Scaling up Floating PV, Agri-PV, and Power-to-X projects to

create a diversified and sustainable renewable energy ecosystem.

Morocco is leveraging its extensive research infrastructure—spanning research centres, universities, and private sector innovation hubs—to foster local technology development and manufacturing. Institutions such as IRESEN and Green Energy Park (GEP) play a pivotal role in advancing digital applications for operation & maintenance (O&M) and the development of solar cells and modules adapted to harsh desert climates.

A major milestone in 2024 is the expansion of local PV module manufacturing, including the increase of Ecoprogetti's production line in Al Hoceima to 1 GW, utilising advanced TOPCon G12 half-cut cell technology. Morocco is also scaling up large-scale PV projects, such as:

- OCP Group's 400 MW solar plants in Benguerir and Khouribga.
- The launch of a new mega PV and wind power project in the Western regions, aligning with Morocco's national hydrogen strategy. This initiative is set to begin in 2025, featuring a 1 400 km high-voltage transmission line to Casablanca.

Additionally, the country is pioneering hybrid solar projects, such as integrating Concentrated Solar Power (CSP) and PV for enhanced efficiency. It is also advancing renewable energy microgrids through MASEN's Battery Energy Storage Systems (BESS).

These initiatives are not only strengthening Morocco's renewable energy capacity but also positioning the country as an emerging solar technology exporter in the MENA region and beyond.

INDUSTRY & MARKET DEVELOPMENT

Morocco's PV sector has shown remarkable growth, with solar power reaching 7.19% of total installed capacity and contributing to a national production of 42 409 GWh. The market demonstrated healthy expansion with total electricity sales of 34 319 GWh (+2.7%), distributed between direct clients (50.8%) and distributors (41.4%).

Morocco's PV industry has experienced significant growth, reinforcing its role in the national power mix as part of the country's ambition to reach 52% renewable electricity by 2030. The solar energy sector has seen increasing investments, particularly in PV module manufacturing, solar research, and grid expansion to support the integration of more solar capacity.

Key industrial developments include:

- The establishment of ALMADEN FZ in Tangier, a 500 MWp/year PV module production facility focusing on glass-glass half-cell panels (G12) starting from 580 W.
- Morocco is also positioning itself as a leader in high-efficiency PV technology, with InnovX & ParkX launching a 1.2 GW HJT solar panel manufacturing unit by 2024, with plans to integrate cells and wafers by 2029.
- Another major initiative is Gi3 - Green Innov Industry Investment, which has launched MySol, Morocco's first industrial unit for solar water heater production, with over 80% industrial integration. The company is also planning a 1 GW TopCon PV module production facility.[13]

Moroccan Experts participate currently in 4 PVPS Tasks involving 2 separate entities as listed here.

[13] This report is based on data and analyses from institutional reports and research outputs from R&D facilities such as IRESEN and the Green Energy Park.

THE NETHERLANDS

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing author: Otto Bernsen, Netherlands Enterprise Agency (RVO), Team Energy Innovation

Photo 26: VIPV Zeelandia. Credit: IMEfficiency.

PV POLICY PROGRAMME

In 2024 the new government decided to gradually phase out the successful net metering scheme for smaller systems and stop it altogether in 2027. Also subsidy schemes for electric vehicles and heat pumps were cancelled. After much debate this decision was finally taken considering; the declining prices of solar panels which shortens the return on investment period, some grid and operational cost for solar are socialised over all citizens, the decline in tax revenues and the still increasing grid congestion. Instead, a “reasonable” remuneration will have to be negotiated between prosumers and their energy supplier which will be supervised by the Netherlands Authority for Consumers and Markets (ACM).

In the SDE++ category for larger systems (> 15 Kwp) the existing categories were expanded to:

- solar panels on roofs which need reinforcement or the use of lightweight panels on the same roofs
- ground mounted solar parks which include and enhance the ecological value of the terrain

The ACM presented a number of measures to combat grid congestion among others:

- non-firm capacity contracts targeting the largest energy users;
- time of use for large energy users for load shifting;
- participation obligation for private grids;
- societal priorities for grid connection like hospitals;
- use it or lose it, large users who do not make use of their capacity over a longer period of time must return it;
- backward banking is no longer allowed for SDE++ solar or wind parks. Yearly solar production higher than the established maximum for subsidy can no longer be transferred to a year with lower yearly production to compensate the difference.

In 2024 many of the policies from the previous government are still in place but for 2025 more and additional changes are expected. The former ministry of Economic Affairs and Climate is now split between a Ministry of Economic Affairs and a Ministry for Climate Policy and Green Growth.

The Netherlands remain committed to achieving net zero carbon emissions by 2050. The transition to sustainable energy forms a key part of this plan. Alongside increasing sustainable electricity production, the Dutch government is prioritising the creation of a national 'hydrogen backbone' – an infrastructure network linking the Port of Rotterdam with other major industry clusters in the Netherlands, Germany, and Belgium.

Cybersecurity of the energy infrastructure and combating grid congestion are other priorities of the new government. Grid congestion is still on the increase due not only to more renewable electricity generation but also to greater electricity demand by the industry, transport and housing.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In 2024 the mission oriented R&D programme topics remained largely the same:

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

In 2024 a large demonstration project for "offshore floating solar" was granted which will start in the summer 2025. In this project the integration with existing offshore wind parks is explicitly sought and so is ecological research on a larger scale. The ecological impact is studied throughout the entire water column under the floating panels to the seabed.

Higher technology readiness levels (TRL) are managed in separate programmes for fundamental research by the national organisations NWO and STW. The research activities themselves are dispersed over several universities and research institutes like AMOLF, DIFFER, Solliance and TNO (the national institute for applied research). For research into perovskites this separation is sometimes problematic since many fundamental questions on a nano scale are found at the interface of material sciences and production technologies where new properties can emerge.

The emergence of new types of solar cells with perovskites gives rise to new start-ups and research agendas.

The National Growth Fund project SOLARNL started in 2023, received strong headwinds in the international market but is making piecemeal progress on specific topics like VIPV, training and education. The three main topics covered are: Si HJT cell factory, Flexible solar foils and Lightweight/integrated PV. SolarNL |

National Dutch PV research, innovation and industry programme

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

INDUSTRY & MARKET DEVELOPMENT

After the accelerated growth of the solar PV market flattened out in 2023 the market for solar panels stabilised in 2024 on a somewhat lower level. In the first half of the year.

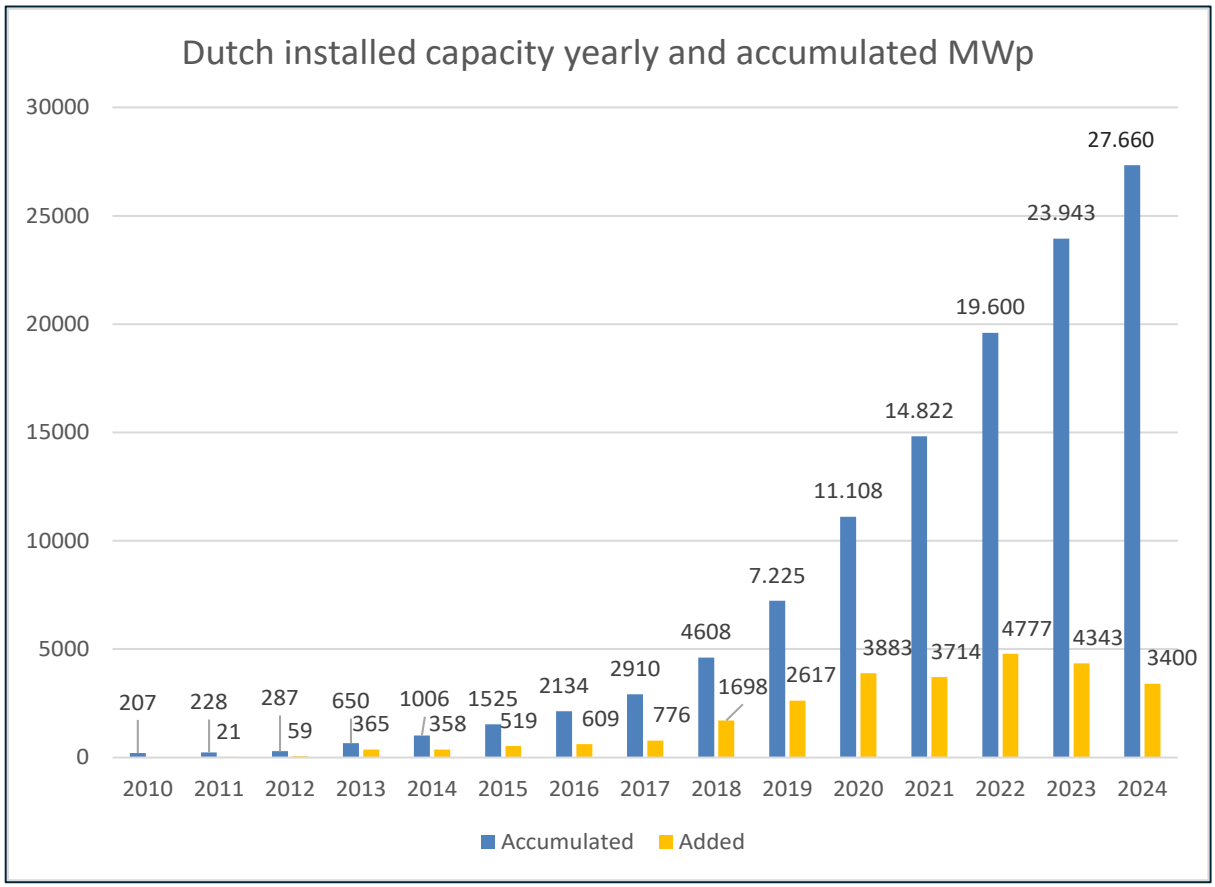

Figure 7: Data from CBS, 2024 estimated.

1.763.338 kWp was installed (source CBS) and figures over the whole year will be published by the CBS in the month of May. Assuming a similar result for the second half of the year, a total of around 3.4 GWp installed capacity can be estimated for 2024. This amount is lower than in previous years, but monthly figures seem to stabilise.

Both the solar rooftop market and ground-mounted systems have reached levels where the proverbial “low hanging fruit” has been plucked. Over 50% of house owners have now installed solar panels in the Netherlands while the rental home market falls behind with an estimated 20%. On business parks and utility construction there is still much space, but congestion and split incentives obstruct a fast roll-out. All markets are therefore changing towards more integrated products and higher degrees of self-consumption within the home, company or so- called energy hubs.

Homeowners are increasingly combining solar panels with home battery storage which will have to be integrated with energy management systems (EMS) and the same goes for EVs if dynamic charging is involved. Heat pumps are another enabler of solar PV, and its market share is on the rise but still an early adopter market.

Solar parks can already use battery storage and cable pooling to relieve the national grid. The national grid operator Tennet has reduced transport tariffs to a maximum of 65% for larger solar parks with battery storage and expects an increase with these measures up to 5 GW of battery capacity for flexibility.

The niche market of BIPV remains predominantly a business-to-business market notwithstanding government initiatives that target renovation of the existing building stock and social housing in particular.

VIPV is taking off in the market segment for trucks and semi-trailer, see Photo 26.

Dutch Experts participate currently in 9 PVPS Tasks involving 8 separate entities as listed here.

NORWAY

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Jarand Hole, The Norwegian Water Resources and Energy Directorate
Birgit Hernes, The Research Council of Norway

Photo 27: Vertical PV is a good match for high latitudes. Over Easy Solar system on Ullevål Stadion, the Norwegian national football arena. Photo: Jarand Hole.

PV POLICY PROGRAMME

Norway has an ambitious target, aiming for a yearly electricity generation of 8 TWh from PV by 2030.

Residential PV systems are supported by the national funding agency Enova. Installing a PV system qualifies for 7 500 NOK + 1 250 NOK per kWp up to 20 kWp. Hence, the maximum support is 32 500 NOK. Self-consumption is exempt from grid tariffs and electricity tax. Surplus electricity can be fed into the grid at electricity retail rates.

Grid customers on the same property can virtually self-consume electricity.

Grid customers on the same property can virtually self-consume electricity as long as the installed capacity generating the electricity is below 1 MWAC.

Grid customers that never feed in more than 100 kW can have a prosumer agreement with the distribution network operator, exempting them from the fixed grid tariff for electricity suppliers.

Ground-mounted PV systems need a licence from the Norwegian Water Resources and Energy Directorate (NVE). In 2024, 57 PV projects (44 new) were sent to NVE. The total installed capacity of the new projects adds up to 2 048 MW_{DC}. By the end of 2024, 8 ground-mounted PV projects had received a licence, and 1 application was declined. The first two ground-mounted projects, one of 7 MW_{DC} and one of 1.1 MW_{DC}, were officially commissioned in 2024.

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 novel solar cell concepts, novel applications such as BIPV, Agri-PV, and Floating PV, as well as applied and fundamental materials research and projects aimed at optimising planning and production for utility-scale PV power plants.

Leading national research groups and industrial partners in PV technology have been participating in the FME Research Centre for Sustainable Solar Cell Technology (www.susoltech.no). This centre will have its final year in 2025. In 2024, the Research Council of Norway launched a call for the next generation of FME centres. One of the centres that was awarded funding is FME Solar, which will start operation in 2025. Research activities will focus on solar cell and solar panel technologies, as well as the use of PV systems in northern European climate conditions. The total centre budget is 400 million NOK (34 million EUR) over its duration (2025–2031).

There are six main R&D groups in Norway's university and research institute sector participating in the Research Centre:

- Institute for Energy Technology (IFE) focuses on the design, production, and characterisation of silicon solar cells and applications of PV systems. IFE also works on environmental and societal challenges regarding solar energy. IFE is the host of FME Solar (mentioned above).
- 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, crystallisation, sawing, and material characterisation.
- 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 hydrogen electrolysis for research on hybrid systems.

INDUSTRY & MARKET DEVELOPMENT

The Norwegian PV industry has been 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 specialising in planning, building, and operating large utility-scale PV plants internationally.

In 2024, Norsun, the last of the three companies that had been producing solar-grade silicon, ingots, and wafers in Norway, ceased operations, leaving the upstream PV industry segment in Norway to The Quartz Corp, which produces crucibles.

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, and module designs adapted to Northern European conditions, such as Over Easy Solar's system with vertically mounted bifacial modules.

Glint Solar has developed software designed for fast solar site identification and efficient project visualisation to help develop PV projects in the early phase.

Scatec is a renewable power producer, with a significant portion of its operations dedicated to developing and operating PV power plants. Equinor and Statkraft are also active in these markets.

Norway's electricity supply is predominantly hydropower (87%) and wind power (11%). PV is still generating less than 0.5% of the electricity in Norway. The Norwegian PV market experienced very strong growth in 2023, doubling the accumulated capacity from 2022 to 2023, but slowed down in 2024. A total of 166 MW_{DC} of PV capacity was installed in 2024, which is approximately half the volume installed in 2023.

Norwegian Experts participate currently in 5 PVPS Tasks involving 6 separate entities as listed here.

PORTUGAL

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Sara Freitas, APREN – Portuguese Renewable Energy Association
Ricardo Aguiar, DGEG – Directorate-General for Energy and Geology

Photo 28: Hybrid power plant: Monte de Vez photovoltaic field and São João wind farm, located in Coimbra, Portugal. EDP Renewables.

PV POLICY PROGRAMME

The main energy policy developments with impact on PV that took place in 2024 relate to the approval of the revised version of the National Energy and Climate Plan 2030 (NECP) in December. This update sets higher targets for 2030 than the original version: -55% reduction of GHG emissions, ref. 2005; and 51% renewable share in the final energy consumption (actually, 60% would be technically compatible with its various sub-targets). Regarding final electricity consumption, a larger increase is now foreseen, to accommodate new industries, such as data centers and batteries, as well as faster electrification of residences and of industrial processes, and larger stocks of electric vehicles. However, the main demand increase is foreseen for intermediate processes, especially production of renewable hydrogen from electrolysis and of its derivatives, like methane, methanol, jet fuel and ammonia. A total

electrolyzer capacity of 3 GW (H_2 output) is envisioned.

These final and intermediate demand increases should be met solely by additional renewable power, with the overall capacity reaching 43.2 GW until 2030. This way the renewable share at the production mix would reach 93% by 2030. Within a context of very high penetration of non-firm renewables, electricity storage will have to play an even larger role than today. The existing reverse hydro capacity is to be increased from 3.6 GW to 3.9 GW, and battery banks from 1 MW to 2 GW.

Although repowered onshore wind, and new offshore wind, are two technologies that will provide a significant part of the renewable capacity increase (4.5 GW and 2 GW respectively), PV power plants – both small and large scale – will be key in the rollout of the NECP, being the technology with the highest yet-to-be-tapped potential. 20.8 GW of installed AC capacity are foreseen for 2030, split between 5.7 GW for decentralised and 15.1 GW for centralised installations.

Considering that the current installed PV capacity is now at 25% of the 2030 goal, see Fig. 8, this will require an acceleration of the PV deployment rate, especially for large power plants.

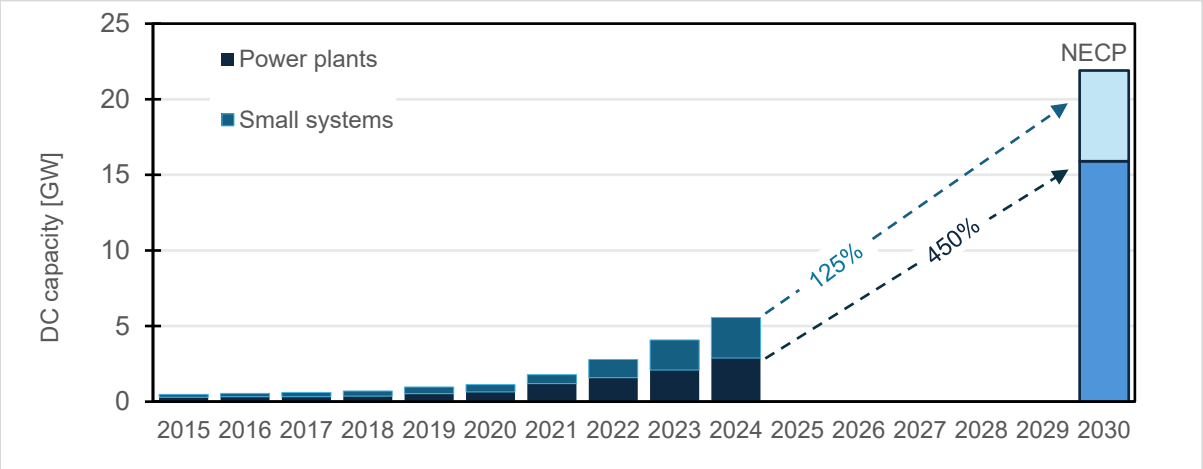

Figure 8: PV capacity (DC): historical 2015-2024, and NECP goals (Sources: DGEG, Ministerial Resolution no.129/2024).

Indeed, the Portuguese legal panorama has seen during 2024 several new legislative pieces and energy policy measures with repercussion in the implementation of PV projects. The Decree-Law No. 22/2024 (March) extended the validity of exceptional measures for simplifying renewable energy project procedures until the 31st of December, which helped to ensure conditions and certainty for the projects in the pipeline. Decree-Law No. 99/2024 (December) partially transposed the revised Renewable Energy Directive, introducing simplifications of renewable projects' licensing, promoting self-consumption and energy communities, revising guarantees and compensations to municipalities, adjusting the electro-intensive customer regime, improving transparency in bilateral energy contracting, and adapting the legislative framework to support the energy transition and green re-industrialisation. Also relevant was the constitution of the Mission Structure for the Licensing of the Renewable Energy Projects 2030 (EMER). With the aim to incentivise the incorporation of renewables in the national electricity system through a more transparent, agile, and simplified procedural regime, EMER is expected to implement a one-stop for the permitting process, consolidate the sector's legal framework, and establish a monitoring system that ensures effective project monitoring and control.

With a 4.5-fold increase of large PV projects needed until 2030, conflicts regarding land use and project permitting are expected to become more frequent. Local communities in the rural

areas already manifest disapproval and complain of lack of added value, and environment-related organisations are concerned about the welfare of habitats and species conservation. Promising approaches in this regard lie in floating PV as well as in AgriPV or EcoPV, with a few pilot examples emerging, pushing for the revision of the current regulation that does not permit renewable projects inside National Agricultural Reserve zones.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Research support programs funded by the Portuguese State do not specifically target PV. Nevertheless, all the major Portuguese universities perform research on PV, most often through projects funded by the European Union.

The subjects addressed seem to concentrate on opposite ends of the PV value chain. On the one hand there are academic groups focusing on materials. The solar cell technologies addressed include amorphous/nanocrystalline silicon, silicon nanowires, Cu2O, Cu(In,Ga)Se_2, dye-sensitised materials, perovskites, kesterites, quantum dots, as well as organic and hybrid inorganic-organic cells, tandem cells, metal oxide photo-electrodes, and replacement of critical materials

On the other hand, there are R&D groups at universities, at the major Portuguese utilities and at some other private companies, that deal with aspects at the other end of the value chain. For instance, PV integration (buildings, vehicles), storage coupling, automation and control of small systems as well as of large power plants, agrivoltaics, floating PV, and energy communities. There is also an emerging SME ecosystem focusing mostly on tools to enhance performance and reliability of PV installations, with a few contributing to the development of new module technologies and solar mobility solutions.

INDUSTRY & MARKET DEVELOPMENT

The PV industry in Portugal is focused on leveraging the technology and service integration rather than on domestic module production, with the implementation of systems currently very much dependent on international suppliers for modules and BOS devices. The value chain in Portugal is mainly geared towards installation, maintenance and integration of PV systems, on both residential and commercial markets; project development and EPC services; and asset management and O&M.

With a 36% increase of installed capacity in 2024, the contribution of PV raised to a 12.3% share of the electricity consumption mix. However, reaching the very high 2030 targets for PV will require more reforms of permitting procedures, taxes, and fiscal loads, as well as a better electricity market design that can avoid increasing occurrences of zero or negative prices in the wholesale market.

Regarding the market, during 2024 PV continued to experience robust growth, see Fig. 9, benefiting from supportive policies, technological advancements, and lower equipment costs.

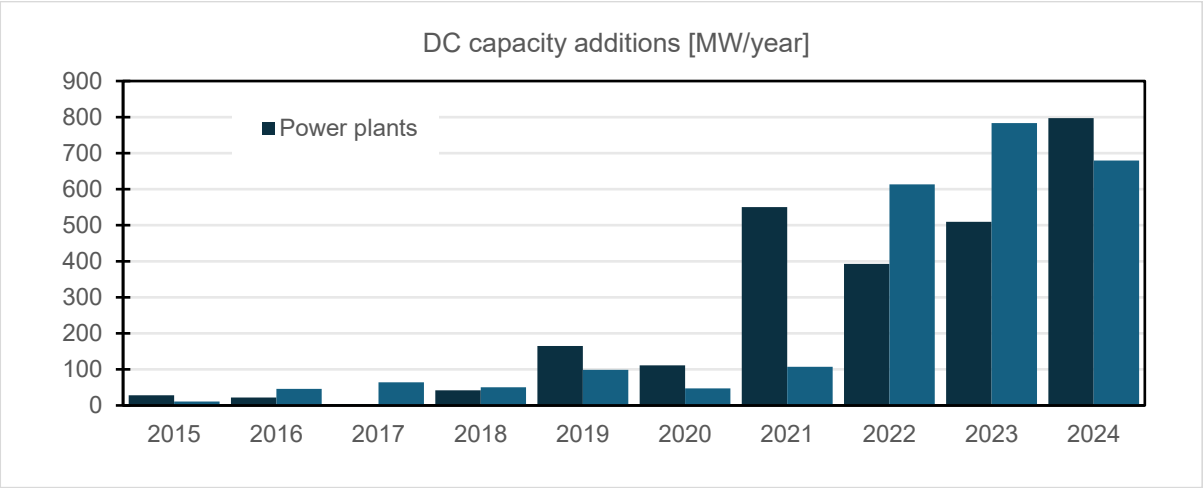

Figure 9: Yearly additions of PV capacity (DC), 2015-2024 (Source: DGEG).

Distributed systems (including self-consumption systems and small power plants) added 0.7 GW, a 34% growth over 2023 installed capacity.

Regarding large PV power plants, new 0.8 GW entered in operation, including projects from the 2019 and 2020 solar auctions, signifying in this case a 38% growth over 2023 installed capacity. Nevertheless, this 36% increase (+1.8 GW), represents some deceleration from the corresponding 2023 value, that was 46%.

The national PV capacity (DC) has reached 5.6 GW by the end of the year, (2.7 GW decentralised and 2.9 GW centralised), consolidating its role in the national electricity mix, see Fig. 10. The contribution of PV was 7.1 TWh (includes self-consumption), translating to a 12.3% share of the consumption mix and a 15% share of the production mix.

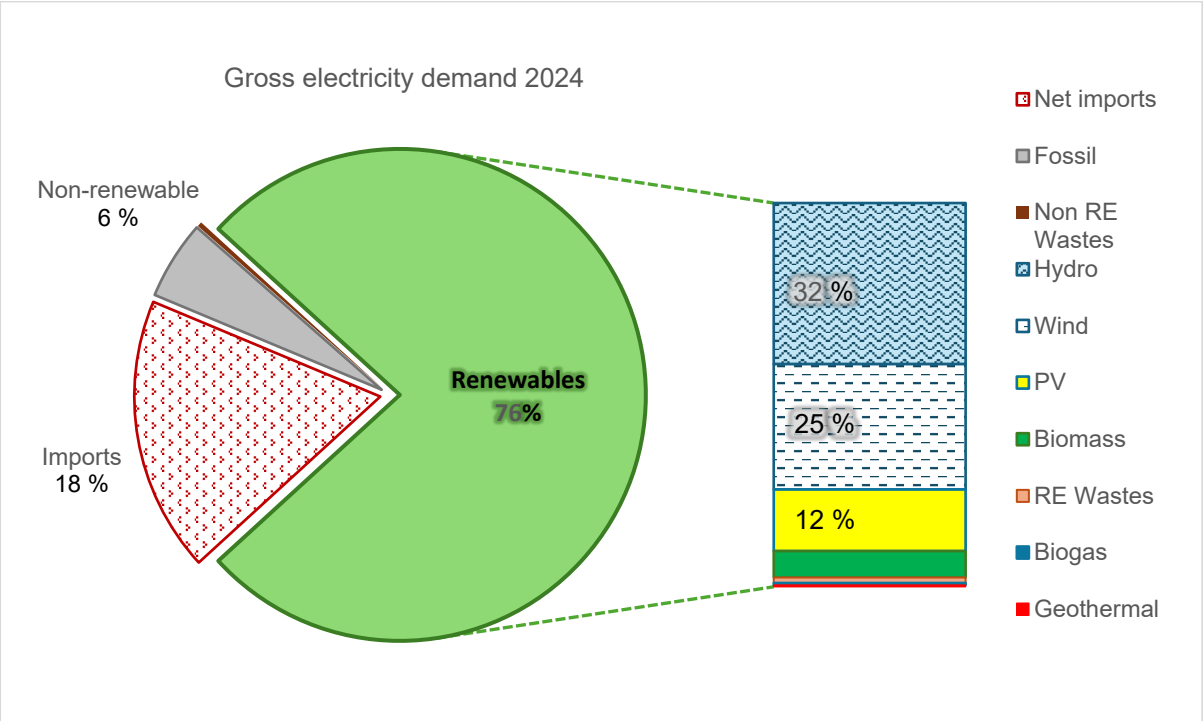

Figure 10: Electricity supply mix in Portugal, 2024 (Source: DGEG).

Although the increased targets of the NECP reflect confidence in attracting private sector investment in renewables, the transition to renewable electricity sources is still requiring significant market design adjustments. As outlined in the Electricity Market Reform, there are weaknesses in the day-ahead and intraday energy markets that have become even more apparent during 2024. The PV power plants without FiT have been dramatically affected by the increasing occurrences of zero or negative prices in the wholesale market, alongside sharp price peaks, particularly during hours of natural gas combined-cycle power plants market clearance. Without a swift regulatory response and considering overall sector growth, new and strategic utility-scale investments will be hindered.

Adding to the uncertainty atmosphere for PV projects, there are the issues related to high taxes and fiscal loads. Apart from the normal Corporate Income Tax (IRC), Value-Added Tax (IVA) and Municipal Property Tax (IMI), additional fiscal burdens exist like Municipal Surtax and Stamp Duty. In addition, there are the fees related to licensing, grid connection, and other regulatory processes. Also very relevant are the Electricity Social Tariff – to which producers still contribute despite the pressure to pass its funding on to State Budget – and the competitive balance mechanism "clawback" that has been reinstated in 2024. Both levies work as advance payment, subjecting the promoters to future adjustments with unpredictable impact in cash flows.

On a more positive side, besides the faster permitting that the new EMER agency may enable, the anticipated revisions of the Transmission and Distribution Network Development and Investment Plans are expected to fast-track many investments. They should contribute with asset modernization and creation of new grid connections, while also starting to introduce flexibility measures and increasing reliability. This will be paramount to ensure greater grid adaptability and resilience to accommodate the growing share of variable PV generation, allowing for its efficient integration into a dynamic and increasingly decentralised energy system.

Portuguese Experts participate currently in 3 PVPS Tasks involving 4 separate entities as listed here.

Photo 29: Colégio Efanor, rooftop PV system for self-consumption located in Porto, Portugal. Capwatt.

SOUTH AFRICA

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Dr. Karen Surridge, South African National Energy Development Institute (SANEDI)

Photo 30: The Solar Photovoltaic – Solar Thermal tandem installation implemented through SOLTRAIN in Bronk-horstspruit, South Africa.

PV POLICY PROGRAMME

Against the backdrop of an energy and electricity constrained environment, limited driving policy and a finite fossil resource, there has been a positive move forward towards consideration of alternative energy technologies. Electricity constraints over the year of 2023 and the beginning of 2024 drove a large uptake of small-scale embedded generation at household and commercial level, the result of this was a boom in the solar photovoltaic (PV) and battery industries; having a knock on effect of technology innovation, as well as a positive effect on cost reduction particularly for batteries. While there may not be policies that are specifically conducive to driving alternative energy uptake, outside of grid, there are no policies prohibiting this, therefore when the need arose, industry and the general public were able to harness current innovative technologies available in the market and drive these forwards. In the midst

of this, government implemented beneficial systems such as tax rebates for those that opt for alternative energy technologies.

Government's policies are designed to ensure energy supply diversity within a primarily fossil fuel reliant electricity mix. A number of policies support this drive towards an energy mix, including alternative energy technologies, not least of these is the Integrated Energy Plan (IEP) and the Integrated Resource Plan (IRP 2023) for the country.

South Africa has several policies to support solar photovoltaic (PV) energy, including tax incentives, the Solar Exclusion Norm, and other regulations. The Solar Exclusion Norm exempts certain PV facilities from environmental authorization in areas with low or medium environmental sensitivity. The policy aims to speed up project approvals, reduce costs, and increase investment in solar energy.

In the beginning of 2023, the Minister of Finance introduced a PV panel tax rebate during the annual Budget Speech. It was designed as a financial incentive for individual taxpayers who choose to privately install solar panels. The rebate applied to qualifying PV panels brought into use for the first time during the period March 2023 to 29 February 2024. Therefore this rebate concluded at the end of February 2024, and saw some market uptake.

In July 2024, on the heels of the above, it was announced that an income import tax of 10% would be levied on all PV panels brought into South Africa. This was credited with having been an initial step towards the execution of support to solar PV through the South African Renewable Energy Master Plan (SAREM). This bold move was designed to drive towards creating a localisation potential for the renewable energy industry in South Africa. However, although the rapid uptake of solar PV with battery backup supported energy security and alleviated some demand on the grid, this announcement was met with mixed responses. It was felt that, with the very small capacity of PV assembly and/or manufacture in South Africa, the panels did not meet desired quality or performance. At this point less than 10% of households were making use of PV technology to meet the energy requirements.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Taking the above into account, local manufacturing potential is quite significant, however the market would need to compete with the prices that can be provided through international imports and will need to be supported by driving policy geared towards localisation. It is important to note that as the world progresses towards a more diversified electricity supply energy source, so does South Africa. The knock-on effect of this is that there is a growing potential for local industry and market development and growth around providing, installing, operating and maintaining these technologies and systems. This, to date, has been an untapped potential in South Africa due to the competition with cheaper products that are imported from overseas. However, should the demand and market grow enough to reach critical mass, South Africa's own manufacturing and value chain support structures would then be able to compete in this space and match the lower prices.

At present, although there is a lot of research taking place at lower technology readiness levels and a few performance testing centres are actively providing data, there is not a large output from the renewable energy PV research space. This is largely due to the facts listed above, that importing panels is a lower cost with less risk involved, particularly for project demonstration purposes. Having stated this, micro demonstration projects targeting technology performance under specific conditions suited to South Africa are underway. One of these forms part of the research being conducted by the South African national energy development institute (SANEDI) in order to determine how the technology performs under extreme and harsh environmental conditions in mining and high temperature areas of South Africa.

Battery technologies allow for balancing of supply and demand particularly in grid scenarios

where a consistent electrical supply is required in order to maintain stability. Current battery technologies are innovating in a number of areas with a number of different approaches. However, all of these include an increased longevity and energy density focus point, particularly when one considers the cleaner mobility sector and the requirement for batteries that can provide longer range for vehicles of all types. The mobility sector stretches across all spheres, including air and water travel, not only land travel and it is against this scenario that one must begin to consider a shift towards sustainable fuels in the industrial sector.

INDUSTRY & MARKET DEVELOPMENT

Within South Africa, grid connected renewable energy technologies, such as solar PV and wind, have seen a marked improvement in technology efficiency in terms of hardware development as well as technology application in terms of hardware placement; for example South Africa has seen several pilots of floating PV utilised in the agricultural sector. It is also exciting that larger capacity wind turbines are being installed, therefore supplying electrons to the grid to support supply during energy constrained periods. Over and above this, South Africa is currently initiating battery energy storage systems at grid scale, the current bidding window that has seen the award of several large-scale projects that will provide energy storage to the grid in order to balance the supply and demand during periods of intermittency from renewable energy resources. Battery storage technologies also seem to have taken an innovative leap forward in terms of energy density, depth of discharge and longevity.

Photo 31: The Solar Photovoltaic Inverter and Battery Backup installation implemented through SOLTRAIN in Bronkhorstspruit, South Africa.

Decarbonisation of heavy industry poses a number of different challenges in the South African context, not least of which is the relatively low cost of fossil fuels and therefore conventional electrical technology applications. It is important to remember that alternative technologies will need to compete with those currently in place and make financial sense through either penalty, carbon credit considerations or bottom-line profit margins in order for industry to be convinced to shift towards a lower carbon technology application. Heavy industry processes are often very reliant on heat, making solar energy a very attractive option to consider for South Africa. However, although the resource is free, the technology is not and therefore the business case for down time on systems and a full system technology switch with associated skills and technological hardware requirements would need to make business sense for industry to consider this shift. At present this is not always the case particularly in the large steel, cement and mining industries of the country. The primary driver for these industries to shift towards alternative energy

resources will probably be the constrained electrical grid, as it stands and into the future, when one takes into account the decommissioning of the older power stations that must occur.

At present the capital expenses required to implement alternative energy technologies including backup storage, is quite significant compared with the current fossil fuel based alternative. However, in the interests of energy security, many companies (and even down to the household level) are indeed making the strategic decision to shift towards a diversified energy mix in order to ensure productivity continues even during periods of constrained energy supply. At present government has a number of initiatives in place in order to support companies that are moving towards either energy efficiency, and therefore a lower energy demand for their same processes, or implementing of an alternative energy technology, these include a number of tax incentives.

South African Experts participate currently in 1 PVPS Task involving 2 separate entities as listed here.

SPAIN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Eugenia Zugasti, National Renewable Energy Centre of Spain (CENER)
Jaione Bengoechea, National Renewable Energy Centre of Spain (CENER)

Photo 32: Floating photovoltaic power plant (Sierra Brava). Courtesy of ACCIONA Energía.

PV POLICY PROGRAMME

Spain has developed a Strategic Energy and Climate Framework to map out a route towards climate neutrality. This framework is composed of four key initiatives, some of which have been updated in 2024:

- Integrated National Energy and Climate Plan 2023-2030 (INECP). The current plan was published in September 2024 after a long consultation process, and it is an update of the previous one launched in 2021, taking into consideration the increased climate-fight ambitions at the European level, as reflected in the European Climate Law, Fit for 55, and REPower EU targets. However, it also includes targets from the latest European initiatives, such as the Net Zero Industry Act and the Critical Raw Materials Act. The new INECP **sets even more ambitious targets** for renewable energy penetration and greenhouse gas (GHG) emission reductions. One of the most important elements of this plan is the central role that photovoltaic technology is planned to play in the energy transition, with an

installed capacity for solar photovoltaic of 76.3 GW by 2030, doubling the initial 39 GW, accompanied by a strong development of energy storage, with a capacity of 22.5 GW.

- Long-Term Decarbonisation Strategy 2050. This strategy is now under revision to adapt to the new targets and requirements set out in the INECP. The Spanish Government opened a public consultation at the end of 2024, which will close in January 2025.
- Law 7/2021, of 20 May, on Climate Change and Energy Transition, was passed in Spain in May 2021 with the aim of ensuring Spain's compliance with the goals of the Paris Agreement, which obliges states to be neutral in emissions in the second half of the century.
- Just Transition Strategy & National Strategy against Energy Poverty were also updated. The Just Transition Strategy seeks to maximise the social benefits of the ecological transformation while mitigating its negative impacts. Currently, the Ministry for Ecological Transition and the Demographic Challenge (MITECO) has started the process of updating the National Strategy against Energy Poverty 2025-2030. This new strategy aims to advance the objective of achieving energy equity by consolidating structural measures to reduce energy poverty permanently and progressively over the medium and long term.

Other relevant initiatives that also form part of the Energy Transition Strategy include the following:

- The Self-consumption Roadmap: In October 2024, the Government launched a Royal Decree for public consultation that will update the regulatory framework for self-consumption.
- The Roadmap for the Sustainable Management of Mineral Raw Materials: The Council of Ministers, at the request of the Ministry for Ecological Transition and the Demographic Challenge, approved this Roadmap in 2022. It reinforces the strategic autonomy of the country and the security of supply of key raw materials for the energy transition and digital development.
- Planning of the Electricity Transmission Network 2021-2026: Updated in 2024. This Grid Planning is a key instrument for developing the electricity infrastructures needed to continue guaranteeing a secure supply and to drive the ecological transition process so that by 2026, renewable energies will account for 67% of the national electricity generation mix.

The current Integrated National Energy and Climate Plan 2023-2030 (INECP) was published in September 2024 after a long consulting process, and it is an update of the previous one launched in 2021, taking into consideration the increased climate-fight ambitions defined at European level, and also including targets from the latest European initiatives as Net Zero Industry Act and Critical Raw Materials Act.

RESEARCH, DEVELOPMENT & DEMONSTRATION

The Spanish Ministry of Science, Innovation and Universities leads the national policy on scientific research, technological development, and innovation across all sectors, including energy. The research and innovation policy is articulated through two main documents: the Spanish Science, Technology and Innovation Strategy 2021-2027 (EECTI), together with the State Plan for Scientific and Technical Research and Innovation 2024-2027 (PEICTI), launched in 2024 as the second part of the previous plan for the period 2021-2023, with the aim of implementing the EECTI and helping to achieve its objectives. The strategy prioritises and responds to the challenges of the national strategic sectors in specific areas that will be key to the transfer of knowledge and the promotion of R&D&I in the Spanish business domain, such as:

- Health.
- Culture, creativity and inclusive society.
- Security for society.

- Digital world, industry, space and defence.
- **Climate, energy and mobility.**
- Food, bioeconomy, natural resources and environment.

Specifically for the year 2024, the budgetary planning for the granting of aid has been more than 6 billion EUR (similar to 2023). The Annual Action Programme establishes the budget allocated to each of the actions foreseen in the PEICTI. In this manner, 1.7 billion EUR have been specifically earmarked for those actions in which energy topics can be applied.

On top of that, in 2024, the Recovery and Resilience Plan had an overall budget of 18.5 billion EUR, out of which a budget of 9.6 billion EUR was allocated for actions related to the energy transition. Projects set to receive funding in 2024 Next Gen funds included the following topics: floating PV, energy communities, and initiatives to boost the manufacturing capacity of renewable components in Spain.

Next, projects related to the development of photovoltaic technology across all stages of the value chain are compiled, encompassing the main research and development Spanish and European calls.

Regarding the Public-Private Collaboration call, three projects were awarded, focusing on the extended lifetime of solar steel structures, lightweight PV modules, and thermal and hyperspectral imagery for detecting soiling.

In the call for Knowledge Generation, several projects related to the development of solar cell technology—ranging from silicon to perovskites, covering germanium—were approved for funding. Unfortunately, the Transmissions call saw no funded proposals related to recycling and sustainability of photovoltaic technology.

CDTI's Research Project call funded two projects related to the management of communications and energy in the photovoltaic sector and an integral solution for the quality control of the pile driving in photovoltaic plants.

Finally, the EMPOWER project, with Spanish presence among the partners, was funded in the HORIZON-CL5-2024-D3-01-01: Alternative equipment and processes for advanced manufacturing of PV technologies call.

INDUSTRY & MARKET DEVELOPMENT

Spain's photovoltaic industry has seen significant expansion in previous decades. Except for silicon feedstock, ingot, wafer, and cell production, Spain has a decisive presence across the rest of the PV value chain. This includes the manufacturing of structures, power electronics, and trackers, despite financial challenges faced by key players in this last segment. Besides, the sector features numerous leading companies engaged in development, engineering, distribution, construction, and operation & maintenance.

In PV module manufacturing, several companies, including new entrants, produce modules, while others offer Building Integrated Photovoltaics (BIPV) solutions. Additionally, a relevant company specialises in producing technological equipment for PV module manufacturing. In 2023, PV-related full-time jobs were estimated to be slightly more than 121 000.

Last year, 2024, PV power installed capacity in Spain amounted to 7 517 MW (6 097 MW in utility scale, 1 387 MW in distributed PV, and 32 MW off-grid PV; data at the moment of writing the report, which will surely be revised throughout the year). These figures reflect a slower pace of deployment compared to 2023, when 6 940 MW and 2 020 MW of utility-scale and distributed PV, respectively, were installed.

Currently, Spain has 47 181 MW of accumulated capacity (37 417 MW of utility scale, 9 646 MW of distributed PV, and 119 MW off-grid PV). The planning process indicates substantial expansion for utility-scale PV plants, with over 36 705 MW of projects approved and ready for construction in the near future. This planned development highlights the industry's robust pipeline and its crucial role in transitioning to a renewable energy future.

Regarding distributed PV in Spain, it is adapting to evolving market conditions. The end of

COVID-era subsidy programmes, which significantly boosted installations during the pandemic, signals a shift towards a more market-driven approach.

In 2024, renewable energy generation in Spain, as estimated by Red Eléctrica, accounted for slightly over 55% of the national generation mix, thus recording a historical maximum of production, with PV covering 17% of the national energy demand. In 2024, the average electricity price in Spain was 62.90 €/MWh. No auction for PV electricity generation was held during 2024.

Spain's robust PV industry, along with its supporting components, complemented by an abundant solar resource ideal for PV plant installations, can foster a powerful techno-economic ecosystem, promoting a sustainable, efficient, and profitable economy across Europe. Nevertheless, a slower-than-expected pace of electricity demand, a deceleration of the broader electrification process, sustainability and social acceptance issues, together with the increasingly frequent periods of negative prices experienced last year, remain challenging aspects hampering the deployment of this technology.

Spanish Experts participate currently in 9 PVPS Tasks involving 19 separate entities as listed here.

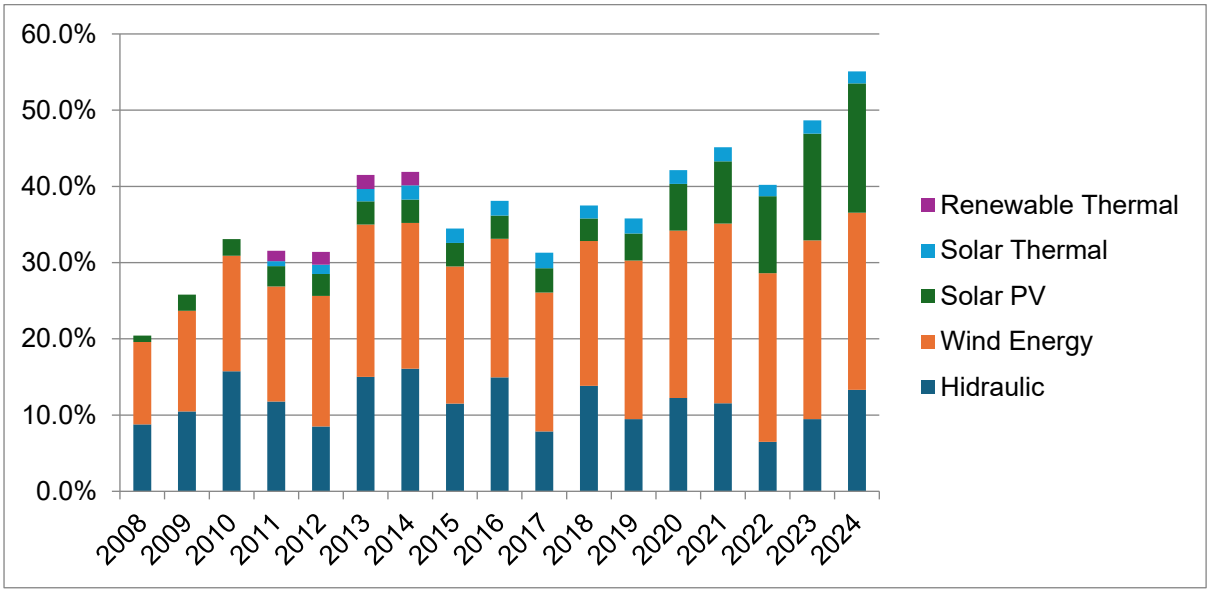

Figure 11: Percentage of demand coverage from renewable energies in Spain.

SWEDEN

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing author: Jonas Pettersson, Swedish Energy Agency

Photo 33: Helia bifacial PV power plant in Luleå, Sweden

PV POLICY PROGRAMME

Swedish energy policy aims to combine security of supply, competitiveness, and ecological sustainability. It is based on legislation established within the EU. Sweden's energy and climate goals include the following targets:

- By 2045 at the latest, Sweden must achieve net zero emissions. Emissions from Swedish territory should be reduced by at least 85% from 1990 levels (excluding land use).
- By 2040, electricity production must be 100% fossil-free.
- By 2030, an energy efficiency target of 50% more efficient energy use compared with 2005 must be achieved. This target is expressed in terms of energy relative to GDP.

The Swedish power system is divided into four bidding areas (SE1–SE4) by the Swedish National Transmission System Operator, Svenska Kraftnät. The aim of this division is to address electricity supply-demand imbalances.

The bidding areas should pinpoint regions in Sweden where grid expansion is necessary and where increased electricity production can alleviate consumption demands, thus reducing the need for long-distance electricity transport.

Sweden and Norway share a technology-neutral, market-based support system for renewable electricity production called the electricity certificate system. This scheme has been a key driver of renewable energy deployment. The 2030 target of 46.4 TWh of new renewable electricity production was reached as early as 2021. Since the end of 2021, the scheme has been closed to new applications.

Since 2021, there has been a tax deduction for individuals installing green technology. Under this incentive:

- A 20% deduction applies to labour and material costs associated with PV installations.
- The tax deduction is capped at 50 000 SEK per person per year.
- For batteries used to store self-produced electricity and for charging equipment for electric vehicles, the deduction is 50%.
- From 1 July 2025, the PV deduction will be lowered to 15%.

In 2015, Sweden introduced a tax credit scheme for small-scale renewable electricity production. Under this scheme:

- Owners of PV systems with a main fuse ≤100 A are entitled to a feed-in premium in the form of a tax credit of 0.6 SEK per kWh of electricity fed into the grid. However, credit cannot be received for more kWh than the amount of electricity consumed from the grid.
- The tax credit is capped at 30 000 kWh (18 000 SEK) per year.
- As of 1 January 2026, the tax credit is set to expire.

Additionally, a solar electricity producer that owns one or more PV systems with a total installed capacity of less than 500 kWp is exempt from paying energy tax on self-consumed electricity, provided it is used on the same premises where the PV systems are installed.

RESEARCH, DEVELOPMENT & DEMONSTRATION

Research, development, and demonstration is supported through several national research funding agencies, universities, and private institutions in Sweden. However, among the national research funding agencies, the Swedish Energy Agency (SEA) is specifically responsible for the national research related to energy and is the largest funding source for research and innovation projects within PV.

Starting in 2022, the main program of SEA for the funding of projects related to the electricity system is Future Power Systems (Framtidens Elsystem). This is a broad research and innovation program covering topics ranging from electricity production and the electricity grid to research related to electricity use. The current program period is from 2022 to 2029, with a total budget of 1 327 MSEK. International projects are funded within the EU collaboration CETPartnership.

The Swedish Energy Agency also funds the Solar Electricity Research Centre (SOLVE), a centre of excellence that serves as a strategic partnership between research institutions, private sector stakeholders, and public sector partners. The activities in SOLVE are funded equally by the academic partners, public/private sector partners, and 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 (Vetenskapsrådet), the Swedish Governmental Agency for Innovation Systems (Vinnova), and the Swedish Foundation for Strategic Research (SSF) also support PV-related research. In total, about 68 MSEK was allocated by these four major institutions to Swedish PV research in 2023.

The Swedish solar cell research largely focuses on fundamental research into new types of solar cells and photovoltaic materials. Several research groups in this area are internationally recognised for their contributions. Additionally, some research groups at universities and research institutes focus on PV systems and PV integration within the energy system. Further details on active research groups are available in the National Survey Report of PV Power Applications in Sweden 2021.

INDUSTRY & MARKET DEVELOPMENT

Generally, PV development in Sweden is primarily distributed, with solar PV electricity accounting for roughly 2% of total net electricity production in 2023. A clear trend for 2023 and 2024 is the increasing popularity of standalone batteries coupled with PV, both in large-scale electricity storage facilities and among homeowners.

At the end of 2023, the cumulative installed grid-connected PV power in Sweden was close to 4.0 GW. The Swedish PV market saw 101% growth in 2023, with 1.6 GW of new capacity added. According to the National Survey Report 2023, PV accounted for about 1.9% (3.1 TWh) of Sweden's total electricity generation in 2023.

Utility-scale solar is still in its early stages in Sweden, with the primary business model being corporate PPAs. In recent years, large-scale solar developers have formed an association to advocate for better conditions for PV parks, focusing on permitting and processing time challenges. There is a significant pipeline of PV park projects at various stages of the permitting process. Some of Sweden's largest PV parks, each around or slightly above 20 MW, are located in Kungsåra, Studsvik, Fjällskär, and Lindesberg.

The Swedish PV industry mainly consists of small to medium-sized installers and retailers of PV modules and systems. The downstream industry of installers and retailers has been growing for several years, while there is a trend of declining upstream PV industry companies. By the end of 2023, only two active module manufacturing companies remained in Sweden, though with small production volumes. However, Sweden does have several companies manufacturing production machines, balance-of-system components, and conducting R&D.

There are no official national PV targets, but the Swedish PV industry has set a goal of reaching 30 TWh of annual solar electricity generation by 2030.

The cumulative installed grid-connected PV power in Sweden was close to 4.0 GW at the end of 2023. The annual market for PV in Sweden grew by 101% in 2023, as 1.6 GW was added.

Swedish Experts participate currently in 5 PVPS Tasks involving 10 separate entities as listed here.

SWITZERLAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Stefan Oberholzer, Swiss Federal Office of Energy SFOE

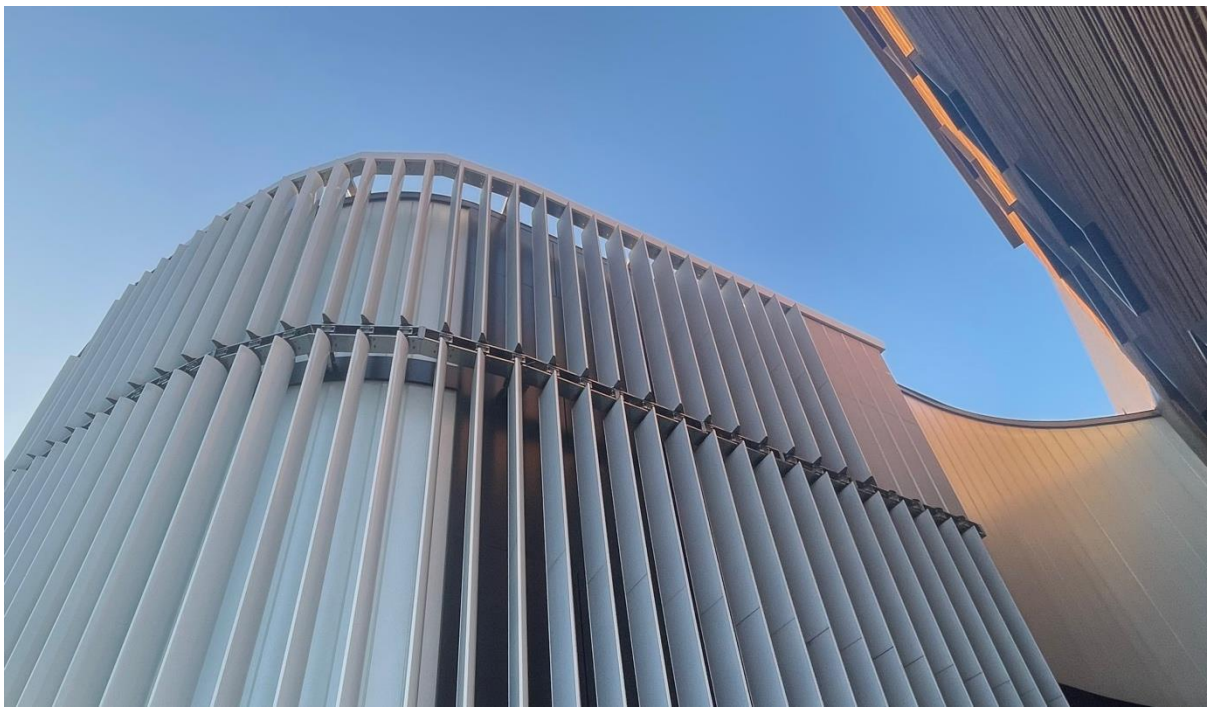

Photo 34: A dynamic photovoltaic skin at campus of Franklin University in Lugano. The white photovoltaic louvres follow the sun's orientation (source: Aziende Industriali di Lugano SA).

PV POLICY PROGRAMME

With the Federal Act on a Secure Electricity Supply from Renewable Energy Sources, the Energy Strategy 2050 has moved a step forward. The Swiss electorate approved this legislative package on 9 June 2024 and the Act will come into force in stages from January 2025. Ambitious targets have been set for the expansion of new renewable energies: 35 TWh of electricity should be generated from new renewable sources by 2035, around 60% of today's electricity consumption, which will continue to rise in the coming years due to increasing electrification. No specific target has been set for PV, but it's likely that PV will account for around 80% of this increase, in other words, 28 TWh. Thus, solar power generation in Switzerland should increase fourfold in the next ten years. In 2024, solar electricity accounted already for about 11 per cent (6.2 TWh) of total electricity consumption (Source: Swissolar).

A number of changes come into force in energy legislation. For example, the distribution grid could previously not be used for self-consumption of self-produced electricity. The new rule is that at the low-voltage level (under 1 kV), the power lines and the local electrical infrastructure at the grid connection point may be used.

Grid operators must also allow so-called 'virtual self-consumption communities'. To this end, the grid operator's existing smart metering systems are available as a virtual metering point for the operator and for the self-consumption community, enabling them to bill themselves for their own consumption.

As a new instrument, a variable market price is being introduced that also applies to certain PV installations.

Further changes include higher bonuses for a one-time payment for PV systems on facades, as well as incentives for the installation of large systems on roofs. PV systems installed on uncovered car parks will also benefit from special funding.

More details are available in a factsheet from the Swiss Federal Office of Energy. See also: Legislation governing energy.

RESEARCH, DEVELOPMENT & DEMONSTRATION

According to Swiss energy research statistics, CHF 40.4 million of public funds were spent on research in the field of photovoltaics in 2023, which corresponds to 10% of the total expenditure on energy research in Switzerland (CH 405.6 million). Figures for 2024 are not yet available.

The chart below provides an up-to-date (15.03.2025) overview of the number of projects and the financial commitment, broken down into different subject areas (source: https://pv.energyresearch.ch). 97 research and demonstration projects are in progress, thereof 30.2% in the context of European co-operation in terms of funding. More than half of the effort goes into the area of solar cell research, with a significant increase in cell research projects in the area of tandem technologies

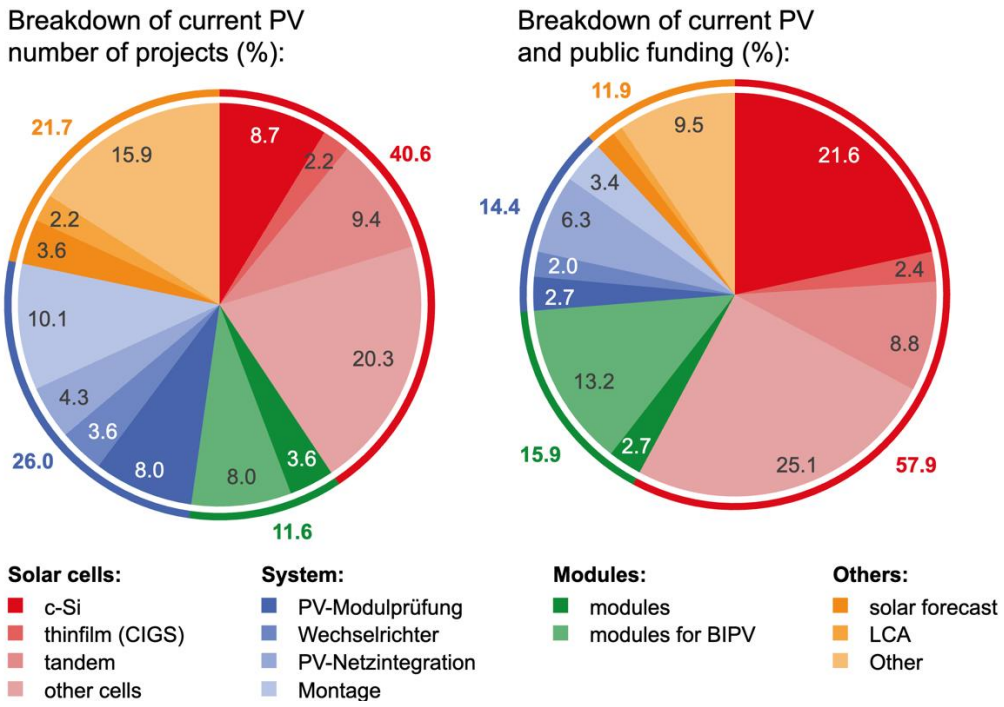

Figure 12: Overview of the number of projects and the financial commitment.

With a relatively small budget, the Photovoltaics Programme of the Swiss Federal Office of Energy (SFOE) aims to maintain expertise in the long term and provide subsidiary support where gaps exist. It also ensures participation in PVPS. From 2025, the SFOE will no longer be able to support any new pilot and demonstration projects, though this does not apply exclusively to PV.

Photo 35: Alpine PV system (343 kW) at the Lago di Lei dam (Source: ©REECH AG, ewz 2022). The findings from the first years of operation with such systems are positive: no critical operational disruptions have occurred and the share of winter solar electricity is high.

INDUSTRY & MARKET DEVELOPMENT

The trend towards solar power generation continues. However, the rate of expansion slowed somewhat in 2024 (see figure below), with around 1.8 GW of newly installed capacity, according to preliminary of the Swiss PV-association Swissolar (see Solarmonitor Switzerland). With 711 Watts of installed capacity per capita, Switzerland was ranked worldwide in 10th place in 2023. Swissolar expects the capacity growth in Switzerland to slow somewhat in 2025 and 2026 due to the temporary uncertainties that have arisen around the new Electricity Act.

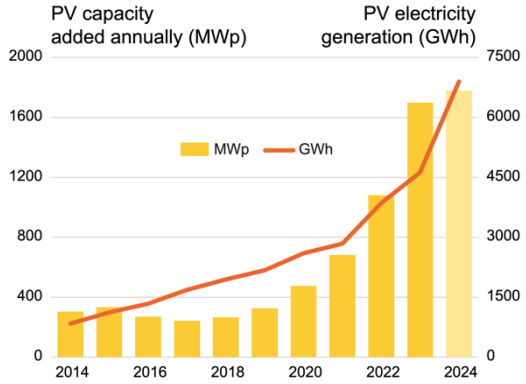

Figure 13: PV capacity added and electricity generation in Switzerland 2014-2024.

About half of the installed capacity is accounted for by residential and commercial areas respectively. Facade-mounted PV systems are still a small but fast-growing segment. Alpine PV plants, which are promoted with the 'Solar Express' subsidy with the aim of increasing winter electricity generation, face technical and economic challenges as well as questions of acceptance, so that only a few plants will be realised by the end of 2025. The question of whether there should be a follow-up regulation is under discussion.

Industry players in Switzerland are grouped along a large portion of the photovoltaic value chain, for an overview, see: https://pv.energyresearch.ch/actors (installers are not listed there). According to Swissolar, the solar industry's total revenue in 2023 was around 3.3 billion Swiss francs, with about 44% being labour costs Under a scenario of 28 TWh of solar power by 2035, its total revenue would grow to over 6 billion Swiss francs in 2035.

Swiss Experts participate currently in 7 PVPS Tasks involving 13 separate entities as listed here.

THAILAND

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Department of Alternative Energy Development and Efficiency

Photo 36: Thailand's largest net-zero energy government building (100 kWp solar PV installed capacity) located at Department of Alternative Energy Development and Efficiency, Bangkok.

PV POLICY PROGRAMME

Thailand continued its roadmap to achieve carbon neutrality by 2050 and net zero emissions by 2065. In terms of power production, our National Energy Plan (NEP) has set the target to achieve at least 50% of new power generation from renewable sources.

The Ministry of Energy has undergone a public hearing for all sub-plans of the NEP, which consist of the Power Development Plan (PDP), Alternative Energy Development Plan (AEDP), Energy Efficiency Plan (EEP), Gas Plan, and Oil Plan.

According to the draft AEDP 2024, which sets the target of a 37% share of renewable energy in total final energy consumption by 2037, the target for solar power installation capacity is set to achieve 38 974 MWp, and the floating solar target, hybridised with hydropower plants, is set at 2 789 MWp.

Additionally, a 10-year Clean Electricity Production Increment Plan (2021–2030) (Rev.2) was implemented in the PDP 2018 (Rev.1) and set

the target for PV installation capacity at 7 087 MW by 2030:

- 5 GW solar ground-mounted, FiT of ~2.17 THB/kWh
- 1 GW solar ground-mounted with BESS, FiT of ~2.83 THB/kWh
- 997 MW floating solar hybrid with hydropower
- 90 MW solar rooftop for the household sector, FiT of 2.20 THB/kWh

As of 2023, Thailand's cumulative installed PV capacity reached 5 034 MWp, consisting of 3 154 MWp solar ground-mounted, 1 775 MWp solar rooftop, 92 MWp floating solar, and 13 MW off-grid solar systems.

Apart from the aforementioned FiT programme for solar PV, Thailand has implemented a number of supportive measures:

- **Utility Green Tariff (UGT)** to facilitate the provision of green electricity for stakeholders/private sectors necessary for their routine services and manufacturing. There are two types of UGT – UGT-1 (non-specified power source) and UGT-2 (specified power source), both expected to be implemented by 2025.
- **Direct Power Purchase Agreement (Direct PPA)** to allow direct purchase of renewable electricity to attract large foreign investments, e.g., data centres in Thailand. This measure is being studied by the Energy Policy and Planning Office and the Office of Energy Regulatory Commission.
- **BOI tax incentives** continue to provide support for projects with solar energy installations – i.e., corporate income tax exemptions/deductions.
- **Solar rooftop promotion programmes** for both government buildings and the household sector are being considered for future implementation. The latter will be implemented via a tax-incentive mechanism.

Thailand is introducing a number of supportive measures, such as the Utility Green Tariff (UGT) and the Direct Power Purchase Agreement (Direct PPA), to enhance the readiness and competitiveness of domestic PV-related stakeholders and to explore new opportunities in global markets.

RESEARCH, DEVELOPMENT & DEMONSTRATION

New solar cell materials were being studied by many academic institutes. For example, Chiang Mai University developed a carbon electrode replacement for rare or valuable elements in thin-film perovskite solar cell research. The power conversion efficiency was shown to increase to around 11%, with over two years of stability without encapsulation. A reduction in production costs was expected to reach around 27%.

Mahidol University was also interested in developing the perovskite fabrication process by using a novel solvent type to increase efficiency and enhance the environmental friendliness of perovskite cell production processes.

Moreover, alternatives to lithium-ion batteries were also being researched in Thailand. For example, Khon Kaen University was conducting a study on electrode replacements derived from rice husks and solar cell waste. The new nano-silicon-based material had shown a 15% increase in electrical capacity. It was expected to reduce raw material imports and promote the circular economy.

INDUSTRY & MARKET DEVELOPMENT

Thailand’s PV industry and market continued its expansion in 2024, driven by policy support, increasing awareness of self-consumption and energy savings, growing manufacturing capacity, and rising export demand.

In 2024, there were 14 PV cell and module manufacturers in Thailand (up from 10 in 2023),

with machine production capacity of up to 10 GW per year. Among these, six were domestic manufacturers. Moreover, six inverter manufacturers and three Li-ion battery manufacturers were present in Thailand.

Export activity remained a key driver, with PV panel exports valued at approximately $3 billion and PV cell exports at $1.3 billion as of June 2024.

In 2024, the price of PV modules in Thailand ranged between $0.10–$0.40 USD/Wp (slightly decreased from the previous year), while installation costs for PV systems in the residential, commercial, and industrial sectors also saw slight decreases, as follows:

- **Residential:** 0.74–1.03 USD/Wp
- **Commercial:** 0.65–0.74 USD/Wp
- **Industrial:** 0.59–0.68 USD/Wp

In 2024, a data acquisition revision was conducted for 2022 and 2023, revealing that the installed capacity was 4.5 GWp in 2022 and 5.0 GWp in 2023.

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

TÜRKİYE

PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS

Contributing authors: Dr. Ömer Faruk Tunçbilek, Clean Energy Research Institute, Turkish Energy, Nuclear and Mineral Research Agency

Dr. İbrahim Ateş, Clean Energy Research Institute, Turkish Energy, Nuclear and Mineral Research Agency

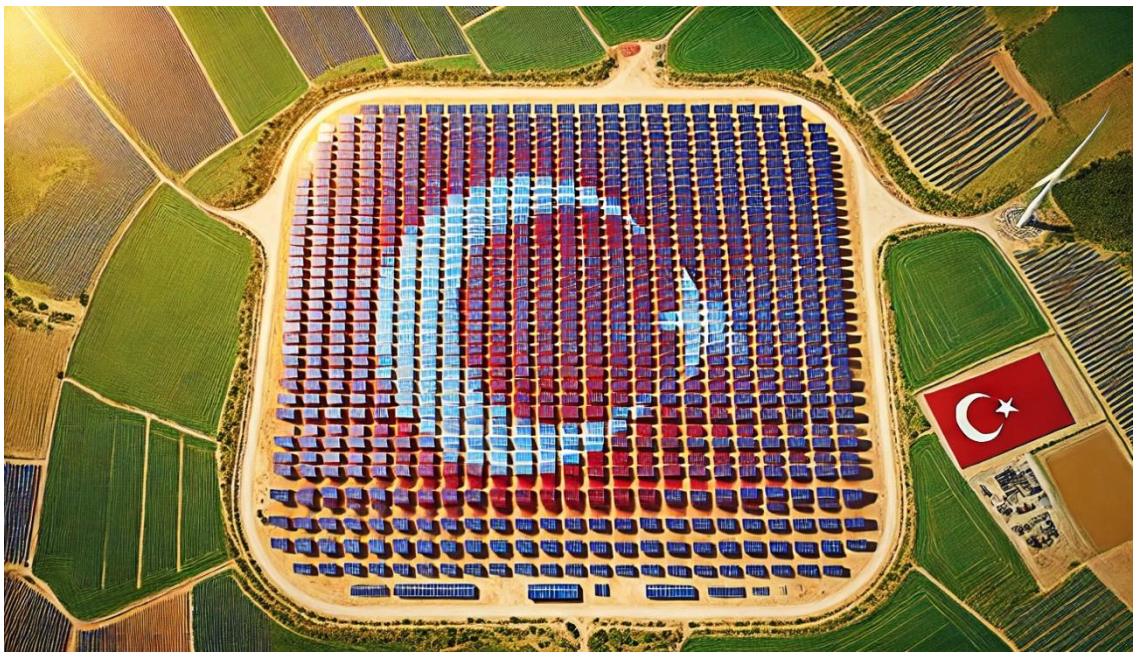

Photo 37: Türkiye's solar power plant installation continues to increase every year on its way to becoming an energy center. This digitally modified photograph acknowledges and celebrates this development and transition in Türkiye.

PV POLICY PROGRAMME

Türkiye's photovoltaic (PV) sector has shown significant growth over the past decade. In 2014, the country had approximately 40 MW of installed solar energy capacity. The installed capacity of solar electricity in Türkiye increased by more than 70% from 11.3 GW in December 2023 to 19.6 GW by the end of 2024.[14] Thus, the end-2025 target of 18 GW, set out in the National Energy Plan prepared by the Ministry of Energy and Natural Resources (MENR) and published in 2023, was reached by August 2024. The fact that this target was reached 1.5 years earlier demonstrates Türkiye's determination to rapidly implement solar energy projects, while also showing the need for a more ambitious revision of the current targets.

[14] https://www.etkb.gov.tr/

In 2022, the increase in unlicensed power plant installations gained momentum with the amendment to the Unlicensed Electricity Generation Regulation, which allows the installation of a power plant in a different distribution region from a different consumption point. This change accelerated investments in self-consumption and contributed to reducing the negative impact of solar power plants on grid interconnection.

With simplified legislation and incentives, the rate of increase in installed solar power capacity has accelerated significantly in recent years. Installed capacity has doubled in the last two years alone. This rapid progress is an important indicator of the progress made by the Turkish solar energy sector and its strong energy infrastructure. In parallel with the increase in installed capacity, the share of solar energy in total electricity generation increased to 7.5% in 2024, with a total of 26 TWh of electricity generated.[15]

As a result of these developments, the Ministry of Energy and Natural Resources updated the Renewable Energy Roadmap in October 2024 and increased the installed capacity of solar and wind-based electricity to 120 GW. In November 2024, the 2030 and 2035 targets were updated in the Long-Term Climate Change Strategy Document published by the Ministry of Environment, Urbanisation and Climate Change at COP29, and the 2035 solar energy installed power target was set at 77 GW.

In 2016, Türkiye introduced the Renewable Energy Resource Area (YEKA) model in its legislation, facilitating the allocation of suitable land to investors for the realisation of large-scale renewable energy projects and aiming to reduce foreign dependency by encouraging localisation in the production of relevant technologies. To date, 3 GW of solar energy has been tendered under YEKA, of which 1.5 GW capacity has been implemented. The results of the last tender held in 2024 were announced in February 2025, providing capacity for another 800 MW of investment. With the amendments made in 2024, the YEKA model was improved in favour of investors with financial incentives such as shortened post-tender permitting processes and exemption from transmission fees.

In 2024, a legal regulation was enacted that paved the way for the establishment of floating solar power plants in Türkiye and included regulations in the field of energy. With this regulation, floating solar power plant applications are expected to increase in Türkiye in the coming years. Thus, in addition to increasing renewable energy capacity, it is aimed to utilise unused water surfaces and prevent water loss due to evaporation.

In 2014, the solar energy sector in Türkiye started to mobilise with the installation of about 40 MW, and by the end of 2024, it had reached an installed capacity of about 20 GW.

RESEARCH, DEVELOPMENT & DEMONSTRATION

In line with the 2053 net zero emission target and green development policy of Türkiye 2053, relevant institutions are working to produce groundbreaking R&D and innovation-based solutions. For this purpose, basic/applied research, technology development and innovation projects are supported to develop photovoltaic cells, panels and systems that have high efficiency and lifetime, are lightweight, flexible and cost-effective, and can be synergistically and ergonomically integrated into applications such as buildings, vehicles, agriculture and water surfaces.

The Turkish Energy, Nuclear and Mineral Research Agency (TENMAK), Clean Energy Research Institute, initiated a study for the recycling of end-of-life or defective solar panels in 2024. The International Energy Agency predicts that the world's solar energy capacity will exceed 2 000 GW by 2025. The world's installed capacity is expected to reach 1 630 GW by 2030, of which 1.7–8 million tonnes of solar panels will be scrapped. Considering the

[15] https://www.teias.gov.tr/

increase in end-of-life PV panels and storage systems, it is aimed to investigate effective and efficient recycling methods to improve waste management in solar energy in our country. The Digitalisation of Energy Systems Project Support Call, announced by TENMAK in October 2023, was concluded in 2024, and many projects such as creating a digital twin of solar power plants and increasing the efficiency of solar power plants with artificial intelligence were applied.

In July 2024, the Ministry of Industry and Technology introduced the High Tech Türkiye (HIT-30) programme to support high-tech industrial investments. Under the programme, a total of USD 30 billion worth of incentives will be provided until 2030 in the areas of electric vehicle production, battery production, chip production, solar panel cell production, wind turbine equipment production and R&D. The HIT-Solar call aims to improve the cell manufacturing capabilities of the Turkish panel manufacturing industry. With a total support budget of USD 2.5 billion, it is aimed to create a total annual cell production capacity of 15 GW, including high domestic contribution and R&D centre investments. Within the scope of the call, investments with a minimum annual production capacity of 5 GW, focusing on cell production starting from the ingot stage, will be supported, and investors will be provided with grant support of up to 8 000 dollars per megawatt.

The Türkiye Green Industry Project, funded by the World Bank with a budget of USD 450 million and lasting for six years, aims to support the green transformation of capital companies in Türkiye by TÜBİTAK and KOSGEB. Introduced in 2023, the first application results of the programme were announced in 2024, and more than 100 projects were found eligible for support. In addition to nationally funded projects, research institutions and universities in Türkiye, as well as stakeholders related to photovoltaic technologies, participate in international programmes that support R&D projects through many project calls such as Horizon Europe and IPA-III, coordinated by the relevant institutions of the EU. There are also different programmes for photovoltaic technologies within the scope of bilateral cooperation between countries.

INDUSTRY & MARKET DEVELOPMENT

Türkiye has taken significant steps to enhance domestic production in the solar energy sector, positioning itself as a regional manufacturing hub for photovoltaic (PV) cells and modules. With increasing government incentives, renewable energy targets, and strong investor interest, PV production capacity has expanded rapidly in recent years.

As of 2025, Türkiye hosts several PV cell and module manufacturers with integrated production facilities serving both domestic and international markets. Under the Renewable Energy Resource Areas (YEKA) projects, manufacturers are focusing on developing high-efficiency solar cells and modules.

Crystalline silicon (c-Si) remains the dominant technology in the photovoltaic (PV) industry, and Türkiye has been expanding its role in the upstream production of feedstocks, ingots, and wafers. While Türkiye primarily relies on imports for high-purity polysilicon, recent investments in local ingot and wafer production indicate a strategic shift towards reducing dependence on foreign supply chains.

The prices of TOPCon (Tunnel Oxide Passivated Contact) solar panels in Türkiye can vary depending on the panel's power, brand, and seller. Furthermore, prices can differ based on the wattage of the panel, cell type, and manufacturer. There may also be price variations and discounts between sellers. The prices of TOPCon modules in the market range between 15.5 and 17 cents/Watt.[16]

Developments in Türkiye's solar energy sector are supported by the expansion of domestic production capacity. Incentives for local production and new factory investments have driven progress in areas ranging from panel production to cell and wafer manufacturing. International collaborations and new R&D projects

[16] https://www.kalyonenerji.com/

have accelerated technology transfer in the sector, strengthening Türkiye's position in the global solar energy market.

The Turkish solar energy sector offers sector-specific employment opportunities. According to Solar3GW's report, there are 1 150 companies operating in the solar energy sector, with 43.5% specialising in residential-scale installations. While some firms have professional organisational structures, the sector is still largely dominated by entry-level companies with limited financial strength. The report also deduces that as of 2023, the solar energy sector directly employed approximately 37 000 people. This number can be increased by an additional 10–15% working in related fields, such as the public sector, distribution companies, municipalities, and subcontractors.

In 2024, the World Bank and Türkiye signed an agreement for a USD 1 billion dollar programme in renewable energy. The programme is expected to contribute to the establishment and expansion of Türkiye's distributed and off-grid solar market and the piloting of a battery storage programme in support of the National Energy Plan. The programme will first provide direct financing to private sector investors developing rooftop and ground-mounted solar energy systems for commercial and industrial customers. The programme will secondly support local commercial banks or leasing companies to provide similar loans to solar investors.

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

ANNEX

IEA PVPS

Task Participation Matrix

Status April 2025

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Australia	Australian PV Institute (APVI), UNSW	ExCo	1									
	Ekistica								18			
	Global Sustainable Energy Solutions (GSES)								TM			
	IT Power Australia							17				
	Murdoch University				13							
	RINA Tech				13							
	Sustainable Energy for All	ExCo										
	University of Adelaide										20	
	University of Melbourne					15						
	University of New South Wales (UNSW)		1	12			16	17				
	University of South Australia (UniSA)						16					
Austria	Austrian Institute of Technology GmbH (AIT)				13	15				19		
	Austrian PV Technology Platform (TPPV)	ExCo	1									
	Austrian Research Institute for Chemistry and Technology (OFI)			12	13	15						
	Federal Ministry Climate Action, Environment, Energy, Mobility, Innovation and Technology	ExCo										
	Fronius International									19		
	Polymer Competence Center Leoben GmbH (PCCL)			12	13							
	University of Applied Sciences Technikum Vienna					15					20	
	University of Applied Sciences Upper Austria (FH-OÖ)						16					
	Vienna University of Technology (TU Wien)					15						

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Belgium	3E nv/sa				13							
	Becquerel Institute		TM			15						
	Energyville	ExCo										
	Energyville – IMEC				13			17				
	Energyville - KU Leuven				13					19		
	EnergyVille – UHasselt	ExCo			13	15						
	Lucisun				13	15						
	PV Cycle Association			12								
	Université Libre de Bruxelles (ULB)					15						
Canada	Canadian Renewable Energy Association (CanREA)	ExCo	1									
	Concordia University					15						
	McGill University			12								
	National Research Council Canada					15						
	Natural Resources Canada - CanmetENERGY	ExCo	1		13	15	16					
	University of Waterloo					15						
China	China Electric Power Research Institute									19		
	Energy Internet Research Institute, Tshinghua University							17				
	Institute of Electrical Engineering, Chinese Academy of Sciences (CAS)	ExCo	1		13	15			18	19	20	
	LONGI Green Energy Technology Co., Ltd.		1			15						
	Public Meteorological Service Center (CMA)						16					
	PV Committee of China Green Supply Chain Alliance (ECOPV)	ExCo	1	12								
	Siemens Energy Co., Ltd.									19		
	Sungrow Renewables Development CO., LTD									19	20	
	Trinasolar Co. Ltd.					15						
	Xi'an LONGi Hydrogen Energy Technology Co., Ltd.										20	
	Zhejiang Jinko Solar Co. Ltd.			12								

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Denmark	Danish Institute of Fire and Security Technology (DBI)					15						
	Danish Meteorlogical Institute (DMI)						16					
	EMD International									19		
	European Energy A/S				13							
	FKSol ApS	ExCo										
	Kenergy	ExCo	1									
	Solar City Denmark				13	15						
	Technical University of Denmark (DTU)				13	15	16					
European Union	Directorate-General for Research & Innovation - European Commission	ExCo										
	Joint Research Centre - European Commission		1				16			19		AG
Finland	Aalto University School of Science					15						
	Fortum Renewables Oy				13							
	Innovation Funding Agency Business Finland	ExCo										
	Lappeenranta-Lahti University of Technology LUT		1									
	Turku University of Applied Sciences				13					19		
	University of Turku									19		
	VTT Technical Research Centre of Finland	ExCo										

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
	ADEME (The French Agency for Ecological Transition)	ExCo						17				
	Becquerel Institute France		1									
	Department of Solar Technologies (CEA-LITEN)			12								
	Ecole Polytechnique à Palaiseau						16					
	Electricité de France (EDF R&D)				13		16					
	EnerBIM					15						
	European Space Agency						16					
	French Alternative Energies and Atomic Energy Commission				13			17				
	HESPUL									19		
	Karim Megherbi, Independent Expert									19		
France	Laboratoire PIMENT, University of Reunion						16					
	Lorraine University									19		
	Mines ParisTech			12			16					
	Planair France SAS	ExCo	1					17				
	Réseau de Transport d'Électricité (RTE)						16					
	SAP Labs France							17				
	Scientific and Technical Centre for Building (CSTB)					15						
	SOREN (PV Cycle France)			12								
	TotalEnergies			**TM**	13		16					AG
	Université de Technologie de Compiègne							**TM**				
	UPEC									19		

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Germany	Africa GreenTec								18			
	Asantys								18			
	CSP Services						16					
	Ecolog Institute								18			
	Energienautics GmbH									19		
	Forschungszentrum Jülich GmbH							17				
	Forschungszentrum Jülich GmbH, Projektträger Jülich (ESE)	ExCo	1									
	Fraunhofer Centre for Silicon Photovoltaics (CSP)				**TM**							
	Fraunhofer IEE									19		
	Fraunhofer Institute for Solar Energy Systems (ISE)			12	13	15	16		18			AG
	German Aerospace Center (DLR)						16					
	Institute for Solar Energy Research GmbH (ISFH)				13							
	OFRES								**TM**			
	Reiner Lemoine Institute								18			
	Rolls Royce Solutions								18			
	Technische Hochschule Ulm (THU)									**TM**		
India	National Institute of Solar Energy (NISE)	ExCo										
	School of Planning and Architecture New Delhi					15						
Israel	Arava EC&T				13							
	Israeli Public Utility Authority (PUA)		1									
	Ministry of Energy & Infrastructure	ExCo										
	Office of the Chief Scientist, The Ministry of Energy		1									

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Italy	Becquerel Institute Italia (BII)				13							
	Elettricità Futura		1									
	European Academy Bozen/Bolzano (EURAC)				13	15	16					
	Gestore dei Servizi Energetici (GSE S.p.A.)		1		13	15						
	GreenHorse Legal Advisory		1									
	i-em						16					
	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	ExCo	1	12			16			19		**TM**
	Politecnico Milano					15						
	Ricerca Sistema Energetico (RSE S.p.A.)	ExCo	1	12	**TM**		16					
	Sapienza University of Rome				13							
	University of Catania				13							
	University of Naples Federico II					15						
	University of Rome II - Tor Vergata						16					AG
Japan	Lixil					15						
	Mizuho Research & Technologies, Ltd.			12				**TM**				
	National Institute of Advanced Industrial Science and Technology (AIST)				13	15						
	New Energy and Industrial Technology Development Organization (NEDO)	ExCo		12						19		
	Photovoltaic Power Generation Technology Research Association (PVTEC)					15						
	RTS Corporation		**TM**									AG
	Tokyo University of Science									19		
	University of Miyazaki							17				
	Waseda University					15		17				

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Korea	Kentech (Korea Institute of Energy Technology)		1									
	Kongju National University					15						
	Korea Energy Agency (KEA)	ExCp										
	Korea Institute of Energy Research (KIER)	ExCo										
Malaysia	Sarawak Energy Berhad								18			
	Sustainable Energy Development Authority (SEDA)	ExCo	1									
	Tenaga Nasional Berhad									19		
Morocco	Green Energy Park				13					19		
	Institute for Research in Solar Energy and New Energies (IRESEN)	ExCo	1						18			
The Netherlands	bear-ID					15						
	Delft University of Technology			12					18		20	
	Eindhoven University of Technology									19		
	Netherlands Enterprise Agency RVO	ExCo	1						18	19	20	
	Netherlands Organisation for Applied Scientific Research (TNO)			12		15		17				
	SmartGreenScans			12								
	Utrecht University				13		16					
	ZUYD					15						
Norway	Institute for Energy Technology (IFE)				13	15	16			19		
	Norwegian Meteorological Institute						16					
	Norwegian University of Science and Technology (NTNU)					15						
	Norwegian Water Resources and Energy Directorate (NVE)	ExCo	1									
	Research Council of Norway	ExCo										
	RISE Fire Research AS					15						

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Portugal	Directorate-General for Energy and Geology (DGEG)	ExCo	1							TM		
	Finerge									19		
	Portuguese Renewable Energy Association (APREN)	ExCo								19		
	University of Lisbon Instituto Dom Luiz (IDL)							17				
Sponsor Members	Solar Energy Research Institute of Singapore (SERIS)	ExCo			13	15						
	Solar Power Europe	ExCo	1	12								AG
South Africa	Council for Scientific and Industrial Research (CSIR)		1									
	South African National Energy Development Institute (SANEDI)	ExCo										

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Spain	Becquerel Institute Spain					TM						
	Centre for Research on Energy, Environment and Technology (CIEMAT)			12		15	16					
	Escola Superior de Comerc Internacional (ESCi), Oxford Brookes University			12								
	Mactech						16					
	National Hydrogen Centre (CNH2)										20	
	National Renewable Energy Centre of Spain (CENER)	ExCo			13		16					
	Onyx Solar					15						
	Public University of Navarra (UPNA)						16					
	Tecnalia					15		17				
	Trama Tecno Ambiental								18			
	Union Española Fotovoltaica (UNEF)		1									
	University of Almeria						16					
	University of Castilla La Mancha									19		
	University of Jaen						16					
	University of La Laguna									19		
	University of Las Palmas de Gran Canaria						16					
	University of Malaga						16					
	University of Murcia			12								
	University of Sevilla						16					

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Sweden	Becquerel Institute Sweden		1									
	Chalmers University of Technology			12								
	CheckWatt AB				13							
	Dalarna University			12								
	IVL Swedish Environmental Research Institute			12								
	Mälardalen University				13							AG
	Research Institutes of Sweden (RISE)			12	13							
	Swedish Energy Agency	ExCo										
	Swedish Meteorological and Hydrological Institute (SMHI)						16					
	University Uppsala						16					
Switzerland	Bern University of Applied Sciences				13							
	Dr. Schüpbach & Muntwyler GmbH							17				
	Institut für Solartechnik (SPF)						16					
	Megasol					15						
	Meteotest						**TM**					
	NET - Ltd	ExCo										
	Planair SA		1									
	Swiss Center for Electronics and Microtechnology (CSEM)				13			17				
	Swiss Federal Office of Energy	ExCo										
	Treeze Ltd.			12								
	University of Applied Sciences and Arts of Southern Switzerland (SUPSI)				13	**TM**				19		
	Viridén + Partner					15						
	Zurich University of Applied Sciences (ZHAW)			12	13							
Thailand	Department of Alternative Energy Development and Efficiency	ExCo	1									
	King Mongkut University of Technology Thonbury				13							

Country	Entities	ExCo	1	12	13	15	16	17	18	19	20	AG
Türkiye	Middle East Technical University								18			
	Turkish Energy Nuclear and Mineral Research Agency (TENMAK)	ExCo	1									
USA	Case Western Reserve University (SDLE)				**TM**							
	Clean Power Research (CPR)						16					
	David Renne Renewables						16					
	Electric Power Research Institute (EPRI)			12								
	First Solar			12								
	National Aeronautics and Space Administration (NASA)						16					
	National Renewable Energy Laboratory (NREL)		1	**TM**	13		**TM**		18			**TM**
	Sandia National Laboratory (SNL)				13							
	Solar Consulting Services						16					
	State University of New York (SUNY Albany)						16			19		
	Univers Inc.				13							
	University of Central Florida				13							
	University of Oregon						16					
	US Department of Energy	ExCo	1									